Monday, September 12, 2016 **8:15**

M1 **Rosanna Degani Young Investigator Finals**

Chairs: Rob MacLeod and Leif Sornmo

Room: Pinnacle II & III

1-107 **Left Atrial Hypertrophy Increases P-Wave Terminal Force Through Amplitude but not Duration**

Axel Loewe*, Robin Andlauer, Olaf Dössel, Gunnar Seemann and Pyotr G. Platonov

P-wave morphology correlates with the risk for atrial fibrillation (AF). Left atrial (LA) enlargement could explain both the higher risk for AF and higher P- wave terminal force (PTF) in ECG lead V1. However, PTF-V1 has been shown to correlate poorly with LA size. We hypothesize that LA hypertrophy, i.e. a thickening of the myocardial wall, also contributes to increased PTF-V1 and is part of the reason for the rather low specificity of increased PTF-V1 regarding LA enlargement. To show this, atrial excitation propagation was simulated in a cohort of four anatomically individualized models including rule-based myocyte orientation and spatial electrophysiological heterogeneity using the monodomain approach. The LA wall was thickened symmetrically in steps of 0.66 mm by up to 3.96 mm. Body surface ECGs were computed using realistic, heterogeneous torso models. During the early P-wave stemming from sources in the RA, no changes were observed. Once the LA got activated, the voltage in V1 tended to lower values for higher degrees of hypertrophy. Thus, the amplitude of the late positive P-wave decreased while the amplitude of the subsequent terminal phase increased. PTF-V1 and LA wall thickening showed a correlation of 0.95. The P-wave duration was almost unaffected by LA wall thickening (≤2 ms). Our results show that PTF-V1 is a sensitive marker for LA wall thickening and elucidate why it is superior to P-wave area. The interplay of LA hypertrophy and dilation might cause the poor empirical correlation of LA size and PTF-V1.

2-366 **Index of T-wave Variation as a Predictor of Sudden Cardiac Death in Chronic Heart Failure Patients with Atrial Fibrillation**

Alba Martin*, Iwona Cygankiewicz, Antoni Bayés-De-Luna, Pablo Laguna, Enrico G Caiani and Juan Pablo Martinez

Aim: Chronic heart failure (CHF) together with atrial fibrillation (AF) are worldwide leading causes of morbidity and mortality in elders, where an important part of these deaths are due to sudden cardiac deaths (SCD). The high irregularity of ventricular response in AF patients makes the use of standard ECG-based SCD-risk markers inappropriate in this target population. The aim of this study was twofold: i) to propose a new index, suitable for AF patients, sensitive to ventricular repolarization changes; and ii) to evaluate its prognostic value in a population with CHF and AF. Materials and Methods: Holter ECG recordings from 176 consecutive CHF patients with AF, including 22 SCD events were analyzed (2 or 3 leads available, sampling frequency 200 Hz). The index of T-wave variation (ITV), quantifying the average T-wave changes in pairs of consecutive beats under stable rhythm conditions, was computed using a fully-automatic method based on the selective averaging technique. Survival analysis was performed considering SCD as an independent endpoint. Results: ITV was higher for SCD than for non-SCD victims (median (25th;75th percentile): 12.44 (7.21;42.71) µV vs 8.57 (5.63;14.08) µV, p=0.06). In a survival analysis where patients were classified as ITV(+) and ITV(-), setting the cut point at the third quartile of ITV values, ITV (+) outcome was successfully associated to SCD (Hazard Ratio (CI): 3.217 (1.365,7.581) per µV, p=0.008). Conclusion: In this study we have shown that ITV stratifies CHF patients with AF according to their risk of SCD, with larger T-wave variability associated to lower survival probability.

3-435 **Modelling the Effects of Disopyramide on Short QT Syndrome Variant 1 in the Human Ventricles**

Dominic G Whittaker*, Haibo Ni, Alan P Benson, Jules C Hancox anc Henggui Zhang

Introduction: The short QT syndrome (SQTS) is a recently identified genetic disorder associated with ventricular and/or atrial arrhythmias and increased risk of sudden cardiac death. The SQTS variant 1 (SQT1) N588K mutation to the hERG gene causes a gain-of-function to IKr which shortens the ventricular effective refractory period (ERP), as well as reducing the potency of drugs which block the hERG channel. This study used computational modelling to assess the effects of disopyramide (DSP), a class 1a anti-arrhythmic agent, on human ventricular electrophysiology and re-entrant wave dynamics in SQT1. Methods: The O'Hara-Rudy dynamic (ORd) model of the human ventricular action potential (AP) was modified to incorporate a Markov chain model of IKr/hERG including formulations for wild type (WT) and SQT1 N588K mutant hERG channels. The blocking effects of DSP on IKr, INa, and ICaL were modelled using IC50 and nH (Hill coefficient) values from the literature, including different blocking potencies for IKr in WT and SQT1 mutant hERG channels. The ability of DSP to prolong the QT interval was evaluated using a 1D model of human ventricle with transmural heterogeneities and the corresponding pseudo-ECG. An idealised 3D left ventricular wedge model was also constructed in order to investigate the effects of DSP on re-entrant excitation wave dynamics. Results: Upon application of 10 μM DSP, which lies within the clinically-relevant range, the corrected QT interval in the SQT1 case was prolonged from 282 ms to 346 ms. Furthermore, this concentration of DSP increased the ventricular effective refractory period such that sustained re-entrant activity was no longer inducible in the left ventricular wedge model. Conclusion: We have used computational modelling to dissect ionic mechanisms of QT prolongation and anti-arrhythmic effects of DSP on SQT1 in the human ventricles. This study provides new insights into a potential pharmacological treatment in hERG-mediated SQTS.

4-418 **Highest Dominant Frequency and Rotor Sites are Robust Markers for Atrial Driver Location in Non-invasive Mapping of Atrial Fibrillation**

Miguel Rodrigo*, Andreu M Climent, Alejandro Liberos, Francisco Fernández-Avilés, Omer Berenfeld, Felipe Atienza and Maria S Guillem

Background: Inverse-computed Dominant Frequency (DF) and rotor maps have been proposed as non-invasive mapping techniques to locate atrial drivers maintaining atrial fibrillation (AF). This study evaluates the robustness of both techniques in localizing atrial drivers under the effect of electrical noise or uncertainties in the heart-torso structure. Methods: Anatomically realistic model of the atria within the torso was built. Inverse-computed DFs and phase maps were obtained on a population of 30 different mathematical AF simulations maintained by a single rotor and subjected to model variations. Simulated atrial highest DF (HDF) regions and rotor locations were compared with the same inverse-computed measurements following each variation: (i) ECG with white noise to the ECG (60-0 dB signal-to-noise ratio), (ii) linear (0-5 cm) or (iii) angular (0-45º) variation in the location and orientation of the atria inside the torso, or (iv) varying blood conductivity (0.5-9 S/m). Results: Individual inverse-computed EGMs showed a poor correlation coefficient of 0.45±0.12 with the actual EGMs in the absence of variations. The correlation coefficient worsened further to 0.22±0.11 with 10 dB noise, 0.01±0.02 with 3 cm displacement and 0.02±0.03 with 36º angular variation. However, inverse-computed HDF regions showed robustness in correlations against variations: from 82±18% match for the HDF region for the best conditions, down to 73±23% for 10 dB of noise, 77±21% for 5 cm displacement and 60±22% for 36º angular variation. The rotor location also presented a robust measurement: the distance from the inverse-computed rotor to the actual rotor was 0.8±1.61 cm for the best conditions, 2.4±3.6 cm for 10 dB of noise, 4.3±3.2 cm for 4 cm displacement and 4.0±2.1 cm for 36º. Conclusions: Localization of AF sources based on HDF and rotor location from non-invasive mapping is accurate even in the presence of noise and uncertainties in the atrial location or torso/blood conductance.

Monday, September 12, 2016 **10:00**

S21 **System Studies in Cardiovascular Autonomic Function**

Chairs: Andrew Blaber and Sonia Gouveia

Room: Pinnacle II

5-248 **Controlling the Inspiration/Expiration Ratio Benefits the Deceleration Capacity Index of Heart Rate in Assessing the Sympatho-vagal Balance**

Qing Pan, Chenglong Gao, Gongzhan Zhou, Ruofan Wang, Yihua Yu, Luping Fang* and Gangmin Ning

Introduction: Deceleration capacity (DC) of heart rate is a novel index for evaluating the activity of the autonomic nervous system (ANS). We examined whether controlling the inspiration/expiration (I/E) ratio benefits the DC analysis based on a model-generated RR interval (RRI) database. A cardiovascular system model was adopted to simulate RRI time series. The model allows analyzing the role of sympathetic and vagal activities in the ANS. The respiratory pattern can be controlled in the model. Methods: Three hundred RRI time series with random sympathetic and vagal activities were simulated. According to the ratio between the sympathetic and vagal activities (S/V ratio), these subjects were categorized into a case group (S/V>1) and a control group (S/V<1). DC was computed for each subject. The performance of DC in distinguishing the two groups was examined by the receiver operating characteristic (ROC) analysis. The respiratory period is set to 6 s. The I/E ratio was controlled as 1:2, 1:1 and 2:1, respectively, and the performances of DC under different I/E ratios were compared. Results: The numbers of subjects in the case group and the control group are 161 and 139. With the I/E ratio as 1:2, 1:1, and 2:1, the mean area under the ROC curves (AUCs) of DC are 0.64, 0.74 and 0.75. DCs obtained with the I/E ratio of 1:1 and 2:1 have significantly larger AUCs than that obtained under the normal physiological I/E ratio of 1:2 (p<0.05). Conclusions: Controlling the I/E ratio above the normal physiological level renders a better ability of DC in assessing the sympatho-vagal balance.

6-525 **Post-Stroke Alterations in Cardiovascular Responses and Heart Rate Variability during Orthostatic Challenge**

Nandu Goswami*, Joel Rodriguez, Markus Kneihsl, Irhad Trozic, Rebecca Ruedl, Andreas Rössler, David A Green, Helmut Hingofer-Szalkay, Franz Fazekas and Andrew P. Blaber

Background: Older following stroke have a higher incidence of orthostatic hypotension, syncope and fall risk, which may relate to impaired autonomic responses limiting the ability to maintain cerebral blood flow. Thus, we investigated cerebrovascular and cardiovascular regulation in 10 elderly stroke patients (218 ± 41 days post-insult) and 13 age-matched healthy controls when sitting at rest and upon standing. We hypothesised that the stroke subjects on average would; 1) have a greater drop in arterial blood pressure upon standing, 2) take longer to re-establish normal stable blood pressure after standing; and 3) have less low-frequency (LF) heart rate variability (HRV) power spectra, indicative of sympathetic drive, upon standing. 4) attenuation of the spontaneous baroreflex response. Materials and Methods: Arterial blood pressure, heart rate and cerebral blood flow velocity were recorded while sitting for 5 minutes and then during quiet standing for 6 minutes. Results: In the seated position, the stroke group had significantly greater RR interval standard deviation (RRSD) (25.5 ± 13.6ms vs. 14.3 ± 7.4ms; p=0.024), which decreased upon standing (12.9 ± 10.9ms vs. 4.4 ± 7.7ms; p=0.041). Conclusions: The stroke group demonstrated altered HRV via significantly greater resting RRSD that decreased a greater magnitude upon standing. All other assessments of autonomic function showed no differences between both groups. These findings suggest that neuronal insult following could potentially result in attenuation of the autonomic responses to standing, but further investigation is needed to clarify the mechanisms behind increased likelihood of orthostatic hypotension, syncope and falls post-stroke.

7-241 **Analysis of Endocardial Micro-Accelerometry during Valsalva Maneuvers**

Clément Gallet, Virginie Le Rolle, Jean-Luc Bonnet, Christine Henry, Albert Hagège, Philippe Mabo, Guy Carrault and Alfredo Hernandez*

Background: The analysis of cardiac mechanoacoustic signals has been shown to be useful for the evaluation of the cardiac mechanical function. A particular kind of cardiac mechanoacoustic signal, the endocardial acceleration (EA) signal, can be acquired by using a micro-accelerometer, embedded at the tip of a pacing lead, that may be chronically implanted inside a cardiac chamber. In our past works, we have proposed EA processing methods for the estimation of cardiac electro-mechanical parameters that have been applied to improve patient selection and to optimize device configuration in the context of Cardiac Resynchronization Therapy. In this work, we analyze the evolution of the main EA-derived markers during severe cardio-respiratory modifications. Method: ECG, intra-ventricular pressure and EA data obtained from the right ventricle, were acquired from 6 sheep during a set of Valsalva-like maneuvers comprising a baseline phase, a continuous positive pressure (CPP) phase and an apnea phase. Data have been processed offline to estimate the inotropic state and to segment the main EA components during each phase, in a beat-to-beat basis. Segmented EA components were further processed to extract the energy, the peak-to-peak amplitude and duration of each component. Results: The correlation between the energy of the EA1 component and the dP/dtmax is confirmed in this work. Significant differences were observed: i) on the mean instant of detection of EA2 during the baseline, CPP and apnea phases; ii) on the energy of EA1 (baseline vs. apnea) and EA3/4 (baseline vs CPP and baseline vs apnea) and iii) on the duration of the EA2 component during the three phases. Conclusion: The EA signal provides interesting information on cardio-respiratory dynamics, that may be useful to characterize respiratory events (apnea or hypopnea) from implantable devices. Moreover, this information may be useful to adapt the device therapy, according to the observed cardio-respiratory events.

8-287 **Volatility Leveraging in Heart Rate: health vs disease**

Ana Paula Rocha*, Argentina Maria Leite and Maria Eduarda Silva

Heart Rate Variability (HRV) data exhibit long memory and time-varying conditional variance (volatility). These characteristics are well captured using Fractionally Integrated AutoRegressive Moving Averag (ARFIMA) models with Generalized AutoRegressive Conditional Heteroscedastic (GARCH) errors, which are an extension of the AR models usual in the analysis of HRV. GARCH models assume that volatility depends only on magnitude of the shocks and not on their sign, meaning that positive and negative shocks have a symmetric effect on the volatility. Moreover, HRV recordings indicate further dependence of volatility on the lagged shocks. Thus, this work considers Exponential GARCH (EGARCH) models which assume that positive and negative shocks have an asymmetric effect (leverage effect) on the volatility, which copes with complex characteristics of the HRV data. ARFIMA-EGARCH models, combined with adaptive segmentation, are applied to 24 hour HRV recordings of 30 subjects from the Noltisalis database: 10 healthy (N), 10 patients suffering fror congestive heart failure (CHF) and 10 heart transplanted patients (T). The results (mean ± sd) are for each group: long memory parameter d (0.44±0.06, N; 0.52±0.14, CHF; 0.76±0.10, T), percentage of segments with volatility (95.5±3.7, N; 81.7±11.5, CHF; 75.7±16.9, T), percentage of segments with leverage (81.7±13.1, N; 53.8±20.4, CHF; 41.9±12.8, T), volatility parameters u (0.28±0.07, N; 0.20±0.09, CHF; 0.21±0.13, T) and v (0.72±0.06, N; 0.64±0.18, CHF; 0.56±0.20, T) and leverage parameter w (0.18±0.11, N; 0.05±0.07, CHF; -0.01±0.02, T). The values indicate lower memory (d) in healthy subjects, as in previous studies. Diseased subjects present lower percentage of segments with volatility and leverage and also lower values for the volatility (u, v) anc leverage (w) parameters. Overall, the results for the leverage parameter indicate that volatility responds asymmetrically to values o HRV under and over the mean.

9-338 **Increased Systolic Blood Pressure driven Skeletal Muscle activation Following Stroke: A causality analysis**

Nandu Goswami*, Ajay Verma, Amanmeet Garg, Da Xu, Reza Fazel Rezai, Kouhyar Tavakolian and Andrew P. Blaber

Background: Elderly individuals following stroke have a higher incidence of orthostatic hypotension, syncope and fall risk. Thus, in a pilot study we investigated the relationship between the arterial and skeletal muscle pump baroreflexes in 5 elderly (64.0 ± 4 yr) stroke patients (208 ± 14 days post-insult) and 5 age-matched healthy controls (61.4 ± 4 yr) during standing. We hypothesised that the stroke subjects would have attenuated baroreflex sensitivity (BRS), and increased reliance on skeletal muscle pump. Materials and Methods: The project received approval from the Ethics Committee of the Medical University of Graz. Simultaneous continuous non-invasive lower leg muscle activity (electromyography: EMG), 3-lead ECG and blood pressure were recorded continuously during the 5-minute stand portion of a sit-to-stand test. Subjects were instructed to breathe normally and when standing, to sway or shift their weight if they felt uncomfortable, but asked to stay as still and relaxed as possible, with their feet shoulder width apart Causality was analyzed between EMG and systolic blood pressure (SBP) in the last 4 minutes of standing. Data were segmented into a time window of 45 seconds, translated with an overlap of 5 seconds on the entire 4-minute data. Convergent cross mapping (CCM) was used for studying causality between the blood pressure and EMG signals. BRS was calculated using the sequence method. Statistical analysis was performed using repeated measures ANOVA. Results: Between the two groups there was no difference in spontaneous baroreflex (stroke: 4.5±1.1; control: 5.2±1.1 ms/mmHg; $p=0.53$) or EMG causality towards SBP (stroke: 0.71±0.05; control: 0.60±0.05, $p=0.17$). The causality relationship from SBP to EMG was greater in stroke patients (0.64±0.06) compared to controls (0.43±0.06, $p=0.03$). Conclusion: Although arterial baroreflex was not different between groups, elevated SBP to EMG activity suggests a potential compensatory action by the muscle pump towards blood pressure regulation following stroke.

10-157 **Sex Differences in Cardiac Autonomic Status during Autonomic Provocations**

Marek Malik*, Katerina Hnatkova, Peter Smetana, Tomas Novotny and Georg Schmidt

Compared to men, women are known to have increased baseline vagal cardiac modulations. However, systematic data on sex differences during autonomic provocations are sparse. A population o 572 healthy subjects (279 females) aged 33.3±8.5 years, BMI 25.3±2.8 kg/m2 had repeated continuous 12-lead ECG recordings made during strict undisturbed supine, unsupported sitting, and unsupported standing position. Each position lasted at least 10 minutes of which data of 5 minutes stable heart rates (after at least 5 minutes of heart rate stabilization following position change) were used to calculate heart rate [HR] and quasi-normalized spectral components of heart rate variability. In women, the HR values at supine, sitting and standing were 69.7±8.64, 79.2±9.80, and 99.7±14.83 beats per minute [bpm], respectively. The corresponding HR values in men were 64.8±7.31, 74.1±9.02, and 93.2±14 .00 bpm, respectively. At all positions, the HR values were significantly different between women and men. Thus, while as expected, women had HR approximately 5 bpm faster than men, in both sex groups, HR increased by approximately 10 bpm from supine to sitting, and by approximately 3(bpm from supine to standing in both sexes. In women quasi-normalized HF components of HRV [HF/(HF+LF) expressed in percent] at supine, sitting, and standing were 43.4±17.18, 32.1±16.58, and 20.0±11.91, respectively. In men, the corresponding values were 35.9±15.69, 24.9±14.44, and 18.9±12.77, respectively. Highly statistically significant differences between women and men were present at supine and sitting but not at standing. The change from supine to sitting was approximately 11 percent in both sexes but the change from supine to standing was 23 percent in women and 17 percent in men. On postural provocation, cardiac vagal modulations in women are thus suppressed much more than those in men. Substantial differences in cardiac autonomic regulation therefore exist

Monday, September 12, 2016 **10:00**

S22 **ECG Repolarization**

Chairs: Simon Rabkin and Cadathur Rajagopalan

Room: Pinnacle III

11-402 **Postextrasystolic T Wave Change to Stratify Risk of Pump Failure Death in Patients with Chronic Heart Failure**

Gustavo Lenis*, Robert Menges, Julia Ramírez, Iwona Cygankiewicz, Antoni Bayés de Luna, Juan Pablo Martínez, Pablo Laguna and Olaf Dössel

The postextrasystolic T wave change (PEST) is an electrocardiographic phenomenon in which the morphology of the normal T wave is alterec for a short time after a ventricular ectopic beat (VEB). It has been observed in patients with other cardiac pathologies but it has not beer proposed as a risk index for cardiac death. Since PEST seems to be potentiated in patients with depression of myocardial contractility, we hypothesize that PEST could be used to predict pump failure death (PFD) in patients with chronic heart failure (CHF). For the purpose of quantifying PEST, the parameters morphological change onset (MCO) and morphological change slope (MCS) were introduced. MCO describes an initial morphological change of the T wave after a VEB, while MCS is responsible for the description of the restitution to its original shape. An example of how the quantification of PEST is carriec out for a patient in the MUSIC database can be seen in the figure. 537 records from the MUSIC study were separated according to their cause of death and comparisons against the others (including survivors) were carried out. In addition, receiver operating characteristic (ROC) curves were used to determine the optimal separating thresholds for MCO and MCS that maximized the sum of sensitivity and specificity for PFD risk prediction. The results showed that no significant differences could be established and the proposed parameters do not seem to be related to any kind of cardiac death. In future, other forms of PEST quantification together with more databases can be used to definitely conclude that PEST has no predictive power.

12-314 **Automated ECG Ventricular Beat Detection with Switching Kalman Filters**

Julien Oster* and Lionel Tarassenko

The explosion of clinical data, and especially physiological recordings such as ECG, creates a real need for highly accurate and fully automated analysis techniques. An automated detection of ventricular beat is proposed, which is an extension of a recently published switching Kalman filter (skf) approach. The latter technique enables automatic selection of the most likely mode (beat type), and makes novelty detection possible by incorporating a mode for unknown morphologies (X-factor). The previously published technique is semi-supervised and relies on the manual annotation of the different clusters (or modes), thus making it less readily applicable in Big Data scenarios. Here we propose to extend the switching Kalman filter technique by automating the labeling of the modes. Each heartbeat in a mode was classified individually using a feature-based approach, and the cluster was assigned a given type by majority voting. Two different feature-based classifications were tested. First, ecgkit, a state-of-the-art toolkit recently made available online provide an heartbeat classification based on clustering and Linear Discriminant Analysis. Second, a Support Vector Machine (svm) approach was used with the same features (than ecgkit). Therefore two different automated switching Kalman filter techniques were tested, ecgkit-skf and svm-skf that differed only by the way the modes were classified. Both approaches were assessed on an independent subset of the MIT-BIH arrhythmia database (22 individual subjects, 30-minute recordings), and were compared to the semi-supervised switching Kalman filter approach (skf), as well as to the classification techniques, ecgkit and svm. F1 varied from 81.2% for ecgkit, 85.4% for svm, 91.8% for ecgkit-skf, 92.3% for svm-skf, and 98.6% for skf. The proposed combined techniques demonstrated improved automatic beat classification, compared to state-of-the-art fully automatic techniques (ecgkit). Performances were however still lower than what was achieved with semi-supervised techniques (skf), highlighting the fact that some clusters were mislabeled.

13-311 **Temporal Alignment of Asynchronously Sampled Biomedical Signals**

Samuel Emil Schmidt*, Kasper Emerek, Ask Schou Jensen, Jacob Melgaard, Kasper Sørensen, Claus Graff, Peter Sogaard and Johannes Jan Struijk

Temporal alignment of signals obtained using different acquisition systems is often complicated by asynchronous sampling. Especially in long recording sequences, drifting clocks result in varying delays between signals. In the current example we aligned 3-lead ECGs recorded in a phonocardiogram setup with 12-lead Holter ECGs. Methods: Two signals with common morphology (lead II from both devices, recorded synchronously with closely placed electrodes) were resampled to approximately similar sample rates. An initial alignment was obtained using cross-correlation analysis. Delays were estimated between short subsegments of one signal with the full length of the other. The median delay was then used for a coarse alignment of the two signals. Next, instantaneous delays were estimated using cross-correlation analysis of the two signals in a running window of four seconds duration. The first derivative of the instantaneous delays is related to the variation in sample rate between signals. Consequently, a smoothed version of this derivative was used for local resampling of one of the signals before final alignment. We validated the current method by visual inspection of the alignment between the 3-lead and 12-lead ECGs in 15 recordings of at least 45 minutes duration. In addition, the delay between R-peaks in the two signals was measured in windows of 10 seconds in the beginning, middle and end of each recording. Results: Visual inspection confirmed that all recordings were synchronized by the alignment procedure. The mean and standard deviation of the delay between R-peaks in the synchronized ECGs was 0.5±5.7 ms. Conclusion: We present a fully automated method for alignment of signals sampled asynchronously with drifting clocks.

14-461 **Comparison of two methods for assessment of Microvolt T-Wave Alternans: discrete vs continuous T-wave analysis**

Thaís Winkert*, Paulo Roberto Benchimol-Barbosa and Jurandir Nadal

Micro T-wave alternans (MTWA) is a risk marker for life threatening ventricular tachyarrhythmia. Classically, MTWA is assessed by quantification of beat-by-beat Twave amplitude alternation. This method requires accurate determination of T-wave peaks (discrete method) to create a sequence of T-wave amplitude series, which undergoes spectral analysis using the fast Fourier transform (FFT) for analysis. The need of precise measurements of T-wave amplitudes turns this method sensitive to noise. To overcome this limitation, a new method was developed, based on Hilbert Transform of the T-wave morphology series (continuous method). To accomplish this task, a 300 ms window containing the T-wave of every beat was isolated, and concatenated to form an artificial and continuous signal with T-waves. The Hilbert Transform was then applied to calculate the envelope of this signal. The alternans was detected after FFT of the envelope, as a peak on the frequency that corresponded to half of the main signal frequency. Both methods were tested in 50 ECG signals of Physionet T-Wave Alternans Database, 31 synthesized and 19 real world signals. The comparisons of the methods were carried out by linear correlation test, Wilcoxon test, and Bland-Altman charts, in channels 1 and 2. There was no significant differences between both methods in all tests, either synthesized or real world signals. The nove continuous method to quantify micro T-wave alternans based on whole T-wave morphology is feasible, accurate and reproducible, and have potential clinical application.

15-137 An Index for T-wave Pointwise Amplitude Variability Quantification

Julia Ramírez*, Michele Orini, J. Derek Tucker, Esther Pueyo and Pablo Laguna

Background: The comparison between the pointwise amplitude of different T-waves provides insight into ventricular repolarization liability, but there might be physiological variability present in the time-domain of such T-waves, like heart rate changes or increased repolarization heterogeneities, that may corrupt the measurement of amplitude variability. This motivates the seek for a robust marker of T-wave pointwise amplitude variability, independent from the underlying time-domain variability. Methods: We, first, studied the performance for removing time-domain variability (warping) of two algorithms, one using the original and another one using transformed T-waves (SRSF). We, next, compared the robustness against additive Laplacian noise of two markers, d_y and d_a, of T-wave pointwise amplitude variability, after compensating for the underlying temporal variability with the preferred warping algorithm. d_y was obtained from the transformed T-waves while d_a was proposed in this work and was derived from the original T-waves. We finally used the most robust marker to measure the T-wave pointwise amplitude variability, between every T-wave recorded during a Tilt test and their mean T-wave, in a database of 17 healthy subjects. Results: The preferred warping algorithm was the SRSF because it is not affected by differences between the amplitudes of the original T-waves. Besides, the marker d_a showed lower relative error values than d_y for every level of noise. The analysis of actual electrocardiogram records proved that d_a was significantly lower during the tilt than in supine position (-5.5 $\%$ vs 6.5 $\%$, $p<0.01$). Conclusions: The proposed marker, d_a, robustly quantified physiological variabilities of the T-wave amplitude, showing its potential to be used as an arrhythmic risk predictor in future clinical situations.

Monday, September 12, 2016 **10:00**

S23 **Ventricular Arrhythmias/Resuscitation**

Chairs: Ravi Ranjan and Sofía Ruiz de Gauna

Room: Shaughnessy II

16-537 **Cardiac Imaging and Modeling: Predicting the Future**

Ravi Ranjan*

a;lskdj ;asldkf j

17-181 **Subject-Specific Detection of Ventricular Tachycardia Using Convolutional Neural Networks**

Sandeep Chandra Bollepalli, S Sastry Challa and Soumya Jana*

Aim: Onset of ventricular tachycardia (VT) is clinically significant, including as a trigger to defibrillator implants. We propose a reliable technique to detect such onset using convolutional neural network (CNN). Method: The proposed CNN adds convolution and pooling layers below the input layer and above the hidden and output layers of usual neural network (NN). While traditional methods, such as NN and support vector machine (SVM), operate on ad hoc features, our additional layers learn suitable linear features from training data, providing an advantage. In the above figure, learned filters, and their outputs (features) for normal sinus rhythm and VT are depicted. Results: Taking Creighton University ventricular tachyarrhythmia database, the baseline wander was removed, and overlapping signal vectors, each of duration 5s, were formed. Altogether, the 35 patient records amounted to 22,772 such vectors. Three experiments were performed, where the respective training data consisted of (subject-oblivious) a random 80% of all signal vectors; (unseen subject) signal vectors from a random 28 subjects (80%); and (subject-specific) signal vectors from a random 28 subjects and suitable 20% duration of rest of the subjects. In each case, remaining vectors were used for testing. Each experiment underwent 100 independent trials, and mean and standard deviation of sensitivity (Se), specificity (Sp) and accuracy (Acc) are reported in the table. Contribution: We (i) adopted a subject specific approach recommended by ANSI/AAMI EC57: 2012 for VT detection, and compared with subject-oblivious (optimistic) and unseen subject (conservative) experiments; (ii) learned features using CNN instead of using ad hoc ones; and (iii) achieved high mean performance as well as high robustness (standard deviations two orders of magnitude lower compared to existing methods).

18-449 **Enhancement of Life-threatening Arrhythmias Discrimination in the Intensive Care Unit with Morphological Features and Interval Features Extraction via Random Forest Classifier**

Farhad Asadi, Mohammad Javad Mollakazemi, Shadi Ghiasi* and S. Hossein Sadati

Introduction: Intelligent patient monitoring has continued to enhance and develop in hospitals from early stage of monitoring systems. So, practical medical monitoring devices to react to patient conditions and also detect unwanted clinical conditions are very important. Aims: Our algorithm uses pulsatile waveforms and simultaneous ECG and the aims of the proposed algorithm is the detection and enhancement for determination of the life threatening arrhythmia alarms in the context of the PhysioNet 2015 Challenge. Methods: our analysis steps included: In our algorithm, features for training the random forest classifier (RFC) were derived from applying the signal quality assessment to both pulsatile signals and ECG signal too. Primarily, preprocessing step was done by applying the band pass filters to multiple sources, such as alterial blood pressure (ABP), photoplethysmogram (PPG) and electrocardiogram (ECG) and then heart beat detection through the adaptive threshold were determined. The SQI approach for the pulsatile signals were applied through the ppgSQI and the jSQI algorithms and also spectral and statistical features was extracted for ECG channel as well. In a next process, the heuristic thresholding of each ABP pulse are estimated with the function of abpfeature and also heart rate (HR) features from the ECG and pulsatile signals in a segment before the alarm was extracted and computed. Also, for assessing regularity of the beats, inter-beat intervals for pulsatile waveforms and also checking the frequency maxims for better suppression of ventricular flutter/fibrillation in the ECG channel were computed. Finally, RFCs were trained with arrhythmia features set for every type of the arrhythmia. Results: our algorithm was trained with the use of 750 records provided by PhysioNet dataset for the challenge of 2015 and according to the types of arrhythmia, our overall scores varied. Our average score for our best performance for all the alarms in terms of ture positive were 67% and for true negative were 77% and for false negative were 1.8%.

19-378 **Nonlinear Energy Operators for Defibrillation Shock Outcome Prediction**

Beatriz Chicote Gutiérrez, Unai Irusta Zarandona*, Elisabete Aramendi Ecenarro, Iraia Isasi Liñero, Daniel Alonso Moreno, Fernando Vicente Casanova and Maria de las Cruces Sanchez Fernandez

Aim: To predict defibrillation success by the local analysis of the energy content of the pre-shock ventricular fibrillation (VF) waveform acquired by automated external defibrillators (AED). Accurate prediction of shock success would avoid futile defibrillation attempts that may damage the myocardium, and would help optimizing treatment decisions for out-of-hospital cardiac arrest (OHCA) patients. Materials: Data came from 163 OHCA cases treated by the Emergency Medical Technicians of the Basque Health Service between 2013 and 2015. Patients were treated with different AED models, but all ECGs were resampled to fs=250 Hz. Shocks were considered successful if sustained QRS complexes (rate>30min-1) appeared within one minute The dataset had 107 successful and 312 unsuccessful shocks. Methods: A Smoothed Nonlinear Energy Operator (SNEO) was applied to 5 second pre-shock VF waveform segments, and its median value was used to predict shock success. Smoothing Kaiser windows of different lengths (L) and shape factors (beta) were used to adjust to typical windows. Performance was evaluated in terms of balanced error rate (BER) to equally weight Sensitivity (Se) and Specificity (Sp). Results were compared with typical predictors based on time, slope or spectral analysis. Finally, the analysis segment duration was shortened to determine the minimum for an accurate prediction. Results: The best results were obtained for L=8 and beta=9. The minimum BER was 0.22 with Se 81% and Sp 75%. The best time, slope end spectral features had a BERs of 0.24 (Se/Sp of 78/73%), 0.24 (Se/Sp of 78/74%) and 0.26 (Se/Sp of 71/77%), respectively. For pre-shock segments as short as 2-second the BER was under 0.25. Conclusions: The median value of SNEO is an accurate shock outcome predictor, even for VF-segments as short as 2 second.

20-218 **Additive Model to Evaluate the Accuracy of Chest Compression Feedback Systems in Moving Vehicles**

Digna M González-Otero*, Jesús Ruiz, Sofía Ruiz de Gauna, James K Russell, Luis Alberto Leturiondo and Purificación Saiz

Introduction: Chest compression quality affects survival from cardiac arrest. For optimal results, feedback devices can be used to guide chest compression depth and rate. Most devices analyze chest acceleration during CPR, and thus could be inaccurate when used in moving vehicles. Accuracy could be assessed by providing chest compressions to a sensorized manikin in the moving vehicle and comparing the computed feedback parameters with a gold standard. However, this solution may be difficult to implement in certain vehicles. Aim: To develop an additive model to evaluate the accuracy of accelerometer-based CPR feedback devices in moving vehicles and to apply it to the case of a plane. Materials and Methods: A resuscitation manikin was equipped with a displacement sensor for chest compression depth and rate reference. Twenty volunteers provided chest compressions to the manikin in the laboratory (static conditions) during 1-min episodes with a tri-axial accelerometer placed beneath their hands. Target rate was 100 compressions per minute (cpm) and target depth 5 cm. Tri-axial acceleration of a plane (dynamic noise) was measured during the trips Bilbao-Munich and Frankfurt-Bilbao. The acceleration that would have been measured by a feedback device used in a plane was modeled as the sum of the acceleration measured in static conditions and the dynamic noise acquired in the plane. Accuracy of a CPR feedback algorithm was evaluated both in static conditions and when applying the additive model. Results: In static conditions, median (P_{25}, P_{75}) unsigned error in depth and rate estimation were 1.4 (0.6, 2.3) mm and 0.9 (0.4, 1.5) cpm, respectively. When adding dynamic noise of the plane, errors were 1.6 (0.7, 2.9) mm and 0.9 (0.4, 1.5)cpm. Conclusions: The additive model simplifies evaluating the accuracy of CPR feedback devices in moving vehicles. In the evaluated conditions, the algorithm was accurate and could be safely used.

21-219 **Chest Diameter Measurement in Pediatric Patients for Chest Compression Feedback Calibration**

Sofía Ruiz de Gauna*, Digna M González-Otero, Jesús Ruiz, Stefano De Nigris, Purificación Saiz, José Julio Gutiérrez, James K Russell and Elena De Momi

Introduction: During cardiopulmonary resuscitation (CPR), rescuers should provide high-quality chest compressions to the victim. For adults, target depth is fixed (between 5 and 6cm), and feedback devices, usually based on accelerometers, can be used to guide the maneuver. For pediatric patients, conversely, target depth is one third of the antero-posterior diameter of the chest, and thus varies depending on patient age and morphology. Aim: To develop an algorithm to estimate chest diameter in pediatric patients using accelerometers.   Materials and Methods: Five volunteers participated in the data collection. Using a tri-axial accelerometer, we measured the accelerations generated when moving the sensor from the floor to different heights (8, 10, 12, 14, and 16\,cm), that simulated chest diameter. Two records were generated per volunteer and height. A total of fifty records were acquired.   Chest diameter was measured by applying double integration to the acceleration in the z axis (perpendicular to the chest). First, acceleration was calibrated and gravity was subtracted. Second, the trapezoidal rule was applied to integrate the acceleration from the instant in which the movement began, t_i. This instant was identified by applying a threshold to the acceleration. Third, the resulting signal (velocity) was band-pass filtered, and the trapezoidal rule was applied once again to compute the displacement signal. Finally, chest diameter was identified as the displacement value at the instant in which the movement finished, t_e, identified as a zero-crossing point in the velocity. Results: Median (P_25, P_75) unsigned absolute and relative errors were 0.9 (0.3, 1.9)cm and 9.2 (2.5, 14.6)%, respectively. This would imply an error in the target depth (one third of the chest diameter) below 6.5 mm in 75% of the cases. Conclusions: The proposed algorithm could be used to calibrate CPR feedback devices for pediatric patients.

Monday, September 12, 2016 **10:00**

S24 Magnetic Resonance Imaging

Chairs: Victor Mor-Avi and Carolina Vallecilla

Room: Shaughnessy I

22-440 **Aortic Flow and Morphology Adaptation to Deconditioning after 21-Days of Head-Down Bed-Rest Assessed by Phase Contrast MRI**

Enrico Caiani*, Giovanni Riso, Federica Landreani, Alba Martin, Selene Pirola, Filippo Piatti, Francesco Sturla, Pierre Vaida and Pierre-Francois Migeotte

Aims. Prolonged immobilization generates cardiac deconditioning, a risk factor for cardiovascular disease. Our aim was to assess the effects of 21-days of strict head-down (-6 degrees) bed-rest (BR) deconditioning, and effectiveness of reactive sledge jump countermeasure (CM) daily application, on ascending aortic flow by Phase Contrast (PC) MRI, capable to provide in vivo quantitative blood flow assessment. Methods. Twenty-four healthy men (mean age 28±6) were enrolled, and assigned to control (CTRL, N=12) or countermeasure (CM, N=12) group. The experiment was conducted at DLR (Koln, Germany) as part of the European Space Agency BR studies PC-MRI images (Symphony 1.5T, Siemens) with interleaved three-directional velocity encoding (VENC: x and y: 80 cm/s; z: 150 cm/s) were obtained transecting the ascending aorta, on top of the aortic root (spatial resolution 1.4 x 1.4 mm2), before and after 21-days of BR The resulting planar magnitude data and three-directional velocities were imported into a previously validated in-house segmentation and data analysis tool. In particular, semi-automated region growing and thresholding, exploiting texture properties, were applied to segment the lumen, thus providing the region in which to limit the computation of the following fluid-dynamic parameters from velocity images: area lumen (AL), flow velocity, stroke volume (SV), flow rate (Qpeak), time-to-peak flow, systolic duration and heart beat duration (RR). Results. After 21 days, in CTRL significant decreases in SV (14%), Qpeak (5%) and AL (4%) were observed compared to baseline values. Conversely, for CM no changes were observed in these parameters, but only in RR (-8%) and time-to-peak flow (+6%). Conclusions. Cardiac adaptation to deconditioning due to immobilization resulted in a reduction of SV and Qpeak that might have induced a remodeling process in the ascending aorta, by shrinking of its lumen. The applied CM seemed to counteract these effects.

23-429 **Development of 3D Patient-specific Models for Left Atrium Geometric Characterization to Support Ablation in Atrial Fibrillation Patients**

Maddalena Valinoti*, Claudio Fabbri, Dario Turco, Roberto Maantovan, Antonio Pasini and Cristiana Corsi

Introduction. Radiofrequency catheter ablation (RFA) is an important and promising therapy for atrial fibrillation (AF) patients. About 50% o patients present AF recurrence during the first three months of follow up. Several studies have been performed to assess the relationship between left atrium (LA) volume and AF recurrence following RFA. In fact, atrial enlargement is a consequence of AF and may facilitate AF induction. The aim of this study was to develop a unified workflow for LA segmentation from magnetic resonance angiography to provide (1) a 3D patient-specific LA model without pulmonary veins (PVs) in order to characterize LA size and (2) a 3D patient-specific model including PVs to assist RFA procedure. Methods. Eleven patients were enrolled in the study. A fully automated edge-based level set approach guided by a phase-based edge detector was developed for LA segmentation. A 3D LA patient-specific model with PVs geometry was obtained from 2D contours. The subsequent PVs deletion was obtained by applying thinning morphological operators and by removing the spurious segments corresponding to the PVs. Atrial volume estimates were computed and validation was performed by comparison with volumes derived from manual tracing by an expert radiologist. Results Automatic segmentation was feasible in all patients. Linear regression and Bland-Altman analyses resulted in very good agreement between LA volume estimates and reference values (y=0.92x+4.9, r=0.97, bias=-1.8ml (-2.1%), SD=5.6ml (6.5%)). Mean percentage difference was -1.8%±7.4% (abs value: 5.9%±4.4%). Conclusion. A unified and fast workflow for the development of 3D patient-specific LA models was presented. A more realistic LA anatomy provided by the 3D patient-specific LA model with PVs could support RFA procedure by the integration with voltage information. The 3D patient-specific LA mode without PVs could allow accurate LA size characterization providing better understanding of the link between LA volume and AF recurrence.

24-237 **Automatic Segmentation of Left Ventricular Myocardium by Deep Convolutional and De-convolutional Neural Networks**

Xulei Yang*, Like Gobeawan, Si Yong Yeo, Wai Teng Tang, Zhen Zhou Wu and Yi Su

Motivations: Deep learning has been integrated into several existing image segmentation methods to yield impressive accuracy improvement for LV endocardium segmentation. However, challenges remain for segmentation of LV epicardium due to its fuzzier appearance. In this work, we develop a deep learning method to segment the whole LV myocardium from cardiac magnetic resonance (CMR) in one step, i.e., to derive the endocardium and epicardium simultaneously. Methodology: A deep convolutional network was constructed on the Caffe deep learning platform. It consists of 5 convolutional layers, 2 pooling layers, and 2 de-convolutional layers. The layer parameters are trained using myocardium-annotated CMR datasets from 33 subjects. A new loss function based on the dice coefficient similarity was designed for training the network. This allows even the smallest myocardium to be recognized on a large CMR image background. Of the total 5,011 frames, 3,229 frames were used for network training, 861 frames were used for validation, and 921 frames were used for testing. The training took around 2.7 hours to complete (40,000 iterations), while the subsequent myocardium segmentation took 0.044 second per frame. Results: We evaluated the performance of our deep convolutional net-work by comparing the segmented areas with the manually segmented ones in terms of Dice metrics (DM) - a DM value between 0 and 1 indicates the degree of overlap normalized against the union of the auto- and manually-segmented areas. Without any further post-processing, the average DM for the 921 test frames was 0.72. Conclusions: In its current form, the proposed one-step deep learning method cannot compete with state-of-art myocardium segmentation methods. Nevertheless, it delivers promising first pass segmentation results. Moving ahead, we aim to develop a hybrid method by fine-tuning deep neural networks, augmenting training samples, and post-processing broken myocardium segmentations using state-of-art techniques.

25-356 **Right Ventricular Endocardial Segmentation in CMR Images using a Novel Inter-Modality Statistical Shape Modelling Approach**

Concetta Piazzese, M. Chiara Carminati, Rolf Krause, Angelo Auricchio, Lynn Weinert, Gloria Tamborini, Mauro Pepi, Roberto M. Lang and Enrico G. Caiani*

INTRODUCTION. Statistical shape modelling (SSM) approaches have been proposed as a powerful tool to segment the left ventricle in cardiac magnetic resonance (CMR) images. Extending it to segment the right ventricle (RV) is not an easy task, due to the highly variable RV shape from apex to base, thin and often indistinguishable myocardial walls and presence of trabeculations. We developed a new inter-modality SSM method to segment the RV cavity in CMR images and validate it compared to the conventional gold-standard (GS) manual tracing. METHODS. A database of 4347 intrinsically 3D surfaces, obtained segmenting the RV from transthoracic 3D echocardiographic (3DE) images throughout the cardiac cycle in 219 retrospective patients, was used to train a RV SSM. Manual initialization of four points (two for tricuspid valve leaflet insertion, one for RV apex and one for the aorta) was performed to derive the initial pose and scaling factor of the SSM inside the stack of short-axis (SAX) CMR images. The detection process consisted in iteratively align and globally deform the SSM on the base of some features extracted, with different strategies, from each SAX plane until a stable condition was reached. RESULTS. Algorithm segmentation was feasible in 14 CMR patients, with an average time of 1 minute per patient. The comparison of volumes with GS showed high correlation (r2 = 0.97). Bland-Altman resulted in a significant bias (+9.3 ml) and narrow limits of agreement (± 9% error) . Also, point-to-surface distance resulted in 1.94 ± 0.35 mm. CONCLUSIONS. A novel application of SSM trained on intrinsically 3D RV endocardial surfaces extracted from 3DE images and applied to segment the RV cavity in SAX CMR images was proposed. Preliminary results showed this approach to be fast and accurate in segmenting the RV endocardium.

26-227 **A Bi-centric Study of Myocardial Circumferential Strain from CMR by Using Hyperplastic Wrapping Approach**

Hua Zou, Ce Xi, Xiaodan Zhao, Ju Le Tan, Lik Chuan Lee, Kenneth Guo, Martin Genet, Fei Gao, Ru San Tan, Jun-Mei Zhang* and Liang Zhong

Introduction Hyperelastic warping is an image based finite element (FE) analysis of the regional strains for the assessment of the cardiac deformation. Recently, a novel program based on the hyperelastic warping approach was developed to analyse the circumferential strains of the whole heart: left ventricle (LV), right ventricle (RV) and the septum. This study aimed to study the reproducibility of this approach in obtaining the circumferential strains of the LV, RV and the septum. Methods 10 patients were enrolled and underwent standard CMR scan (3T Philips scanner). Whole heart models (i.e. including LV, RV, and the septum) were reconstructed by using the following steps: 1) contour delineation; 2) surface generation; 3) mesh generation; 4) material region partition; 5) fibre orientation assignment; 6) deformable image registration through the hyperelastic warping approach; 7) circumferential strain calculation. The models were re-constructed and the circumferential strains were calculated by two independent investigators from NHCS (ZH) and MSU (CX). Coefficient of determination of R2 values were computed for the comparison of circumferential strain produced by each investigator. Results There were good correspondence between two investigators, with the R2 values for RV circumferential strain (y=1.0054x-0.0004; R2 =0.9471, p<0.0001), LV circumferential strain (y=0.958x-0.0118, R2=0.9433, p<0.0001) and septum circumferential strain (y=1.089x+0.004, R2 =0.9382, p<0.0001) respectively (see Figure 1). The bias of circumferential strain in RV, LV and septum are 0.000708±0.01597, 0.006886±0.008246 and 0.002778±0.006562. No significant bias and narrow limits of agreement were observed. Conclusions The study demonstrated that the hyperelastic warping was able to provide strain computation of systolic contraction of the right ventricle, left ventricle and septum.

27-224 **A Novel Left Ventricular Volumes Prediction Method Based on Deep Learning Network in Cardiac MRI**

Gongning Luo*, Guanxiong Sun, Kuanquan Wang, Suyu Dong and Henggui Zhang

Aims: Accurate estimation of left ventricular (LV) volumes plays an essential role in clinical diagnosis of cardiac diseases using MRI. Conventional methods of estimating ventricular volumes depend on the results of manual or automatic segmentation of MRI. However, manual segmentation of MRI sequences is extremely time-consuming and subjective, and automatic segmentation is still a challenging task. Therefore, this study aims to develop a new LV volumes prediction method without segmentation, motivated by the Second Annual Data Science Bowl from Kaggle (SADSB) in 2016. Methods: The proposed method is based on a deep learning framework, which includes a convolution network of five layers for features representation, and a full connection network of three layers for prediction. The two kinds of features (Gabor features and intensity) from multi-orientation (apex, mid, and base slices from short axis, four chambers slice and two chambers slice from long axis) images are used for initial inputs, and the outputs of the network are the end-diastolic and end-systolic volumes (EDV, ESV). The deep learning network was trained and tested on cardiac MRI datasets from SADSB including 1140 patients (500 train patients and 640 test patients). At last, the proposed method was evaluated by the recognized criterion in this field, including the linear regression fit ($y = ax + b$, ideally $a = 1$ and $b = 0$), correlation coefficient (R) and mean errors (ME) for EDV, ESV and ejection fraction (EF). Results: The clinical indexes predicted by our method were compared with ground truth from SADSB, and the results are as following: EDV: $y=0.91x+11.7$, $R=0.95$, $ME=5.1\pm3.1$ml; ESV: $y=0.97x+9.5$, $R=0.92$, $ME=3.6\pm2.7$ml; EF: $y=0.87x+0.2$, $R=0.9$, $ME=6.1\pm4.1\%$. Conclusion: The proposed LV volumes prediction method based on deep learning has been proved accurate and effective.

Monday, September 12, 2016 **11:45**

S31 Ambulatory ECG

Chairs: Marek Malik and Luca Mainardi

Room: Pinnacle II

28-156 **Curvatures of QRS/RR Relationship in Healthy Individuals**

Katerina Hnatkova, Peter Smetana, Ondrej Toman, Georg Schmidt and Marek Malik*

The relationship between QRS duration and underlying heart rate is known to be individual-specific with intra-subject stability and inter-subject differences. Nevertheless, the pattern of the QRS/RR profiles has not been studied in detail. QRS duration and its heart rate dependency were evaluated in 420,615 electrocardiograms (ECG) from 523 healthy subjects (mean age 33.4±8.4 years, 254 women). QRS durations were measured under careful visual control in superimposed representative complexes of all 12 ECG leads. The measurements were made at stable heart rates. In each subject, the relationship between QRS duration and underlying heart rate was modeled by a curve-linear regression QRS[i]=A+D(1-RR[i]^G)+e[i] where QRS[i] and RR[i] are individual QRS measurements with RR intervals (in seconds) representing underlying heart rate, and where A is a subject-specific QRS duration at RR of 1 second, G is the curvature of the QRS/RR relationship, D/G is the slope of the relationship (note that the derivative of x^g equals to g at x=1), and e[i] are normally distributed zero-centered errors. The regression residuals of this curve linear regression were compared with those of linear regression. As expected, QRS durations at RR=1s were shorter in women compared to men (98.7±5.6ms vs 103.3±5.9ms, p<0.00001). The curve-linear QRS/RR regression residuals were also lower in women compared to men (1.18±0.59 vs 1.37±0.60ms, p=0.0001) and substantially smaller than the linear regression residuals (5.99±5.02 and 6.91±5.86ms in women and men, respectively). In both sexes, the curve-linear residuals correlated with QRS durations at RR=1s (r2=0.34 and r2=0.32 in women and men, respectively). While the QRS/RR slopes did not differ between women and men, the non-linear patterns were significantly more curved in women compared to men (-3.22±12.58 vs -1.2±9.3, p=0.038). Thus the QRS/RR patterns are not only highly non-linear in healthy subjects but also more curved in women compared to men.

29-517 **The Effects of 40 Hz Low-pass Filtering on the Spatial QRS-T Angle**

Daniel Guldenring*, Dewar Finlay, Raymond Bond, Alan Kennedy and James McLaughlin

The spatial QRS-T angle (SA) is a vectorcardiographic (VCG) parameter that has been identified as a marker for changes in the ventricular depolarization and repolarization sequence. The SA is defined as the angle subtended by the mean QRS vector and the mean T vector of the VCG. The SA is typically obtained form VCG data that is derived from resting 12-lead ECG. Resting 12-lead ECG data is commonly recorded using a low-pass filter with a cutoff frequency of 100 Hz or greater. The ability of the SA to quantify changes in the ventricular depolarization and repolarization sequence make the SA potentially attractive in a number of different 12-lead ECG monitoring applications. However, the 12-lead ECG data is obtained in such monitoring applications is typically recorded using a low-pass filter cutoff frequency of 40 Hz. The aim of this research was to quantify the differences between the SA computed using 100 Hz low-pass filtered ECG data (SA100) and the SA computed using 40 Hz low-pass filtered ECG data (SA40). We quantified the difference between the SA100 and the SA40 using a study population of 726 subjects. The differences between the SA100 and the SA40 were quantified as systematic error (mean difference) and random error (span of Bland-Altman 95% limits of agreement). The systematic error between the SA100 and the SA40 was found to be 0.13° [95% confidence interval: 0.10° to 0.15°]. The random error was quantified as 0.97° [95% confidence interval: 0.47° to 1.49°]. The findings of this research suggest that it is possible to accurately determine the value of the SA when using 40 Hz low-pass filtered ECG data. This finding indicates that it is possible to record the SA in monitoring applications where 40 Hz low-pass filtering is common.

30-300 **Artificial Rhythm Recognition using Portable Cardiomonitor and Mobile Application**

Maria Chaykovskaya*, Alexander Kalinichenko, Ekaterina Fetisova, Sergey Mironovich and Alexey Kiprensky

Patients with implanted pacemakers (PM) are usually not familiar with their pacing modes and other device settings. Modern bipolar endocardial pacing leads with close proximity of cathode and anode produce such a small pac-ing artifact that often could not be separated from noise. It becomes a chal-lenge to judge about the underlying rhythm and current pacing mode using single ECG tracing. Good stimuli artifacts visualization and understanding of its interaction with QRS plays crucial role in ECG. In case of broad complex arrhythmias, PM dependent patients and patients with resynchronization system, stimuli artifacts and QRS shape are useful for differentiation normal paced rhythm from ventricular arrhythmias and PM malfunctions. The novel portable cardiomonitor includes removable iPhone (5/5S) case with built-in electrodes and an application with original algorithm. ECG was recorded between hands, and equals to I lead of standard 12-lead ECG. Cardiomonitor uses high sensitivity capacitive electrodes and original algo-rithm of stimuli artifact detection. All recordings were made in patients during hospitalization due to device (re-) implantation or follow up visits. The whole spectrum of cardiac pacing devices from different manufactures was tested: PMs (n=37), implantable cardioverter-defibrillators (n=34) and cardiac re-synchronization systems (n=16). In 85 consistent patients, we made 100 re-cordings using different pacing modes: DDD (n=66), VVI (n=11), biventricu-lar pacing (n=17), AAI (n=6). Using novel cardiomonitor paced rhythm was identified in 100% of recordings by too independent experts. Recognition of modes switch (93%), loss of capture (84%) was also high. Definition of fusion and pseudo fusion beats was absolute (100%). Interpretation of pacing mode, made by an ex-perts 100% correlates to initially programmed ones. Single lead ECG recording with well-visualized stimuli artifacts al-lows a doctor properly to define intrinsic rhythm and all events, recorded by cardiomonitor.

31-526 **Optimisation of Electrode Placement for New Ambulatory ECG Monitoring Devices**

Alan Kennedy*, Dewar Finlay, Daniel Guldenring, Raymond Bond, James McLaughlin and Keiran Moran

New single-lead ECG devices can provide continuous monitoring of cardiac rhythm for extending periods of time (72 hours – 2 weeks). A challenge of these devices is the accurate detection of the waveform features in the presence of high signal noise. In this study we aim to determine the optimal bipolar electrode placement for maximising the R-wave amplitude. The study data consisted of 117-lead body surface potential maps (BSPMs) recorded from 229 normal subjects. The dataset was randomly divided into a training dataset (172 subjects) and a testing dataset (57 subjects). A lead selection method was applied to each subject of the training dataset and a median BSPM created. The optimal bipolar ECG lead (R-lead) was then determined as the location of the absolute minimum and absolute maximum values on the median BSPM. This new bipolar lead was then compared to all leads of the Mason-Likar 12-lead ECG. The optimal placement of electrodes for recording of the R-wave are the fourth left intercostal space adjacent to the sternum and the 5th left intercostal space on the left anterior axillary line. These positions also correspond to the location of the precordial electrodes associated with V2 and V5 of the 12-lead ECG. The R-lead showed significant improvement in median R-wave amplitude over the next best lead, Mason-Likar lead II (2493.65µV vs. 1579.60µV, Wilcoxon sign ranked test, $p<0.001$). The R-lead can provide an improvement in signal amplitude of the R-wave. This modified electrode position may lead to more accurate identification of R-waves in the presence of high signal noise and as such can lead to more accurate cardiac rhythm monitoring.

Monday, September 12, 2016 **11:45**

S32 **Health Informatics**

Chairs: Raymond Bond and Thomas Hilbel

Room: Shaughnessy II

32-242 Old Dog, New Tricks - In Silico Characterization of Antazoline Cardiac Safety

Sebastian Polak*, Bartosz Lisowski, Bogna Badyra, Roman Piotrowski, Piotr Kułakowski, Joanna Giebułtowicz, Piotr Wroczyński and Barbara Wiśniowska

Antazoline is a first generation antihistaminic drug with high efficiency in termination of atrial fibrillation (72% vs 10% placebo). However, the mechanism of antiarrhythmic activity of antazoline and its impact on the ion channels in myocardium are unknown. Unlike quinidine it has fewer side effects, and may be free of the problem of "sudden cardiac death" attributed to quinidine. The aim of this preliminary study was to investigate the effect of antazoline on human left ventricle electrophysiology as an element of its safety profile assessment. Input data included free plasma concentration measured at 11-time points after intravenous injection of antazoline mesylate (100 mg) to 10 healthy volunteers. Four scenarios were investigated for various concentration dependent (expressed as IC50) ionic currents inhibition values: IKr (PatchClamp measured = 3.34 µM or QSAR predicted = 6.07 µM) alone or in combination with QSAR predicted IKs = 0.19 µM, INa = 21.07 µM, and ICaL = 369.5 µM. TNNP04 model implemented in Cardiac Safety Simulator (CSS) was utilized to run the simulation at the population level including physiological (volume of cardiomyocytes and sarcoplasmic reticulum) and circadian variability (plasma ions concentration and heart rate). Heterogeneous 1D string of cells (Epi, Mid, Endo) were utilized and pseudoECG was analysed for QT and QRS intervals values and their antazoline concentration dependence. Study was blinded in a way that simulations were run prior to the clinical ECG readings, and compared afterwards. Regardless of the tested scenario there was no significant concentration – QTcF correlation. For scenarios including four main ionic currents maximum QTcF value reached 511 ms (1 individual > 500 ms), which suggests that QSAR predicted IKs inhibition was overestimated. The results are also in good agreement with the observed values (max QTcF = 495 ms), and shows potential use of in silico models for drugs characterization.

33-515 **An Eye-Tracking Assessment of Coronary Care Nurses during the Interpretation of Patient Monitoring Scenarios**

Jonathan Currie, Raymond R. Bond*, Paul McCullagh, Pauline Black, Dewar D. Finlay and Aaron Peace

Introduction: Given patient monitoring is a crucial duty, nurses need to be optimally trained regarding the interpretation of vital signs at the bedside. Training solutions and policies have been introduced to improve patient monitoring but issues such as alarm fatigue, incorrect readings and sub-optimal decision making still exist. The visual attention of a nurse when reading a vital signs monitor has yet to be determined and analysed for whether it can identify levels of competency. Eye-tracking has been used in healthcare research (e.g. for surgery, document reading, situational awareness) and has provided insight into cognitive processes. Methods: An eye-tracking study was designed to capture the visual attention of nurses when verbally interpreting five different monitoring scenarios using text vignettes and simulated vital signs as displayed on a monitor. Assessment (competency) was scored 0-10 and with each given a grade of low (0-5), medium (6-7) or high (8-10). Recording of delta heart rate (DHR) and NASA-TLX was used to assess effort and cognitive workload. Audio was recorded to capture interpretation and their stated confidence (1-10, 10=confident). 11 coronary nurses (mean experience: 8.73±5.09 years) were recruited. 55 observations collected. 101 eye tracking metrics (ETMs) were used in the analysis. Results: Mean score = 6.64±1.37 with mean confidence = 7.15±1.2. Mean NASA-TLX score = 254.55±55.25 (42.4±9.2%) for cognitive workload and DHR of -3.9±22.33bps. Mean duration for all scenarios (TotalDur) = 440.45±66.81s. Whilst no 'strong' correlations were found between score and any individual ETM, DHR, NASA-TLX, confidence or TotalDur, a selection of ETMs were statistically significant ($p<0.05$) in correlating with score (Table 1). Conclusion: Even small eye-tracking studies such as this one (n=55 observations) can show statistically significant correlations between some ETMs (n=7) and the level of competency (score). Further work could discover the full extent of ETMs for discriminating between novices and experts.

34-146 **Estimating Fetal Gestational Age Using Cardiac Valve Intervals**

Faezeh Marzbanrad*, Ahsan Habib Khandoker, Yoshitaka Kimura, Marimuthu Palaniswami and Gari Clifford

Estimation of the gestational age (GA) is crucial for antenatal diagnosis, monitoring fetal growth, predicting the delivery date and management of pre- and post-term pregnancies. The established gold standard involves obstetric ultrasound measurements to estimate Crown-Rump Length, which provides accurate GA estimation but is affected by genetic variations, inherent variability of growth, unsuitable positioning of the fetus and operator error. High equipment cost, lack of skilled sonographers or physicians also limit the use of ultrasound in low income countries. Various Fetal Heart Rate Variability (FHRV) parameters have been used as affordable and less specialized alternatives for estimating the GA. FHRV patterns can also be used to assess the development of the fetal brain. However, FHRV patterns are influenced by arrhythmias, fetal behavioral states, heart rate patterns and maternal conditions. In this paper a novel automated method is proposed to estimate the gestational age based on the intervals between fetal cardiac valve timings and the Q-wave of fetal electrocardiogram (fECG). The intervals were estimated automatically from one-dimensional Doppler Ultrasound and noninvasive fECG. Among the intervals, Electromechanical Delay Time (the interval between Q-wave and mitral closing), Isovolumic Contraction Time (the interval between mitral closing and aorta opening), Ventricular Filling Time (the interval between mitral opening and closing) and their interactions were selected in a stepwise regression process. Compared with Crown-Rump Length as gold standard, a mean absolute error of 3.8 weeks was obtained using leave-one-out cross validation. This method also outperformed a FHRV-based approach which resulted in mean absolute error of 5.1 weeks. Since valve intervals reflect the autonomic function, the proposed method provides a novel measure of the fetal autonomic nervous system development that may be growth curve independent. As a result the proposed method might also provide indications of IUGR early in pregnancy and potentially lead to early interventions.

S33 **Special Session: ECG Imaging in Atrial Electrophysiology**

Chairs: Maria de la Salud Guillém and Olaf Doessel

Room: Dundarave

35-337 **ECG Imaging of Focal Atrial Excitation: Evaluation in a Realistic Simulation Setup**

Danila Potyagaylo, Axel Loewe and Olaf Dössel*

Introduction: Recently, the ECG imaging field experienced great attention from both clinical and engineering communities. One very promising potential application is noninvasive reconstruction of atrial activities. However, despite numerous clinical studies, which are mostly concerned with complex irregular excitation patters, there are relatively few in silico investigations on the imaging of ectopic activations. In the present work, we explore the localization accuracy of ECG imaging of atrial focal sites. Methods: For the forward calculations, we used 4 realistic geometrical models with complex anatomical structure and a rule-based fiber orientation embedded into the atrial model. Excitation propagation was simulated with the monodomain model. For each geometrical model, 8 activation sequences were simulated: 4 foci were situated near the superior vena cava and thereby corresponded to variability in the sinus node location. Furthermore, 4 pulmonary vein (PV) foci – two from left and right PVs respectively – were considered. Based on the bidomain theory, the body surface potential maps resulting from these focal events were computed. For the inverse reconstructions, we employed a full-search procedure based on the fastest route algorithm (FRA). Results: The FRA-based method delivers the whole heart correlation coefficients (CC) maps together with the computed best solution. In all considered reconstructions, the location of a true focus was situated within the regions of highest correlation. Conclusion: In this study, we examined the performance of the rule-based FRA method in localization of atrial foci simulated with highly realistic anatomical and electrophysiological models. The analysis demonstrated the ability of CC maps to correctly image the areas of high probability for atrial foci locations.

36-540 **Evaluation of Combined Noninvasive Electrocardiographic Imaging and Phase Mapping approach for Atrial Fibrillation: A Simulation Study**

Remi Dubois*, Ali Pashaei, Josselin Duchateau and Ed Vigmond

Background: Recent developments in body surface mapping and computer processing have allowed non-invasive mapping of atrial activation during cardiac arrhythmias with increasingly finer resolution. We developed a "non-invasive atrial fibrillation (AF) mapping workflow" that combines Electrocardiographic Imaging (ECGi) and phase mapping to localize reentry and focal areas during ongoing AF. However, it remains challenging to determine the accuracy of this approach because data for validation is inaccessible in humans and animal models. The aim of this study was to use simulated data to quantitatively evaluate the methodology. Methods: We used a computed tomography (CT)-derived bilayer computer model of the atria, which incorporated structural and conductive elements, including left and right atria, discrete connection paths between them, fiber orientation, pectinate muscles, and inflow vessels. A modified Courtemanche human atrial ionic model was used. We ran the first simulation (Sim1) on a structurally normal model, inducing reentry by an ectopic focus centered around a pulmonary vein after a normal beat originating from the sinoatrial node. A seconc simulation (Sim2) was run on a 'diseased' model in which fibrotic tissue was introduced by stochastic element removal based on Late Gadolinium Enhancement Magnetic Resonance (LGEMR) data of AF patients. The extracellular potentials on the epicardium were computed and propagated homogeneously to the surface using a Boundary Element Method. The body surface potentials obtained were spatially sampled in 252 locations to replicate clinical settings. The "non-invasive AF mapping workflow" was applied to body surface data to reconstruct the potentials and the phase signals on the epicardial surface of the heart. Phase signals, phase singularity locations, and local AF cycle length were compared to those computec directly from the transmenbrane potentials. Results: The AF cycle lengths were well estimated for the two sets of data (mean magnitude of relative errors MRE=5.4% and 3.8% for Sim1 and Sim2 resp.). These results were stable when adding up to 10 dB of noise on the body surface electrodes or 7.5+/-3.4mm error on electrode locations (5.6%,and 3.9%). The phase locking value (PLV) were respectively 0.62

and 0.78, indicating a fair correlation between the phase signals. Regions showing reentries were well localized with phase singularities that were stable according to electrical and geometrical noise. Conclusion: The spatial distribution of the AF cycle length and the location of the phase singularities are useful features to target ablation. We showed in this work that they can be estimated using a combine approach of ECGi and phase mapping.

37-331 **High Frequency Driving Sites Anchor to Fibrotic Regions in Chronic Atrial Fibrillation**

Nathan Angel, Derek Dosdall, Rob MacLeod and Ravi Ranjan*

Introduction: Atrial fibrosis is linked to atrial fibrillation (AF). We used a chronic animal model of AF to test the hypothesis that fibrosis anchors sites of high frequency activation during AF, which may drive the arrhythmia. Methods: Endocardial electrical recording were measured from a constellation catheter placed in the left atrium (LA) of chronic AF dogs (n=6) (AF > 12 months). A geometric shell, created using an electro-anatomical mapping system was then fused with a LA wall created by segmenting a T1 MRI. Regions of the lowest 10% T1, were used as a surrogate measure of fibrosis. Electrograms with high frequency activations were determined through dominant frequency (DFs) analysis during AF. The highest 10% DF values for each minute of AF were placed in a spatial map of probability during the 30 min AF episode and were compared with regions of fibrosis. Results: The AF animals had at least one site of high DF which was stable for at least 22.5 (75 %) of 30 minutes of AF and these sites were within 1.4±1.2 mm of T1 determined fibrosis. Stable high DF sites occurred more significantly within 2 mm of fibrosis than in other regions of the atrium (p<0.05, chi square). The mean DF was 8.5±1.2 Hz and the highest DF sites showed an average DF of 10.3±1.1 Hz. In 5/6 chronic AF animals, regions of high DF bordered regions of structural remodeling as determined by T1 MRI. Discussion: Heterogeneous atrial remolding, specifically the development of fibrosis, arising from chronic AF may provide a substrate that anchors sites of high DF. Cardiac T1 Mapping MRI provides a means to determine such fibrotic sites noninvasively and ablating these sites reduced the stability of AF.

38-420 **Noninvasive Identification of Atrial Fibrillation Drivers: Simulation and Patient Data Evaluation**

Maria de la Salud Guillem Sánchez*, Andreu M Climent, Miguel Rodrigo, Ismael Hernández-Romero, Alejandro Liberos, Francisco Fernández-Avilés, Omer Berenfeld and Felipe Atienza

Background Identification of atrial drivers as singularity points by using the inverse problem of electrocardiography is being used to guide atrial fibrillation (AF) ablation. However, the ability of the inverse problem to reconstruct fibrillation patterns and identify AF drivers has not been validated. Methods Position of AF drivers was compared between recorded and inverse computed EGMs by making use of (1) realistic mathematical models and (2) simultaneous endocardial and body surface recordings during AF ablation procedures. Specifically, 30 different AF episodes with different degrees of complexity were simulated with realistic atrial and torso anatomies. In addition, for two patients with chronic AF, endocardial (128 recording points distributed in both atria) were recorded together with torso surface recordings (57 leads). Inverse problem of electrocardiography was computed by applying 0-order Tikhonov regularization. Atrial drivers were defined as the areas with the highest dominant frequencies (HDF) or at the sites with a higher incidence of long-lasting phase singularities (PS). Results On simulation data, HDF analysis allowed the correct identification of the chamber that harbored the AF source in 30 out of 30 of the models evaluated vs. 26 out of 30 models for PS analysis. On patient data, the highest incidence of PS was inscribed inside the highest DF area for the actual EGMs recorded by the multipolar catheter baskets. Solution of the inverse problem only allowed identifying atrial drivers on the correct atrial chamber by HDF analysis (2 out of 2 patients vs. 0 out of 2 patients for PS analysis). Conclusion Identification of atrial sources by solving the inverse problem of the electrocardiography is more reliably accomplished in the frequency domain than based on PS detection. Alternative methods for inverse problem resolution to zero-order Tikhonov regularization may be required for their application in AF.

S34 **Cardiac Imaging: Motion Analysis**

Chairs: Cristiana Corsi and Yi Su

Room: Shaughnessy I

39-459 **Automatic Segmentation of Mitral Leaflet Movement in Doppler Tissue M-Mode Ultrasound**

Kasper Sørensen*, Samuel Emil Schmidt, Peter L Sørensen, Anne-Sofie Korsager, Jacob Melgaard, Peter Søgaard and Johannes Struijk

Introduction: Doppler Tissue M-Mode ultrasound facilitates a method for measuring both mitral and aortic valve opening and closing. These measures can be used when assessing global information about the cardiac cycle. The method depends on an operator to manually setting points in the ultrasound image to obtain the timing intervals. We developed an automatic segmentation algorithm that segmented the mitral leaflet movement line, to guide the clinician in this work. Methods: The algorithm used a series of steps to reduce noise in the image, leaving only the region of interest left with the mitral leaflet movement line. Next the gradient of the image was calculated with a the Sobel method, creating a high gradient on the edge of the mitral leaflet movement line. Using a multidimensional weight matrix the mitral leaflet movement was tracked in the image. The automatic algorithm is validated against three human operators. Results: In 19 of 29 images the correlation coefficients are larger then 0.8 between the algorithm and the mean of the operators. The median operator standard deviation within the 95% CI was 5 pixels. The median rms error for the algorithm was 4 pixels. Conclusion: The novel method of automated segmentation the mitral leaflet movement line has a high accuracy but depends on the quality of the image.

40-323 **Respiratory Motion Correction for 2D Cine Cardiac MR Images using Probabilistic Edge Maps**

Ozan Oktay, Giacomo Tarroni*, Wenjia Bai, Antonio de Marvao, Declan O'Regan, Stuart Cook and Daniel Rueckert

Background. Short axis (SA) cine MR images are of crucial importance for the accurate assessment of cardiac anatomy and function. SA cine stacks are routinely acquired during multiple breath-holds: different breath-hold positions can have detrimental effects on a variety of clinically relevant tasks (e.g. volumetric estimation). In this study, we proposed a novel approach to spatially align motion corrupted SA slices in MR image stacks using 3D probabilistic edge maps (PEMs) generated with structured decision forests. Methods. PEMs are learning-based image representations outlining the contours of a specific object of interest (the myocardium, in this case). Through training, structured decision forests are able to associate to each 2D SA image (slice i of the stack) 3D PEMs representing the contours for slices i and i+1. The overlap between 3D PEMs generated from adjacent slices allows to correct the in-plane spatial misalignment using a block matching registration algorithm. This approach was tested on SA cine stacks acquired from 26 healthy subjects for whom anatomical 3D (A3D) cardiac images were also available as reference. A 3D multi-atlas segmentation technique was applied to estimate end-diastolic left ventricular volumes respectively from the A3D images (EDVref), the 2D SA image stacks before (EDVpre) and after slice-alignment using the proposed approach (EDVpost-PEMs) and using a conventional intensity-based registration method (EDVpost-I). Inter-slice alignment was assessed measuring differences between EDVref values and EDVpre, EDVpost-PEMs and EDVpost-I values, respectively. Results. Volume differences between EDVpost-PEMs and EDVref (7.73±6.55 ml) were smaller compared to differences between EDVpre and EDVref (10.34±9.41 ml) and EDVpost-I and EDVref (10.76±9.64 ml). The improvement in volume estimation was observed to be statistically significant ($p = 0.01$). Conclusion. The experimental results show that volumetric measurements on 2D cine cardiac MR stacks can be improved by using the proposed respiratory motion correction method.

41-452 **A Miniaturized MEMS Motion Processing System for Nuclear Medicine Imaging Applications**

Mojtaba Jafari Tadi*, Eero Lehtonen, Jarmo Teuho, Antti Saraste, Mikko Pänkäälä, Mika Teräs and Tero Koivisto

Background. In cardiac and oncologic Positron Emission Tomography (PET) imaging, cardiac and respiratory motions may impair the image quality and the quantitative accuracy of the heart imaging. To reduce motion-related inaccuracies, cardiac and respiratory gating methods are the most common approaches applied in clinical PET imaging. Methods. We used tri-axial micro-electromechanical (MEMS) accelerometer and gyroscope sensors attached to the test subjects' chest to extract seismocardiographic (SCG) and gyrocardiographic (GCG) motion signals. Our main objective was to assess the capability of MEMS motion sensor -based measurements in improving the dual gating technique. The main hypothesis for this work was that mechanical sensors could be used improve the quality of detection and estimation of the quiescent periods in cardiac respiratory cycles. Concurrent 10 minute recordings of MEMS-based SCG and GCG, electrocardiography (ECG), and Real-time Position Management (RPM) were performed, processed and analysed using healthy volunteers as test subjects. Results. Signal processing algorithms for extracting PET gating information from cardiac and respiration signals were developed. The cardiac cycles detected with the MEMS-based SCG and GCG measurements are highly correlated with the reference ECG cycles in terms of interval durations (RSCGvs.ECG = 0.999, RGCGvs.ECG = 0.998). Mechanical signals are also able to accurately indicate the timings of systolic and diastolic phases suitable for cardiac gating, as compared to the ECG. Moreover, gyroscope and accelerometer derived respiratory (GDR and ADR) motion signals are found to have high linear correlation with the reference RPM (RGDRvs.RPM= 0.998, RADRvs.RPM= 0.997). Conclusion. The proposed MEMS motion sensor -based gating, and the developed algorithms, may potentially improve the accuracy of nuclear medicine imaging specifically in cardiac and oncologic PET images. These promising first results warrant for further investigations, and the application of the developed methods on PET imaging data.

Tuesday, September 13, 2016 **8:30**

S41 **Health Analytics and Software**

Chairs: Johan De Bie and Matthias Gorges

Room: Shaughnessy II

42-205 **Closing the Data Loop: An Integrated Open Access Analysis Platform for the MIMIC Database**

Mohammad Adibuzzaman*, Ken Musselman, Alistair Johnson, Paul Brown, Zachary Pitluk Pitluk and Ananth Grama

Recent advances in computational sciences have brought major changes in many fields such as image processing and computational biology. However, that change has not been translated to clinical application to its potential. Primary obstacles include lack of communication between data scientists and clinicians, technical difficulties due to the heterogeneous data and lack of understanding of the risk and benefit resulting in the absence of regulatory guideline. One major initiative for large data collection in clinical setting is MIMIC III, created and maintained by the Laboratory for Computational Physiology at MIT. It has two main components, 'clinical' and 'waveform'. With the current access platform, it is difficult for a researcher to use the database without extensive knowledge of programming language and different database architectures. For any research initiative with this database, many steps are recurrent to each research project; e.g., i) high level exploration of the database, ii) integration of heterogeneous data sources, iii) cohort selection according to clinical criteria, and iv) use of different algorithms. Consequently, researchers use significant resources to reinvent the wheel for each research project which acts as a major barrier for translational clinical research with this publicly available dataset. To address this issue, we have designed and developed a software tool that would enable the researchers to integrate disparate data sources, automatic cohort selection and use different well known algorithms. The architecture uses an array database, 'SciDB' with distributed computing for the 'waveform' and structured query language 'PostgreSQL' for the 'clinical' database. The 'R' software platform is used for the integration. The demonstration of this open source software tool would show the ease and flexibility of using the tool for terabytes of data for different research problems. The software architecture would help expedite clinical research to address the gaps between large data collection and translational impact.

43-437 **Telecardiology under Resource Constraint: Low-complexity Compact Representation of ECG**

Roopak Tamboli and Soumya Jana*

Aim: Compact, yet faithful, representation of ECG signals to meet bandwidth and power constraints remains central to successful telecardiology in infrastructure-deficient areas. Towards practical realization, we seek desired compactness in the class of low-complexity transform representations. Key Idea: A typical ECG signal consists of a strong rhythmic (low-pass) component, with compact Fourier transform (FT) representation, and temporally localized (high-pass) features, efficiently represented by wavelet transform (WT). Accordingly, we propose a compact representation consisting of suitable Fourier and wavelet coefficients. As computation of such coefficients is at most O(n log(n)), our representation inherits the desired low complexity. Method: We considered 43 annotated ECG records of the MIT-BIH Arrhythmia database. From those, overlapping signal vectors of length 256 samples, each containing an R-peak, were formed. We then optimized the pair (K1, K2), where K1 Fourier coefficients and K2 wavelet (Daubechies-4, `db4') coefficients respectively represent the rhythmic component and localized features, and jointly achieve a target fidelity. The number, K1+K2, of coefficients in our method was compared to that required to achieve the same target fidelity using (i) WT (`db4'), (ii) discrete cosine transform (DCT), and (iii) FT. Results: Compared to DCT, FT and WT representations, respectively, the proposed method used 51%, 30% and 11% less number of coefficients on the average at a target fidelity R^2=98%. Indeed, the figure shows the superiority of our method for most individual records. Our result assumes practical significance as improved efficiency was achieved without sacrificing low complexity. Here, note that Karhunen Loeve transform (KLT) provides the best compaction, albeit, at a higher complexity.

44-388 **Design of an Electronic Upload and Reporting System aimed at Corelab Tasks and Responsibilities in Multi-center Clinical Trials**

Jan Walter Benjamins*, Yoran M. Hummel, Jan Peter Busman, Frans Riepma, Bernard Dorhout and Joost P. van Melle

Echocardiography plays a substantial and ever growing role in cardiovascular clinical trials. In large scale multicenter clinical trials these images are interpreted and analyzed by an imaging core laboratory (ICL) to generate consistent results with the least possible variance. Currently, transfer of the images can be achieved in 2 ways; via postal services (physical media) or web-based via upload portals that merely act as a digital substitute for traditional logistics. We describe the design of a new software system that facilitates general ICL logistics, such as digital transfer of images, automated DICOM data verification, semi-automated image quality assessment, reporting and database generation in multicenter clinical trials. It fully integrates with most commonly used medical systems and contributes to cost efficiency aspects of running multicenter trials. The system was built in .NET, implementing modern web standards, HL7 and DICOM healthcare communication standards. Web security principles were applied to the developed components and the deployed application configuration. The system consists of two major subsystems, first being an internet application that serves as an upload portal for sites and as a report tool for clinical research organizations (CRO's). The second component is an intranet application which is accessible through the local network. Both components have access to a shared database and file-share, where images are stored by the internet application and pushed forward to the medical system by the intranet application. After images have been interpreted by ICL-personnel, the analysis results are reported back to the ICL system, that sends automated notifications to CRO's with relevant updates about the specific trial. All steps in the workflow are guided by and validated against the trial design. Validation failure(s) at any point are reported instantaneously to all persons concerned with the specific event, consequently increasing efficiency and possibly reducing trial costs.

45-209 **Machine Learning Approaches for Supporting Patient-Specific Cardiac Rehabilitation Programs**

Danilo Lofaro*, Maria Carmela Groccia, Rosita Guido, Domenico Conforti, Sergio Caroleo and Gionata Fragomeni

Cardiac rehabilitation is typically recommended for the follow up management of cardiovascular diseases. Physical training prevents the recurrence of cardiovascular events, and increases life expectancy, lowering cardiovascular morbidity and mortality risk. Previous studies investigated the application of Machine Learning approaches for the prediction of the rehabilitation outcome in terms of physical performance as well as of the length of stay after acute cardiovascular events, but fewer reports are focused on using predictive models to support clinicians in the choice of a patient-specific rehabilitative treatment path. In this work, we analysed data relative to two years activity of a rehabilitation clinic in South Italy to derive a prediction model for supporting clinicians in the planning of personalized rehabilitation programs. We collected data concerning 129 patients admitted for cardiac rehabilitation after a major cardiovascular event, relative to: anthropometric measures, surgical procedure and complications, comorbidities and physical performance scales at admission. The prediction outcome was the rehabilitation program divided in four different paths. Algorithms used to find the best predictive model were tailored implementations of Lasso Regression, Linear/Polynomial/Radial SVM, Random Forest, Bagged Flexible Discriminant Analysis, C5.0 and Bagged CART. Models performance were measured by prediction accuracy. Parameters tuning has been optimized basing of performance on a 5-fold cross-validation. R 3.2 and caret package 6.0 were used for analyses. Mean model accuracy was 0.748 (SD 0.0165). Best model selected was polynomial SVM with parameters degree = 3, scale = 0.01 and C = 2, showing a global classification accuracy of 0.769. Five most important variables for prediction were cardiac risk class, six minutes walking test, borg scale, age, MRC dyspnea scale and FEV1/FVC ratio at rehabilitation initiation. Machine Learning techniques have shown to be a reliable tool for support clinicians in the decision of cardiac rehabilitation treatment path.

46-277 **An Annotation Driven Rule-based Algorithm for Suggesting Multiple 12-lead Electrocardiogram Interpretations**

Andrew Cairns*, Raymond Bond, Dewar Finlay and Daniel Guldenring

The 12-lead Electrocardiogram (ECG) is ubiquitously used as a diagnostic support tool to detect cardiovascular disease. However, it is difficult to read and is often incorrectly interpreted due to the significant cognitive load forced upon the interpreter. To help alleviate this cognitive workload and to decrease diagnostic time, this format of ECG presentation is often supplemented with computer analysis, which routinely presents the interpreter with an automatically generated ECG interpretation. That being said, computerised analysis of an ECG is often inaccurate as machine algorithms struggle to recognise patterns and shapes in noisy ECG signals. Therefore, it is recognised that computerised ECG interpretation should always be over-read by a clinician. However, since current computerised ECG interpretation often only provides a single diagnosis, it can contribute to a number of cognitive biases. To combat these concerns, a decision support algorithm has been developed to provide multiple potential ECG diagnoses. As part of a de-biasing strategy multiple possible interpretations are presented to encourage differential diagnosis. This study augments an interactive sequential approach to ECG interpretation (IPI model) with a semi-automatic rule-based algorithm to suggest multiple potential diagnoses. To accomplish this, the rule-based algorithm assesses an interpreter's response to each question in the IPI model. The algorithm is semi-automatic and is based on annotations inputted by the human interpreter. Therefore, this is an optimal man-machine model for ECG interpretation as a human observer is better at recognising patterns and shapes in noisy signals whilst a machine is better at reasoning based on a large set of rules. Therefore, we hypothesise that the algorithm may have greater accuracy compared to conventional computer ECG diagnostics which focus on signals that are often noisy and difficult to process. The algorithm was implemented using web technologies and uses the independent storage format JSON to define the rules

Tuesday, September 13, 2016 **8:30**

S42 **Modeling: Tissue and Defibrillation**

Chairs: Martin Bishop and Gunnar Seeman

Room: Pinnacle II

47-369 **Impact of Three Dimensional Atrial Fibrosis on Development and Stability of Rotational Activity in Atrial Fibrillation – A 3D Simulation and Clinical High-density Mapping Study in Peristent Atrial Fibrillation**

Markus Rottmann*, Ufuk Aslan, Wenzel Kaltenbacher, Viktor Markstein, Thomas Arentz, Olaf Dössel and Amir Jadidi

Introduction: The arrhythmogenic mechanisms of AF are still not understood. Increased atrial fibrosis is a structural hallmark in patients with persistent AF. Methods: We assessed the electrogram signature rotational activity and their spatial relationship to low voltage areas (increased fibrosis) in patients with persistent AF. Computer simulations implicating 3-dimensional atrial tissue with different amount of atrial fibrosis were used to assess development and stability of rotational activities (rotors) during AF. Results: A series of computer simulations with 3-D atrial fibrosis (40% de-gree) implemented in an area of 10mmx10mmx2mm was carried out. Rotor anchoring occurred at the borderzone between fibrosis and healthy atrial tissue with 12 consecutive rotations prior to rotor extinction. Rotational activity in fibrotic tissue resulted in fractionated signals and were overlapped with large negative electrograms in unipolar recording mode from neighbouring healthy tissue – impressing as a focal source. Conclusion: Necessary conditions for development and stability of rotational activities around fibrosis were on the one hand a minimum size of atrial fibrosis area equal or larger than 10mm x 10mm and on the other hand a degree of atrial fibrosis of 40%. Clinica data showed that AF termination sites were located within low voltage areas (displaying <0,5mV in AF on the multi-electrode mapping catheter) in 80% and at their borderzones in 20% of cases.

48-233 **The Effect of Conductivity Values on Activation Times and Defibrillation Thresholds**

Barbara Johnston*, Josef Barnes and Peter Johnston

Aims: Uncertainty in the input parameters used in simulation studies needs to be taken into account when evaluating the results produced by such studies. This work considers the effect of using various sets of bidomain conductivity values in simulations of activation times and defibrillation thresholds in a realistic whole heart model. Methods: Activation time maps indicating the propagation of the depolarisation wavefront through the cardiac tissue are generated using two types of sets of bidomain conductivity values: four-conductivity datasets (where normal and transverse conductivities are assumed equal) and six-conductivity datasets, including newly proposed sets that are based on experimental measurements. These maps are produced by solving the bidomain model, along with an individual cell model of the electric current, on a mesh of a canine heart. In addition, simulations are carried out in a 'heart in a bath' model, where a shock is delivered from two opposing patch electrodes. Defibrillation thresholds that indicate the minimum potential difference that is required to defibrillate the heart are determined for the above sets of conductivities. Results: The activation time maps show significant differences depending on the conductivity set used, as do the defibrillation thresholds. The defibrillation thresholds vary by more than 20%, whereas the activation times for epicardial breakthrough and total depolarisation both vary by approximately 50%. It is found that the most extreme values in each case are produced by two of the four-conductivity datasets. Conclusions: Significant differences in activation time maps and defibrillation thresholds are found, depending on the conductivity set that is used for the simulation. Since these differences are sufficiently large that they may lead to different conclusions in such studies, it is suggested that the four-conductivity datasets may not be an appropriate choice for use in simulation studies in the heart.

49-263 Biventricular Pacing Optimization by Means of the Dyssynchrony Parameter

Pavel Jurak*, Pavel Leinveber, Josef Halamek, Filip Plesinger, Tereza Postranecka, Jolana Lipoldova and Miroslav Novak

Introduction: Cardiac Resynchronization Therapy (CRT) represents an effective treatment for ventricular dyssynchrony. Biventricular pacing synchronizes delayed left ventricle lateral wall (LV) activation with the septum and right ventricle wall (RV). A positive response is manifested by shortening of the QRS and increase of the LV ejection fraction. To improve the CRT effect, different interventricular delay (VV) settings can be used to optimize resynchronization. Here we test two different VV delay settings: 0 ms. – simultaneous LV and RV activation, and 20 ms LV pre-activation. Methods: 12-lead 5 kHz ECG during 5-minute resting supine position was measured in 47 patients with CRT OFF and CRT ON with VV delay 0 (CRT_0) and -20 ms (CRT_20). The atrioventricular delay was minimized to suppress any spontaneous conduction. We detected QRS duration (QRSd) and computed the dyssynchrony parameter DYS as the time difference between center of gravity of 500-1000 Hz averaged envelopes in the V1 and V6 leads in the QRS complex region (see Fig, bottom panel). Results: 32 of 47 patients (68 %) had a positive CRT_0 response manifested by QRSd shortening of 33.2±20.9 ms and DYS decrease of 51.9±30.9 ms. 28 of 32 patients (87 %) had a positive LV pre-excitation effect: QRSd additional shortening of 4.7±5.9 ms and DYS decrease of 12.6±7.5 ms. The correlation coefficient of QRSd and DYS changes (CRT_0 vs CRT_20) was 0.23 and indicates the information diversity. Conclusion: both the QRSd and DYS parameters during LV pre-excitation manifest significant decrease ($p < 0.001$). The DYS parameter differs from QRSd and provides significantly higher response to VV delay change ($p < 0.001$). There is potential for the use of the DYS parameter as an additional predictive value for improved CRT VV delay selection.

50-487 **Can Continuous Models Capture Details of Reentry in Fibrotic Myocardium?**

Tanmay Gokhale*, Eli Medvescek and Craig Henriquez

Motivation: Cardiac arrhythmias have traditionally been simulated using continuous models that assume tissue homogeneity and use a relatively large spatial discretization. However, it is unclear how well the continuous model is able to accurately capture the discrete effects of fibrosis that may be implicated in arrhythmogenesis. The objective of this study was to build microstructural discrete models of fibrosis and compare behavior with conduction velocity-matched continuous models. Methods: Two dimensional models of anisotropic cardiac monolayers (6mm x 3mm) that incorporate discrete cells with uniformly distributed gap junctions were randomly generated. 70% of lateral gap junctions were decoupled to replicate adult tissue connectivity. Collagen septa of variable length (mean = 300 micron) were inserted, parallel to cardiac fiber orientation, to disrupt between 0% and 30% of the remaining transverse coupling between myocytes. The Bondarenko membrane model of the mouse ventricular myocyte was used. Conduction was simulated in each tissue, and an equivalent continuous model was created, with longitudinal and transverse conductivities selected to match the longitudinal and transverse conduction velocities of the microstructural model. Spiral waves were then induced in each tissue mode via cross-stimulation, and the cycle length and tip trajectory were recorded. Key Results: 20% fibrosis lead to a 45% slowing in transverse conduction. At 0% fibrosis, the spiral wave behavior of the microstructural model was closely matched by the continuous model (cycle length 67 msec vs 64 msec). However, at 20% fibrosis, the cycle length was substantially longer in the microstructural model than the continuous model (92 msec vs 72 msec), due to a longer reentry pathway because of the pattern of fibrosis in the tissue. Conclusion: These results suggest that continuous models adapted to simulate fibrotic tissue may still fail to capture key details of reentry caused by the discrete nature of fibrosis induced heterogeneity.

51-206 **The Strength-Interval Curve for Blood Vessels**

Adam Connolly* and Martin Bishop

Wavefronts from virtual-electrodes, in response to field-stimulation, are thought to be the main mechanism behind the success of low-energy defibrillation protocols. In this work the concept of the strength-interval curve, usually associated with uni-polar stimulation, is extended to field-stimulation for specific geometrical features - in this case blood-vessels (with realistic fibre architecture and lumen structure) - as the coronary vasculature is known to be an important source of virtual-electrode induced wavefronts, in response to field-stimuli. Using the bidomain model for myocardium, we observed break-excitations in response to low-strength field stimuli, at early diastolic intervals - while the surrounding tissue was relatively refractory. Break-excitations were only possible due to the relative proximity of regions of de and hyper-polarization around the vessel, and the associated strength-interval curves (for sufficiently large vessels) displayed a reduction in shock-strength for early diastolic intervals - an effect known from the literature on uni-polar stimulation. This leads us to conclude that it may be possible to optimize low-energy defibrillation shock protocols to take advantage of this effect, in order to minimize the total energy used and maximize the probability of successful defibrillation.

52-405 **Regularity of Node Distribution Impacts Conduction Velocities in Finite Element Simulations of the Heart**

Eike Moritz Wülfers, Olaf Dössel and Gunnar Seemann*

Cardiac excitation propagation simulations on complex geometries benefit from flexible tetrahedral meshes. These meshes can contain elements of different sizes. Unfortunately, simulated conduction velocity (CV) seems to not be independent from mesh element sizes as shown in a monodomain N-version benchmark of the cardiac modeling community. Use of the consistent (vs. lumped) mass matrix as well as ionic current integration techniques have previously been identified as influencing this mesh-dependency. This work shows that regularity of node distribution in meshes contributes strongly as well. Although the existence of effects caused by regular node distributions is known for other applications of the finite element method (FEM), they have not previously been studied in cardiac electrophysiology simulations. Excitation propagation was simulated using a FEM discretization of the monodomain equation. Operator splitting was used to separate integration of the partial differential equation and ionic current calculations. The resulting linear algebra problem was solved with the PETSc framework. Simulations were conducted on tetrahedral meshes of a cuboid (dimensions 3mm x 7mm x 20mm). At different spatial resolutions h, meshes of regularly arrayed nodes (Delta{x,y,z}=h) were created. Corresponding meshes with less regular node distributions were generated using a 3-d Delaunay triangulation (Gmsh algorithm, with mean and standard deviation of element edge length matching the regular meshes). After stimulation at one corner, resulting simulated activation times (ATs) of the node in the diagonally opposite corner were evaluated. Using the consistent mass matrix and h=0.1mm, ATs of 40.11ms and 39.72ms were recorded for the regular and irregular mesh, respectively. ATs increased with increasing h, but at h=0.7mm the AT observed on the regular mesh was 80.01ms already, whereas only 47.52ms were recorded for the irregular mesh.

Tuesday, September 13, 2016 **8:30**

S43 **Cardiac Pressure and Bloodflow**

Chairs: Dingchang Zheng and Roberto Sassi

Room: Shaughnessy I

53-149 **The Pressure Gradient across the Endocardium**

rachad shoucri*

Based on the theory of large elastic deformation of the myocardium, a mathematical relation for the pressure-volume relation (PVR) in the left ven-tricle was derived, in which the active pressure of the myocardium (also called isovolumic pressure Piso by physiologists) is included in the mathematical formalism describing the PVR. Also a mathematical expression for the non-linear end-systolic pressure-volume relation (ESPVR) was derived, from which an expression of the pressure gradient (Piiosm – Pm) /Pm across the inner surface of the myocardium (endocardium) was obtained (Pisom = peak isovolumic pressure when the myocardium reaches its maxi-mum state of activation, Pm = corresponding left ventricular pressure). In the figure we compare the calculated ratio of pressures Pisom / Pm to the ejection fraction EF (stroke volume / end-diastolic volume) and to the ratio of areas SW/TW (stroke work / total area under the ESPVR), for a group of normal patients (*) and a group of patients with aortic stenosis (o). The figure shows that the three indexes give consistent results. In particular we see that the group of aortic stenosis can be subdivided into three subgroups, one subgroup (three cases) corresponds to normal values for EF and SW/TW, a second subgroup (seven cases) has increased values for Pisom / Pm and reduced values of SW/TW with respect to the normal group, and a third subgroup (two cases) has reduced values of Pisom / Pm and increased values of SW / TW with respect to the normal group. In the second subgroup, an increase in Pisom corresponds to an increase in TW and a decrease in Pm corresponds to a decrease in SW (≈ Pm*stroke volume), resulting in a decrease of SW/TW. In the third subgroup a decrease in Pisom corresponds to a decrease in TW and an increase in Pm corresponds to an increase in SW, resulting in an increase in SW/TW.

54-108 **Estimation of End-Diastolic Pressure via Deconvolution**

Christoph Hoog Antink*, Daniel Rüschen, Steffen Leonhardt and Marian Walter

Left ventricular assist devices (LVADs) can significantly improve survival rate and quality of life for patients suffering from end-stage heart failure. Several promising strategies to control LVADs are being developed, some being focused on the end-diastolic pressure (EDP). For those, the problem of EDP estimation in real-time has to be solved. In this work, a generally applicable deconvolution-based method to identify features in cardiac signals is presented. This method is applied to the estimation of the EDP from the left-ventricular pressure (LVP) signal and evaluated on animal trial data. In 11 trials with adult sheep, a myocardial infarction was induced and an LVAD was implanted. A total of 37.6 hours of LVP data, corresponding to 201885 ED time points, was annotated by a medical expert. Using these annotations, a desired signal that highlights the end-diastolic (ED) time point is created. Next, linear FIR filter coefficients are estimated that transform the LVP signal into an estimation of the desired signal. To evaluate the concept, the filter coefficients estimated in one trial are used to estimate the desired signal in the remaining 10 trials. In this forward operation, convolution of the LVP signal with a linear FIR filter is performed, which is computational inexpensive and introduces a delay of only 36 ms. Next, a basic peak detection strategy is applied to locate the ED time point. Using this form of cross validation, an average root mean square error of 11.6 ms / 4.1 mmHg was achieved. This demonstrates the potential of the presented deconvolution method for feature extraction and processing of cardiac signals. With a robust, real-time capable method for EDP detection at hand, it is possible to implement closed-loop LVAD control strategies that restore physiological left ventricular filling pressures.

55-262 **Diastolic Augmentation Index Improves Augmentation Index in Assessing Arterial Stiffness**

Yang Yao, Lisheng Xu*, Yu Wang, Yahui Zhang, Yingxian Sun and Liang Guo

Arterial stiffness is an important risk factor for cardiovascular (CV) events and is increasingly used in clinical practice. Radial augmentation index (AI) is used in assessing arterial stiffness, but is not only dependent on pulse wave velocity (PWV), but also on several other factors like the reflect distance of the pulse wave and height. This paper improved radial AI in assessing arterial stiffness by d-value (the subtraction between radial AI and dAI). Twenty-one subjects agec 22 to 80 years (mean±SD, 44±22 years) were enrolled in this study. The PWV, AI and dAI of each subject were measured. The d-value (r=0.81, P<0.0001) shows better linearity with PWV than AI (r=0.76, P<0.0001) and dAI (r=-0.72, P<0.005) do. In conclusion, dAI improves AI in assessing arterial stiffness.

56-410 **Exploratory Study of the Cardiac Dynamic Trajectory in the Embedding Space**

Jorge Oliveira*, Bruna Cardoso and Miguel Coimbra

In this paper, the topological and dynamical properties of the heart sounds are assessed. The signal is pre-processed and projected into an embedding subspace, which is more suitable to detect the irregularities and the unstable trajectories registered during the cardiac murmurs than the original heart sound signal. We present a method for heart murmur classification divided into five major steps: a) signal is divided into heart beats; b) entropy gradient envelogram is computed (per heart beat) from the pre-processed signal; c) the orbital trajectories are reconstructed using the embedding theory; d) r orbits in the embedding subspace are extracted (per heart beat); e) the median of the n orbits is used as an input to K-Nearest Neighbors (KNN) classifier. The experimental results achieved in the mitral, tricuspid pulmonic spots are in agreement with the current state of ar for heart murmur classification.

57-456 **Heart-valve Sounds Obtained with a Laser Doppler Vibrometer**

Johannes Struijk*, Kim Munck, Bolette Dybkjær Hansen, Nina Jacobsen, Louise Pilgaard, Kasper Sørensen and Samuel Emil Schmidt

Aims: Several modalities for recording of heart sounds have been used since the late 1800s. Microphones and accelerometers have been the obvious choices since the beginning of the 20th century, showing that a wealth of information about cardiac movement is available outside the audible fre-quency range as well as about the audible valve sounds and murmurs. The present work investigates the use of a Laser Doppler Vibrometer (LDV) to record valve sounds and characterizes those recordings. Methods: An LDV (Polytec PDV-100) was used to measure the normal component of the velocity of the chest wall at 30 points (grid of 6 x 5 points) in each of seven subjects. The recorded signals were analyzed in the frequen-cy domain and bandpass filtered (20-80 Hz) to obtain the S1 and S2 heart sounds. From all grid points, a center of energy (CoE) was calculated for the signal energy, separately for the S1 and S2 sounds. Results: The LDV signal reached a noise floor for a frequency of >80 Hz, whereas 99% of the signal energy was below 80 Hz. The signal to noise ratio was approximately 24 dB if measured directly on the (caucasian) skin, and up to 45 dB if special markers were used. There was little difference in signal amplitudes between measurement points on the ribs as compared with the intercostal spaces. Amplitudes of the valve sounds were below 1 mm/s. The mean centers of energy were to the left of the sternum, with the CoE of the S2 sound about 11 mm superior to the CoE of the S1 sound on average. Conclusion: The LDV is an interesting new, non-contact, modality for the recording of heart sounds with excellent signal quality and reproducibility.

58-424 **Computer Simulations of Three-dimensional Blood Flow in Patient-specific Aorta Models with Aortic Aneurysms**

Jun-Mei Zhang*, Dian Farhana Binte Haron, Adrian Shoen Choon Seng Low, Boyang Su, Kenny Yoong Kong Sin, Ru San Tan, Hua Zou and Liang Zhong

Background and Aims: Aortic diameter is considered as the primary criterion to decide surgical repair of abdominal aorta aneurysm (AAA) and thoracic aorta aneurysm (TAA). However, it has limitations as some aneurysms rupture below size thresholds, while others grow to a large size without rupture. We hypothesize that low wall shear stress (WSS), whereas flow recirculation and thrombus deposition predominated, may be associated with the progression and rupture risk of aortic aneurysm. Methods: Two patients (subject 1 and 2) with both TAA and AAA were recruited. Standard computed tomography (CT) or magnetic resonance imaging (MRI) were performed at baseline and follow-up. Phase contrast MRI was performed to obtain the blood flow at the ascending and descending aorta positions. Patient-specific aorta models were reconstructed from the most recent MRI images and the computational domains were discretized by a total of 572,622and 781,691 cells respectively. To solve Navies-Stokes equations, time-average flow rate measured with phase-contrast MRI was assigned to the aorta inlet and resistance boundary conditions were used for all the outlets. During 3-month follow-up, TAA of subject 1 was found to grow from 6.2 cm to 7.1 cm., therefore subject 1 was elected for surgical repair of TAA. However the size of aneurysms kept stable for subject 2, who was only clinically followed-up. Results: Skewed streamlines were observed in the bulge of aneurysms for the two subjects (see planes AA, CC, DD, EE and FF in figure), wherein there were vortices and relatively low WSS. In contrast to subject 2, subject 1 had relative larger size of low WSS regions at TAA. Conclusion: The low WSS obtained from computer simulation, as a stimulus of wall degeneration, may be associated with the rapid growth of TAA in size for subject 1. Customized patient-specific simulation may facilitate the disease monitoring and treatment planning.

Tuesday, September 13, 2016 **8:30**

S44 **ECG Miscellaneous**

Chairs: Elaine Clark and John Wang

Room: Pinnacle III

59-436 **A Vectorcardiographic Evaluation of the Consensus Criteria for Early Repolarization**

Peter L Sørensen*, Kasper Sørensen, Jacob Melgaard, Johannes J Struijk, Steen M Hansen, Jørgen K Kanters, Jonas B Nielsen, Jesper H Svendsen, Stig Haunsoe, Lars Koeber, Anders G Holst, Adrian Pietersen, Christian Torp-Pedersen, Freddy K Lippert and Claus Graf

Introduction: A 2015 consensus paper proposed a unified definition of the early repolarization (ER) pattern based upon quantification of end-QRS notches and slurs. In this study we investigated the relationship between end-QRS concave “bite” segments in the vectorcardiogram (VCG) and the ER pattern of end-QRS notches and slurs. Methods: Digital 12-lead ECG recordings were obtained from 1561 subjects. Notches and slurs were quantified according to the consensus criteria. Stipulations important to this study are that notches should be entirely above the baseline and occur on the terminal half of the downsloping R-wave. ER manifestations were divided into 3 types: A) notches only B) notch and slur C) slurs only. The 3D VCG was derived from the digital recordings using the inverse Dower transform. End-QRS bites were defined as bites with a starting point in the terminal half of the QRS loop and an end-point within the terminal quarter of the QRS loop. An automatic algorithm developed by the authors was used to quantify bites in 3D. Results: Of 1561 subjects 85 (5.4%) fulfilled the ECG consensus criteria for ER. ER types A and B were in 100% of cases associated with an end-QRS bite in the VCG, whereas type C occurred both in the presence and absence of a bite. Additionally, we observed that bites of similar duration and amplitude, due to a combination of QRS loop orientation and projection onto the 12-leads, could be associated with the following configurations in the ECG: notch, slur, notch not fully above baseline and notch occurring above the terminal half of the R-wave. Conclusion: The results of this study indicate that the ER pattern manifest as end-QRS bites in the VCG and that the orientation of the bite relative to the 12 leads determine the ECG presentation as either notching or slurring.

60-447 **Ensemble Classifier Based on Linear Discriminant Analysis for Classifying Brugada Syndrome Patients According to Symptomatology**

DANIEL ROMERO*, Mireia Calvo, Nathalie Béhar, Philippe Mabo and Alfredo Hernandez

Background: Brugada syndrome (BrS) is characterized by the occurrence of syncope and sudden death due to cardiac arrhythmias. To date, the only effective therapy for symptomatic BrS patients with an aborted sudden cardiac death or documented ventricular fibrillation is the placement of an implantable cardioverter–defibrillator (ICD), however, it is difficult to identify high-risk subjects requiring an ICD among asymptomatic BrS patients. Methods: A 12-lead ECG recording during a standardized exercise test was acquired for 62 patients suffering from BrS (symptomatic, n=14). For each patient, conventional HRV indices from time-frequency analysis and heart rate recovery (HRV features), as well as several morphological depolarization indices (QRS features: wave amplitudes, main QRS slopes and angles, QRS width and QRS vector magnitude) were evaluated at relevant stages of the test. The most discriminant features were selected for both the HRV and QRS features using a feature selection algorithm and applied for model classification building. For the detection step, linear discriminant analysis was used. The performance of the obtained models was assessed via k-fold cross validation and the best features of each model were employed for building the final classification model. Results: After feature selection, the detection performance using the symptomatic group as the target class, was for each individual model as follows: HRV-based model: Se=0.93, Sp=0.98, AUC=0.97; QRS-based model: Se=1, Sp=0.71 AUC=0.91. When joining the best features of both models (HRV-QRS-based model), the classification performance increased up to Se=1, Sp=0.96, AUC=0.99. Conclusion: This study shows that using both HRV and depolarization analysis, a better risk stratification of BrS patients can be performed. The proposed method may provide a quantitative means to confirm the implantation of an ICD on symptomatic patients to select asymptomatic BrS patients that may benefit from an ICD or to perform follow-up on BrS patients.

61-524 **The Role of Reduced Left Ventricular, Systolic Blood Volumes in ST Segment Potentials Overlying Diseased Tissue of the Ischemic Heart**

Brett Burton*, Kedar Aras, Jess Tate, Wilson Good and Rob MacLeo

INTRODUCTION While shifts in the ST segment of the ECG are used routinely in clinical practice to detect myocardial ischemia, there remains ambiguity especially about the interpretation of ST segment depression. In this study, we focus attention on the role of changing ventricular shape and blood volume on ST segment potentials. Myocardial ischemia arises from reduced coronary blood flow, leading to ST segment changes in epicardial and body surface electrodes. To simulate ST segment depression, some computational models have incorporated reduced intracellular or elevated extracellular anisotropy ratios and/or large, thin subendocardial ischemic regions. However, most models fail to consider the effect of cardiac cycle on epicardial ST potentials, i.e. reduced intracavitary blood volume during systole. We hypothesize that reduced ventricular blood, representative of end systole, will alter the ST segment depressions in epicardial leads overlying the ischemic zone. METHODS We incorporated a thin, subendocardial ischemic zone geometry into a realistic canine ventricular model governed by the static bidomain equation. Left ventricular volume was incrementally reduced, while maintaining the size and general shape of the ischemic region, in order to reflect the systolic phase of the cardiac cycle. Epicardial potentials were subsequently assessed to determine the effects on ST-segment depression. RESULTS Using our model, we were able to confirm three previously reported scenarios that resulted in ST depression overlying the ischemic zone. However, the reduced blood volume models also showed that ST-depression magnitudes diminished, and eventually disappeared, during simulated systole. DISCUSSION Our models show that the blood volume at an end systolic state has an important impact on recorded ST depressions in overlying epicardial leads. These results suggest that the blood volume plays a key role in ST-segment shifts and also that incorporating time dependent geometries in cardiac models may be important for accurate simulation of ischemia.

62-138 **Diagnosis and Prognosis of the V-index in Patients with Symptoms Suggestive of Acute Myocardial Infarction in the Emergency Departement**

Roger Abächerli*, Raphael Twerenbold, Roberto Sassi, Luca Minard and Tobias Reichlin

Introduction: The V-index is an ECG marker quantifying the spatial heterogeneity of ventricular repolarization. We prospectively investigated the diagnostic and prognostic value of the V-index in patients with symptoms suggestive of acute myocardial infarction (AMI). Methods: We enrolled 582 patients presenting with suspected AMI to the emergency department (ED) in a prospective observational study. Twelve lead ECG's of five minutes were recorded at presentation to the ED. The V-index was calculated in a blinded fashion. Final diagnosis was adjudicated by two independent cardiologists. Patients were followed for the endpoint of all-cause mortality. Results: AMI was the final diagnosis in 16% of patients. Values for the V-index at presentation were higher in patients with AMI compared to other causes of chest pain (23ms (IQR 18-28) vs. 18ms (IQR 15-24), p<0.001). The diagnostic accuracy of the V-index at presentation for the diagnosis of AMI as quantified by the area under the receiver operating characteristic curve (AUC) was 0.64 (95% CI 0.57-0.71). The use of the V-index in addition to conventional ECG criteria improved the sensitivity of the ECG for MAI from 41% to 85% (p<0.001). Median V-index levels in deceased patients were significantly higher as compared to survivors (28ms (IQR 22-37) vs. 19ms (IQR 15-24), p<0.001). Cumulative 24-month mortality rates were 99.5%, 97.2% and 90.4% according to tertiles of the V-index (p<0.001). In multivariable Cox proportional hazard analysis, the V-index significantly predicted mortality independently of age and high-sensitive cardiac Troponin T (hs cTnT). Conclusion: The V-index, an ECG marker quantifying the spatial heterogeneity of ventricular repolarization, significantly improves the sensitivity of the ECG for the diagnosis of AMI and predicts mortality in patients with suspected AM independently of age and hs-cTnT.

63-395 **Prevalence of Ventricular Ectopy in Older Adults across Different Frailty Levels**

Saman Parvaneh*, Bijan Najafi, Nima Toosizadeh, Irbaz Bin Riaz and Jane Mohler

Background: An increased prevalence of ventricular ectopy (Premature Ventricular Contraction, PVC) is associated with increased incidence of congestive heart failure (CHF) and increased mortality. Previous studies demonstrated that incidence of ventricular ectopy increases with age, but to the best of our knowledge its association with frailty, a geriatric syndrome that is associated with adverse health outcomes, has not been studied. The aim of this study was to study the prevalence of PVC in older adults across different frailty levels. Method: A wearable ECG recorder was used to record four hours of uni-channel ECG in 45 older adults aged 65 and above. Participants were classified as non-frail (n=21), pre-frail (n=18), and frail (n=6) using the well-validated Fried Frailty phenotype. Matlab was employed to identify PVCs, and the subsequently manually reviewed by an expert to ensure accuracy. Number of PVC beats per hour was considered for ECG assessment and Analysis of variance (ANOVA) test was used to evaluate the extracted parameter among frailty groups. Statistical level of significance was set to $p = 0.05$. Results: Number of PVC beats was not significantly different ($p>0.05$) between non-frail (43.74±69.22), pre-frail (48.24±74.48), and frail (22.12±7.83). The average number of PVC beats was higher in pre-frail compared to non-frail. Interestingly, the average number of PVC beats was 52% and 54% less in frail population compared to non-frail and pre-frail Discussion: In this study, no association between prevalence of PVC and frailty level was found. The higher variation in prevalence of PVCs for non-frail and pre-frail may be related to the diversity of participants in these two groups.

64-269 **A Multi-Stage decision support Algorithm to Rule-Out patients with suspected Acute Myocardial Infarction (AMI)**

Cesar Oswaldo Navarro Paredes*, James A Shand, Mary Jo Kurth, David J McEneaney and James McLaughlin

Objective: Provide a multi-stage rule-out algorithm to stratify patients admitted to the Emergency Room (ER) with chest pain of presumed ischemic origin. The aim is to keep at-risk patients in the ER providing a proper care while minimizing overcrowding. The algorithm uses data from biomarkers —heart-type fatty acid–binding protein (H-FABP), high sensitivity cardiac troponin T (hs-cTnT) measured at different times (presentation, 1, 2, 3, 6, 12 and 24 hours) together with ECG at presentation. Methods: Data in a randomly selected training set of 296 patients were retrospectively analysed. 182 cases comprised a test set. STEMI were not considered since biomarkers are not routinely measured for these cases. H-FABP and hs-cTnT were statistically significant for the segregation of non-MI cases over other biomarkers including CK-MB and cTnT. The multi-stage algorithm was trained and tuned looking for maximizing sensitivity (and keeping low numbers of false negative cases in the detection of AMI). Thus after each stage if the algorithm detects non-MI, the patient could be considered for release. Results: Retrospectively applying the algorithm on the whole dataset of 478 cases: 97 MI (NSTEMI) and 381 non-MI. 244 patients could have been recommended for rule-out at presentation with 3 false negatives which in turn could have been identified by other symptoms/history. Sensitivity: 0.97, specificity: 0.63, ppv: 0.40, npv: 0.99. The remaining patients would have needed to be observed and biomarkers measured again at 1 hour were the next stage algorithm would rule-out patients from AMI. The process is repeated to the following stages and the algorithms exhibit high sensitivities (0.94 at 3 hours) with moderately increasing specificity (0.80 at 3 hours). Conclusion: The algorithm serves as a rule-out test for suspected AMI patients which would allow risk stratification and a more efficient use of resources to the health care system.

Tuesday, September 13, 2016 **10:30**

S51 **Atrial Fibrillation**

Chairs: Peter Johnston and Stef Zeemering

Room: Shaughnessy I

65-421 **A New Model of the Human Atrial Myocyte with Variable T-tubule Organization for the Study of Atrial Fibrillation**

Michael A Colman*, Niall Macquaide and Antony Workman

Introduction: Atrial fibrillation (AF) is characterized by an inability of the atria to contract in a coordinated and regular fashion, underlain by rapid and irregular electrical activity. AF can promote strokes through blood clots, and may also predispose to ventricular arrhythmias. As the most common sustained cardiac arrhythmia, AF is a significant drain on healthcare re-sources. Atrial myocytes have been shown to have variable densities and organization of transverse-tubules (TTs), and this may play a role in pro-arrhythmic calcium handling. However, currently available models of human atrial single cell electrophysiology do not account for this property. In this study, we developed a new model human atrial electrophysiology and spatio-temporal, stochastic calcium handling which accounts for various configurations of TT organization and density. Methods: A model of 3D spatio-temporal calcium handling was developed for the human atria, in a similar manner to previous ventricular models. This was then coupled with a newly developed ionic model, fit primarily to single-lab data to ensure self-consistency. A mixed deterministic (ionic model) and monte-carlo (calcium handling) simulation approach was implemented. Calcium release units (CRUs) were then assigned to either contain a TT (with inclusion of L-type calcium channels and the sodium calcium exchanger) or be a 'naked dyad' (without inclusion of membrane ion currents). TT geometry is based on our own imaging data of TTs in multiple human atrial cells. Results: In control conditions, the model reproduces behavior observed experimentally. TT organization had a significant influence on spatio-temporal calcium cycling, promoting gradients in the intracellular space and calcium store. Spontaneous calcium waves often originated from localized regions of CRUs with no TTs due to these gradients. Conclusion: We have developed a novel model of the human atria for the investigation of the influence of TTs on sub-cellular calcium activity and the development of AF.

66-193 **Personalized Modeling Pipeline for Left Atrial Electromechanics**

Thomas E Fastl*, Catalina Tobon-Gomez, William A Crozier, John Whitaker, Ronak Rajani, Karen P McCarthy, Damian Sanchez-Quintana, Siew Y Ho, Mark D O'Neill, Gernot Plank, Martin J Bishop and Steven A Niederer

Atrial fibrillation (AF) is a supraventricular tachyarrhythmia characterized by uncoordinated atrial activation with consequent deterioration of mechanical function. Personalized computational modeling provides a novel framework for integrating and interpreting the combined role of atrial electrophysiology and mechanics in AF development and sustenance. High-resolution coronary computed tomography angiography data were acquired and retrospective analysis was conducted on three patients. Statistics-based image segmentation was performed via isolation of the left atrial blood cavity and identification of the left atrial myocardium utilizing personalized image thresholds followed by standardized mitral valve extraction and pulmonary vein shortening. The smoothed voxel representations were discretized into tetrahedral finite element (FE) meshes using an Octree-based mesh generator for unstructured meshing. To estimate the complex left atrial fiber architecture, the endo- and epicardial surfaces were registered onto an atrial atlas containing distinct landmarks, subsequently projected onto the personalized geometry defining specific left atrial regions. Individual fiber fields were generated according to clinical guidance on both surfaces for constituting regions based on local solutions of Laplace's equation and transmurally interpolated to all tetrahedral elements. Personalized geometrical models included the heterogeneous thickness distribution of the left atrial myocardium and subsequent discretization led to high-fidelity and high-resolution tetrahedral FE meshes. The novel algorithm for automated incorporation of the left atrial fiber architecture provided realistic estimates of the atrial microstructure and was able to qualitatively capture all important fiber bundles. The established modeling pipeline provides a robust framework for the rapid development of personalized model cohorts and facilitates simulations of atrial electromechanics. This allows the comparison between healthy controls and AF patients to quantitatively investigate the causative link between atrial electrophysiology and mechanics to identify the capacity of the atria to sustain AF.

67-199 **Predicting Spiral Wave Stability by Personalized Electrophysiology Models**

Cesare Corrado*, John Whitaker, Henry Chubb, Steven Williams, Matt Wright, Jaswinder Gill, Mark O'Neill and Steven Niederer

Introduction: Identifying atrial tissue that is capable of supporting sustained re-entrant spiral wave activation patterns offers a potential ablation target for atrial arrhythmias. Currently this substrate can only be characterized during fibrillation and requires a large and expensive specialized multi electrode catheter. We propose a novel method to personalize biophysical ionic models from multi-electrode catheter measurements and to predict the spiral wave stability using computer simulations. Methods: Personalized biophysical model of cellular electrophysiology (EP) was fitted to local conduction velocity (CV) and effective refractory period (ERP) restitutions measured using an s1-s2 pacing protocol applied at the central poles of a decapolar catheter. A two dimensional 5 x 5 cm2 homogeneous atrial wall EP model was created using the personalized EP model. A cross-field stimulation was then applied to trigger a spiral wave within the model and the spiral tip path was tracked to quantify spiral wave stability. Results: CV and ERP were measured for 5 cases with paroxysmal AF undergoing pulmonary vein isolation and ionic model fitted. Spiral wave stability in each case was predicted using tissue simulations, identifying distinct stable (2/5), meandering and breaking up (2/5) and unstable self terminating (1/5) spiral tip patterns for different cases. Conclusion: We have developed and applied a novel technique for predicting local tissue substrate using conventional diagnostic catheters and pacing protocols.

68-474 **High Resolution Microscopic Optical Mapping of Anatomical and Functional Reentries in Human Cardiac Cell Cultures**

Andreu M Climent*, Ismael Hernández-Romero, Maria de la Salud Guillem Sánchez, Nuria Montserrat, Maria Eugenia Fernández, Felipe Atienza and Francisco Fernández-Avilés

Introduction: Limited knowledge of the mechanisms of perpetuation of fibrillation is hampering the development of effective anti-arrhythmic treatments. The goal of the present study is to present a novel technology to map with high resolution (500x500um) the center of fibrillation drivers in order to characterize the mechanisms of reentry. Methods: Cell cultures of human cardiomyocytes differentiated from pluripotent stem cells were analyzed with a novel microscopic optical mapping system. Calcium imaging was developed by recording emission light of Fura 2-(AM) (Ca^{2+} sensitive probe, TEFLabs, Inc, Austin, TX. USA). During fibrillation the dominant driver was identified (i.e. anatomical vs. functional reentry) and characterized in terms of its dominant frequency (DF). The pharmacological response to verapamil administration of each type of reentry was analyzed. Results: In all analyzed cell cultures, a reentry was identified as the mechanism of maintenance of the arrhythmia. Microscopic analysis of the reentries allowed their classification into (1) micro-anatomical (46%, N=12) or functional reentries (54%, N=14). Isochronal maps of a representative example of each group are shown in the figure. Anatomical reentries presented lower DFs than functional reentries (i.e. 1.08±0.19 vs. 2.96±0.24Hz, $p<0.01$). Interestingly, the administration of verapamil produced opposite effects in each group: whereas DF increased in 15±3.4% for anatomical reentries, it decreased in 11.9±6.8% for functional rotors ($p<0.01$). Conclusions: Microscopic optical mapping of reentries allows the identification of perpetuation mechanisms which has been demonstrated to be linked with different pharmacological response.

69-216 Epicardial Fibrosis Explains Increased Transmural Conduction in a Computer Model of Atrial Fibrillation

Ali Gharaviri*, Mark Potse, Sander Verheule, Rolf Krause, Angelo Auricchio and Ulrich Schotten

Introduction: Recent work has shown that the transition from persistent to permanent AF in goats coincides with an increase in fibrosis in the outer millimeter of the atrial wall. Macroscopically this leads to reduced electrical conductivity orthogonal to the dominant fiber orientation. A causal relation has not been established yet. Our purpose was to test if epicardial fibrosis can explain the increased incidence of transmural conduction (breakthroughs), which is also observed in permanent AF. Methods: We constructed a detailed geometry of the human atria including epicardial layer and all major endocardial bundle structures. The model also includes realistic one tc three layers of fiber orientations, corresponding to their location in the atrium. Computer simulations were run with a mesh of 0.2 mm resolution and Courtemanche human atrial cell model. Epicardial fibrosis was modeled by assigning zero transverse conductivity to a random selection of model elements in the epicardial layer. Simulations were performed with 0, 50, and 70% affected elements. Results The numbers of waves, phase singularities, and breakthroughs (BTs) were quantified at different degrees of fibrotic tissue. Increase ir the "fibrotic" volume from zero (Control) to moderate (50% Fibrotic), and severe (70% Fibrotic) increased both the number of waves and the number of phase singularities. Along with the increase in fibrosis, the endo-epicardial electrical activity dyssynchrony increased from 8.6% to 18.6%, and 38.4%. Fibrosis increased the incidence of BTs. Conclusion: This model is the first anatomical atrial model to display BTs, a common and conspicuous feature in experimental studies on AF. Epicardial fibrosis in this model increases the degree of endo-epicardial electrical activity dyssynchrony and the incidence of BTs, thus increasing the complexity of fibrillatory conduction. The model offers the opportunity to study transmural conduction, which frequently occurs during AF, in more detail.

70-304 **Dynamic Behavior of Rotors during Human Persistent Atrial Fibrillation as observed using Non-Contact Mapping**

Nawshin Dastagir*, Tiago Almeida, Xin Li, Frederique J Vanheusden, Gavin S Chu, Peter J Stafford, G Andre Ng and Fernando S Schlindwein

Rotors have been related to atrial fibrillation (AF) maintenance. We analyzed the behavior of rotors in persistent AF (persAF) utilizing a novel non-contact methodology and compared this to real time dominant frequency (DF) analysis. 2048 noncontact virtual unipolar atrial electrograms (AEGs) were collected simultaneously (EnSite Array, St.Jude Medical) from 10 persAF patients (duration: 34±25months) undergoing left atrial (LA) ablation. After QRST-removal, FFT was used to identify the global DF of the LA (range 4-10Hz; 1s time-window; 50% overlap; highest-DF (HDF) (DF-0.25Hz); up to 20s/patient). The frequency organization of AEGs was measured by the organization index (OI). Phase was found via Hilbert-transform. Phase singularities (PSs) and their chirality were identified and tracked The PSs were categorized according to their lifespan into short (lifespan <80ms) and long-lived (rotors) (lifespan ≥80ms) (Fig-1A). A total of 6261 PSs were tracked. 5.2% (IQR: 0.44~5.7%) of the tracked PSs were long-lived (Fig-1A) and were observed in 20% (IQR: 2.5~35%) of the windows. The numbers of PSs observed at any instant are shown in Fig-1B, demonstrating that 60% of the time no PSs were observed. Furthermore, up to 13 PSs were also observed at any time instant and complex clustering of PSs were seen. Fig-1C illustrates complex PSs clustering for one patient during 1.5s. The window with rotors showed significantly higher HDF (mean±SD, 8.0±0.43Hz vs 7.71±0.53Hz, $p<0.0001$) and lower OI (0.76±0.04 vs 0.79±0.03, $p<0.0001$) when compared with the short-lived PSs window (Fig-1D). During persAF, the LA showed distinct behaviors as characterized by rotors. Often, no rotors were observed during sustained AF and, when present, the rotors continually switched between organized and disorganized behaviors. Long-lived rotors correlated with higher atrial rates. From these data we conclude that rotors are not the sole perpetuating mechanism in persAF and that dynamic DF analysis can identify sites of long-lasting rotor activity.

Tuesday, September 13, 2016 **10:30**

S52 **Membrane and Cellular Models**

Chairs: Ronald Wilders and Vincent Jacquemet

Room: Dundarave

71-152 **An Algorithm for Fitting Local Membrane Parameters to an Action Potential Duration Map in a Tissue with Electrotonic Interactions**

Angelina Drahi, Akshay Kota Aswath Kumar and Vincent Jacquemet

Repolarization gradients contribute to arrhythmogenicity. They can be introduced in computer models of cardiac tissue by locally adjusting an intrinsic parameter of the membrane model. Electronic coupling, however, modulates the dispersion of action potential duration (APD). We developed an algorithm to iteratively adjust the spatial distribution of a membrane parameter in order to reproduce a given APD map. A 3D atrial monodomain model with Courtemanche-based kinetics and anisotropic conduction was used. The adjustable local parameter was acetylcholine (ACh) concentration. Random patches with a length scale of 2 cm were distributed over the atria. After rescaling and Gaussian smoothing with different widths, synthetic target APD maps covering the range 105 to 135 ms with maximal gradients of 5, 10, 20 and 30 ms/cm were created. APD was computed at a threshold of -70 mV during normal propagation. The problem was first solved in the absence of coupling using spline interpolation of the APD vs ACh curve obtained in an isolated cell. Further refinements of the solution in the coupled tissue were calculated using Newton iterations in which the Jacobian was approximated in the low coupling limit. Each iteration involved a simulation in the atrial model to compute the APD map, compare it to the target APD map, and update the ACh profile. Iterations stopped when the 99th percentile of the error was < 1 ms. After the initial estimate, the error ranged from 3 to 13 ms. In all cases, convergence was reached after fewer than 10 iterations, except for the steepest gradient where the existence of an exact solution was uncertain. Convergence was faster when the maximal gradient was less steep and when coupling was reduced. This algorithm provides a tool to automatically generate arrhythmogenic substrates with controllable repolarization gradients and possibly incorporate experimental APD maps into computer models.

72-178 **Simulation Study on Balance of Glycolytic ATP Production and Oxidative Phosphorylation in Embryonic and Adult Ventricular Cells**

Hitomi Sano*, Yasuhiro Naito and Masaru Tomita

The developmental program of the heart requires accurate regulation to ensure continuous circulation and simultaneous cardiac morphogenesis because any functional abnormalities may progress to congenital heart malformation. Energy metabolism in fetal ventricular cells is regulated differently from that in adult ventricular cells: fetal cardiomyocytes generally have immature mitochondria, and fetal ventricular cells show greater dependence on glycolytic ATP production. Here, we integrated various characteristics of fetal ventricular cells based on a mathematical model and predicted the contribution of each characteristic to maintenance of intracellular ATP concentration and sarcomere contraction under anoxic conditions. Our simulation results showed that higher glycogen content, higher hexokinase activity, and lower creatine concentration helped prolong the time that contraction of ventricular cells was maintained under anoxic conditions. The integrated model enabled us to quantitatively address the contributions of factors related to energy metabolism in ventricular cells. Because fetal cardiomyocytes show similar energy metabolic profiles to stem cell-derived cardiomyocytes and cardiomyocytes in the failing heart, an improved understanding of fetal cardiomyocytes will contribute to understanding processes in stem cell-derived cardiomyocytes and cardiomyocytes under pathological conditions.

73-114 **Na+ Current in Human Atrial Myofibroblasts Alters Myocyte Excitability: A Computational Study**

Heqing Zhan*, Jialun Lin, Xiaoling Li and Jingtao Zhang

Aims: During pathological challenges such as cardiac fibrosis, fibroblasts proliferate and differentiate into myofibroblasts. This differentiation is accompanied by the expression of Nav 1.5 a subunit which may generate a persistent Na+ current in myofibroblasts (INa_myofb) and result in regenerative action potentials (APs) in myocytes and myofibroblasts. The goal of this preliminary study was to identify the role of INa_myofb integrated in electrotonic myofibroblast-myocyte (myofb-m) coupling on the excitability and repolarization of myocyte and myofibroblast. Methods: Mathematica modeling was done using a combination of (1) the Maleckar et al. model of the human atrial myocyte, (2) the MacCannell et al. “active” model of the human cardiac myofibroblast, and (3) our formulation of INa_myofb based upon experimental findings from Chatelier et al. For myofb-m coupling scheme, different ratios of myocytes to myofibroblasts and values of intercellular resistance were set based or available physiological data. Numerically, all state variables in electrophysiological equations were updated by means of the forward Euler method. Results: The simulation results showed that (1) for myocytes, myofb-m coupling reduced the peak of AP (Vmax), shortened the action potential duration (APD) and depolarized the resting membrane potential (Vrest) whether or not INa_myofb was involved in myofibroblasts. However, the addition of INa_myofb decreased the reductions of Vmax and APD, and increased the degree of Vrest depolarization as compared to no INa_myofb integrated in myofb-m coupling. (2) for myofibroblasts, more significant electrotonic depolarizations were exhibited with addition of INa_myofb. Conclusion: The identified effects demonstrated that INa_myofb significantly influenced myocytes and myofibroblasts properties. It should be considered in future pathological cardiac mathematical modeling, such as atrial fibrillation and cardiac fibrosis.

74-143 **Effects of the Transient Outward Potassium Current on Action Potential Upstroke Velocities Tested Using the Dynamic Clamp Technique**

Arie Verkerk, Christiaan Veerman, Jan Zegers and Ronald Wilders*

The voltage-gated transient outward potassium current (Ito1) plays a prominent role in the early repolarization phase of the cardiac action potential (AP) and thereby contributes to the refractory period and inotropic state of the myocardium. The current is largely responsible for differences in AP repolarization between species, between left and right ventricle, and transmurally, and it is affected by various pathophysiological conditions, such as heart failure. Ito1 already activates during depolarization to potentials near –50 to −30 mV, suggesting that Ito1 may be active during the AP upstroke, but whether it modulates the maximal AP upstroke velocity ((dV/dt)max) is unknown. In the present study, we addressed this issue using the dynamic clamp configuration of the patch-clamp technique. Recordings of upstrokes were made (at physiological temperature using an alternating voltage/current clamp protocol) from HEK-293 cells transfected with SCN5A, encoding the alpha-subunit of the cardiac fast sodium current and thus responsible for the rapid cardiac AP upstroke. Ito,f of the Bondarenko et al. mouse ventricular AP model (corresponding to Ito1) was computed in a real-time simulation and injected into the real cell during its upstroke. In control conditions i.e., without Ito,f, (dV/dt)max was 272±25 V/s (mean±SEM, n=11). With the standard settings of the Bondarenko et al. model,(dV/dt)max was unaffected by in silico Ito,f. This Ito,f, however, is based on experimental data obtained at room temperature in the presence of CdCl2. An increased activation rate of Ito,f, thereby representing a more close-to-physiological temperature, results in a small, but significant, decrease in (dV/dt)max. In addition, negative shifts in voltage-dependency of Ito,f activation, thereby balancing the non-physiological CdCl2-induced positive shift, result in a more pronounced decrease in (dV/dt)max. We conclude that Ito1 may modulate (dV/dt)max, but only when its activation is fast and its activation threshold is near −50 to −40 mV.

75-276 **A New Tool for the Action Potential Repolarization Dynamic Analysis: Application to the Discrimination of Diabetic and Control Cells**

Olivier Meste*, Marianna Meo, Sergio Signore and Marcello Rota

Aims: In CinC2015 we have shown that the dynamics of the action potential (AP) repolarization could be tracked throughout the stimulation course. Despite some valuable outcomes, the populations of interest (control, Ctrl, and streptozotocin-induced, STZ, diabetic mice) could not be significantly distinguished in term of dynamics because of the global extracted feature. In this study, the computation of new features for each repolarization percentage allows an accurate and meaningful characterization of the two groups leading to a significant classification. Methods: APs in isolated left ventricular cardiomyocytes obtained from 41 Ctrl and 76 STZ mice were measured by patch-clamp. The progressive changes in AP repolarization for individual cells were tested on a set of 100 consecutive excitations at 2Hz pacing rate. The corresponding repolarizations are stacked in a matrix decomposed with a new approach. Observations are modeled as a sum of vectors multiplied by specific polynomial functions. This approach is similar to the SVD, but the corresponding scalars are replaced by these functions. Model unknowns are estimated by using an Alternated Least Square algorithm. Finally, the mean of the polynomial first derivative is computed for each repolarization percentage as a representative feature. Results: In our case each matrix is represented by one vector and several multiplicative polynomial functions. A Wilcoxon signed rank test ($p<0.05$) has been applied on the features from the two groups. We can observe a significant difference in the late repolarization phase (70%-95% repolarization), with a singular behavior in correspondence with the AP profile shoulder onset (80%). Conclusion: A new matrix decomposition adapted to the observed data has been successfully proposed to quantify the AP repolarization dynamics. The assumption that the discriminative information is hidden in the polynomials but not simply in the raw data is proven to be valid.

76-419 **Numerical Analysis of Conduction of the Action Potential Across the Purkinje Fibre-Ventricular Muscle Junction**

Jue Li*, Henggui Zhang and Mark Boyett

Normally, there is little conduction delay (<0.2 ms) between cells in the heart. However, at the Purkinje fibre-ventricular muscle junction (PVJ), long conduction delays (5-20 ms) are reported. The PVJ therefore has special conduction properties. In support of this, transitional cells are reported at the PVJ. A 1D model was developed consisting of a string of 49 Purkinje cells, connected to 1 transitional cell, connected to one or more strings of 40 ventricular myocytes (a Purkinje fibre is expected to activate a block of ventricular muscle). Rabbit Purkinje and left ventricular action potential models were used the Purkinje model was also used for the transitional cell. The 1D mono-domain model was used to solve conduction. The diffusion coefficient (D) was set to 0.6 and 0.12 mm2/ms for the Purkinje fibre and ventricular muscle to give expected conduction velocities. The effects of (i) the diffusion coefficients between the terminal Purkinje cell and the transitional cell (D1) and between the transitional cell and the first ventricular myocyte (D2) and (ii) the 'load' on the Purkinje fibre (i.e. number of strings of ventricular myocytes) were investigated. The greater D1 (up to ~0.4 mm2/ms), the larger the load that could be supported, although further increase in D1 resulted in little further increase. Also the greater D2 (up to ~0.04 mm2/ms), the larger the load that could be supported, but in this case a further increase in D2 resulted in a decrease in the load that could be supported. The delay in conduction at the PVJ was dependent on D1, D2 and the load and increased markedly at the smallest values of D1 and D2 and the highest loads. At a certain point, a small change could lead to large increase in the delay or even conduction failure.

S53 **Health Informatics and Wearable Systems**

Chairs: Dewar Finlay and Frans Riepma

Room: Pinnacle II

77-432 **Difference in Pulse Arrival Time at Forehead and at Finger as a Surrogate of Pulse Transit Time**

Jesus Lazaro*, Raquel Bailón, Pablo Laguna, Vaidotas Mazoras, Andrius Rapalis and Eduardo Gil

Pulse transit time (PTT) difference (PTTD) to the forehead and finger dynamics are compared to pulse arrival time towards the finger (PATF dynamics during a tilt table test. Two frequency bands, where different physiological information is expected, are analyzed: low frequency (LF) influenced by both sympathetic and parasympathetic activity, and high frequency (HF) influenced by parasympathetic activity. As PATF, PTTD is influenced by PTT, but in contrast to PATF, PTTD is not influenced by the pre-ejection period (PEP). This is advantaging in certain applications such as arterial stiffness assessment or blood pressure estimation. Results showed higher correlation between PTTD and PATF during rest stages than during tilt stage, when the PEP dynamics have stronger effect in PATF dynamics. This suggests that PTTD variability can potentially be a surrogate of PTT variability that is not influenced by PEP, which is advantaging in the previously mentioned applications. However, further studies must be elaborated in order to evaluate the potential of PTTD in such specific applications.

78-163 **Cor/log BAN BT a Wearable Battery Powered mHealth Data Logger and Telemetry Unit for Multiple Vital Sign Monitoring.**

Thomas Hilbel*, Sven Feilner, Matthias Struck, Sven Hofmann, Andreas Heinig and Hugo Katus

The wireless data logger system “Cor/log® BAN BT” (CL) allows seamless 24/7 monitoring of relevant vital sign parameters. CL covers the entire period of acute point of care inside the hospital and the recovery period, when first mobility is achieved and when the patient is released into an ambulatory or homecare environment. CL is the commercial product of the German KARDIKOM telemedicine patient monitoring research project. It was the objective of the KARDIKOM project to prevent secondary life-threatening situations (myocardial infarction, heart failure, arrhythmias) for patients with cardiologic risk constellations by establishing innovative technical and organizational infrastructures for a 24/7 monitoring. Another aim of the project was to certify all components of the CL, the wireless livestream viewer and a health cloud in accordance with the European medical device directive 93/42/EEC(MDD). The CL records the relevant vital signs such as ECG, respiration, pulse oximetry with plethysmogram and movement. The vital data collected with the CL is saved on a memory card for further analysis and is simultaneously transmitted in real-time to a telemedicine server via a smartphone or tablet. The smartphone does also provide GPS position. In addition Cor/log View an Android™ Application for viewing recorded vital sign data originating from the CL was developed. CL has also a connector to the MedM health cloud. MedM is a patient data management system(PDMS) consisting of a cloud portal and a mobile health app. The MedM app runs on Android™, iOS™, Windows™ and Blackberry™. The app does setup a wireless connection to the CL and does store the vital signs in the health cloud. The MedM app and cloud is cleared as a Class I PDMS according to EU MDD. Thus CL together with its mHealth software can be used in clinical application studies for mobile vital sign recording with cloud connection.

79-339 **Atrial Fibrillation Detection Using Photo-plethysmography and Acceleration Data at the Wrist**

Alberto Bonomi*, Fons Schipper, Linda Eerikainen, Jenny Margarito Ronald Aarts, Saeed Babaeizadeh, Helma de Morree and Lukas Dekker

Background: Atrial fibrillation (AF) is a pathological condition leading to increased risk for embolic stroke and cardiac hospitalizations. Screening for AF represents a technical challenge because of the paroxysmal and frequently asymptomatic nature of the condition. Objective: The aim was to investigate whether an unobtrusive wrist-wearable device equipped with a photo-plethysmographic (PPG) and acceleration sensors could be used to detect AF. Methods: Sixteen patients (M = 63%, age: 65.2 ± 14.0 y, BMI: 29.7 ± 7.0 kg/m2) with suspected paroxysmal AF were monitored for 24 hours in outpatient setting using a portable ECG Holter recorder. Simultaneously, a wrist-wearable device equipped with a PPG and acceleration sensor was used to monitor heart rhythm and body movement. PPG data were processed to extract the timing of heart beats and derive inter-beat-intervals (IBI). Acceleration data was used to discard IBI in presence of motion artifacts. An ECG validated first-order Markov model was used to assess the probability of irregularly irregular rhythm of AF being present from PPG-derived IBI. AF detection outcome from the algorithm was compared with adjudications of AF episodes provided by clinical experts after visually inspecting ECG Holter data. Results: Four patients experienced 100% AF burden, while 1 patient suffered from atrial flutter. The remaining patients showed normal sinus rhythm with several premature beats (808 supraventricular, range 0 – 4879; and 656 ventricular premature beats, range 0 – 4795). AF detection was achieved with 97 ± 2% Sensitivity and 99 ± 3% Specificity. During atrial flutter the algorithm output was non-AF 94.6% of the time. Due to motion artifacts, the algorithm did not provide AF classification for 36 ± 9% of the 24 hours monitoring. Conclusion: A wrist-wearable device equipped with a PPG and acceleration sensor can provide accurate detection of rhythm irregularities caused by atrial fibrillation in free-living conditions.

80-334 Cardiac Condition Monitoring through Photoplethysmogram Signal Denoising Using Wearables: Can We Detect Coronary Artery Disease with Higher Performance Efficacy?

Arijit Ukil*, Soma Bandyoapdhyay, Chetanya Puri, Arpan Pal and Kayapanda Mandana

Aims: For affordable cardiac health monitoring, it is required to ensure accurate cardiac condition detection from wearable-extracted photoplethysmogram (PPG) signals through precise identification, and removal of signal corruptions. We need to prove that analyzing on cleaned (denoised) PPG signal yields significant performance efficacy improvement while performing Coronary Artery Disease (CAD) identification from PPG signal. Methods: It is a mono-signal analysis to identify the morphological trend, emphasizing on individual's cardiac characteristics. PPG signal is segmented using slope sum function to recognize each cardiac cycle. Further, the most probable segment duration is computed using DBSCAN clustering. Dynamic time warping (DTW) distances between an ideal PPG segment template and each of the PPG segments are derived to isolate the dissimilar segments. Each segment is restricted to most probable segment length to counter non linearity of the PPG segments. Then Hampel filter, a standard outlier detection method is applied on the computed DTW distances. The detected outliers in the DTW distances are declared as corruption. Corruption Detection Results: We experimented with 10 real-field and 10 MIMICII Physionet Challenge 2015 PPG datasets, each of 5 minute duration. Achieved efficacy of PPG corruption detection: For real-field - Recall (R), Specificity (Sp) and Precision (P) are 79%, 97.4%, 89.4% respectively; for MIMICII - R=80.4%, Sp=96.3%, P=72%. Clinical Utility Results- CAD Identification: We considered 126 PPG signals from MIMCII with 67 CAD and 59 Normal subjects; training dataset: 40 CAD, 30 Normal; test dataset: 27 CAD, 29 Normal. We have chosen Heart Rate and standard deviation of NN intervals –based Heart Rate Variability (extracted from 20 second non-overlapping windows) as the features of linear kernel based Support Vector Machine Classifier. CAD identification results: cleaned PPG datasets: P=51.11%, R=79.31%, F1-score=0.62 and uncleaned PPG datasets P= 43.59%, R=58.62%, F1-score =0.49, which proves higher clinical utility from our method.

81-491 **Multi-Dimensional Kineticardiography in Simulated Microgravity: Preliminary Results from the ESA-RSL 60 days Bed**

Pierre-François Migeotte*, Jean Monfils, Federica Landreani, Alba Martin-Yebra, G.K. Prisk, Irina Funtova, Jens Tank, Philippe van de Borne and Enrico Caiani

Head down tilt bed rest (BR) can simulate to some extent the effects of microgravity leading to cardiac deconditioning. We present preliminary results from the first cohort of subjects of the ESA-RSL long duration bed-rest study which were exposed to -6° head down til (HDT) during 60 days: Control (Ctrl) group n=7, age 27 +/- 4 y; Training (Tr) group n=5, age 31 +/- 8 y. Tr group was assigned to a daily reactive jump in a sledge jump system while Ctrl was assigned to rest. Cardiovascular responses were assessed during imposed breathing protocols: 10 breath at 4, 6, 8, 10 s, increasing in a stepwise way, performed in supine and sitting before (HDT-4) and at recovery (R+1, R+4) and in the -6° HDT position during the BR period (HDT+5, 21 & 58). ECG, ICG, ballisto- and seismo-cardiograms were continuously recorded. Phase contrast MRI protocols were also performed (results presented in a parallel paper). We present Multi-dimensional Kineticardiography (MKCG), a novel technique for the wearable monitoring of the mechanical characteristics of the cardiac contractior which consists in measuring the full body kinetic energy (Ktot) in its 6 degrees-of-freedom via a 3-axis accelerometer and gyroscope placed close to center-of-mass. At HDT+5, in Ctrl RR-intervals and Ktot were found significantly increased from 896 to 1076 +/- 34 ms for RRI and from 16 to 33 +/- 5 mJ for Ktot, while for Tr not changes were observed. During recovery, both groups were tachycardic at 728 and 711 +/- 19 ms (Ctrl and Tr respectively), while three fold increase in Ktot to 48 (Ctrl) and 45 (Tr) +/- 3 mJ, were observed. As these results parallels those found for MRI cardiac output, this shows that MKCG has the potential to offer a significant clinical tool for diagnostic and monitoring.

82-380 **Impact of the Mechanical Interface on BCG Signals obtained from Electronic Weighing Scales**

Ramon Casanella*, Joan Gomez-Clapers, Marc Hernandez-Urrea and Ramon Pallas-Areny

Aims: In the last years, there has been an increasing interest in periodic monitoring of cardiovascular information at home or in other non-clinical scenarios. Weight scales have been recently proposed for recording the bal-listocardiogram (BCG), a signal caused by the forces in the body as a result of cardiac ejection. Several parameters obtained from the BCG have been correlated to important cardiovascular markers such as the pre-ejection pe-riod, cardiac output or the pulse transit time. Nevertheless, weight scales are second-order mechanical systems whose natural frequency when a subject is standing on them can be lower than the BCG bandwidth hence can yield a distorted recording. This work analyzes the reproducibility of the BCG ob-tained in different weight scales. Methods: The BCG and the ECG have been recorded from 5 healthy subjects (27.2 ± 3.7 years) for 60 s by sequentially using the force sensors of three different commercial weight scales connected to the same signal acquisition system. An ensemble average representative of each subject and weight scale has been obtained by applying Woody's method with the ECG as timing reference. Results: Consecutive BCG signals obtained with the three scales show consistent systematic intra-subject differences that can reach up to 30 ms in the timing of the J peak. This timing error is relevant because it is about 50 % of the changes induced by typical respiratory maneuvers, such as that of Valsalva, used to modulate hemodynamic parameters in correlation studies between changes in J timing with respect to different cardiac fiducial points. Conclusions: Due to its ubiquity, weighing scales are indeed very promising devices to monitor cardiovascular function at home but their fre-quency response must be accounted for and minimal performance standards should be defined for them.

Tuesday, September 13, 2016 **10:30**

S54 **ECG Miscellaneous II**

Chairs: Paul Rubel and Fabio Badilini

Room: Pinnacle III

83-172 **Reproducibility of Heart Rate Variability Characteristics Measured on Random 10-second ECG using Joint Symbolic Dynamics**

Muammar Kabir*, Golriz Sedaghat, Jason Thomas and Larisa Tereshchenko

Introduction. The study of heart rate variability (HRV) provides clinically relevant information about autonomic control. Compared to conventional signal-processing approaches which are inadequate for characterizing com-plex system dynamics, joint symbolic dynamics (JSD) has been shown to be an effective technique to provide enhanced information. In clinical practice, 10-second ECG recording is routinely available and therefore could provide clinical studies with the opportunity to investigate clinical utility of HRV characteristics for risk assessment in patients. However, reproducibility of HRV indices using JSD has never been studied. Methods. High resolution (1000Hz) modified (5th intercostal space) Frank orthogonal ECG (XYZ) was recorded at rest in the supine position for at least 3 minutes in 170 healthy participants of the prospective cohort Intercity Digi-tal Electrogram Alliance (IDEAL) study. Two non-adjacent 10-second ECG segments were selected from all ECG recordings. Respiratory signal was derived from the ECG. Parabolic fitting was used to detect ECG R-peaks. Using JSD, time series' of RR' intervals and respiratory phases (calculated using Hilbert transform) were transformed into tertiary symbol vectors based on their successive changes and words of length '3' were formed. Bradley-Blackwood test, Lin's concordance correlation coefficient and Bland-Altman analysis was used to assess the agreement between measured log-transformed JSD characteristics of HRV, and their reproducibility. Results. Traditional HRV measures such as RR' interval changes showed a very high reproducibility. Agreement between two 10-second JSD indices of HRV was low. Interestingly, a significant decrease in low-high alterations of HRV dynamics measured using JSD was observed when respiratory phase transition intervals were excluded (10s: 4.7±9.4 vs. 24.8±21.0%, $p<0.0001$; 3min: 9.8±8.1 vs. 24.8±12.3%, $p<0.0001$).
Conclusion. The HRV parameters calculated using JSD have low reproducibility on 10-second ECG. Respiration-induced ECG changes should be considered for the study of HRV symbolic dynamics.

84-171 **Finding similar ECGs in a large 12-lead ECG database**

Richard Gregg*, Sophia Zhou and Saeed Babaeizadeh

Background: Automated matching of a patient's 12-lead ECG to a large database of 12-lead ECGs to find similar ECGs has many potential appl cations including 1) help by example; 2) statistical diagnosis; 3) confirming patient identification; and 4) reviewing the patient's past ECGs We report the performance of morphology similarity matching in this study. Method: Only patients with multiple ECGs were selected for the study set. The total number of ECG was 24,262 from 8,663 patients. Average beats were created for each ECG by algorithm. Similar ECGs were found by exhaustive search of pair-wise template matching between the average beat of each ECG and all other ECGs. Similarity reference was the patient identification, i.e. two ECGs were similar if they came from the same pa-tient. Pair-wise template matching was performed over the entire QT in-terval with JT heart rate correction for the heart rate difference. For each ECG, 20 nearest neighbors by template match were extracted from the database. Sensitivities are calculated for finding any and all of the ECGs from the same patient in the set of 20 nearest neighbors. Results: In the exhaustive search, sensitivities were 68% and 37% for finding any and all of the ECGs from the same patient respectively. Conclusion: Pair-wise exhaustive search of template match found similar ECGs with good sensitivity. Further research is needed to determine if acceptable performance in ECG retrieval can be achieved by low com-plexity similarity database search.

85-361 High Frequency QRS for Detection of Myocardial Ischemia

Pavel Leinveber*, Josef Halamek, Pavel Jurak, Filip Plesinger, Jolana Lipoldova, Juraj Jurco and Miroslav Novak

Introduction: Changes of high frequency components of QRS complex (HFQRS) have been reported as a sensitive indicator of myocardial ischemia. Different markers were suggested. Our aim was to test differences in HFQRS parameters between healthy and coronary artery disease patients (CAD). Methods: 5 min ECG of 106 controls and 103 CAD were analyzed. The data were acquired during rest in supine position with conventional 12-lead ECG (sampling frequency 5 kHz, dynamic range 24 bit and low pass cutoff frequency 2 kHz). Data were analyzed offline. The first step was QRS detection and sorting. Only regular beats were analyzed. Frequency envelopes in frequency band 150-250Hz were computed and averaged to increase SNR. The next parameters were analyzed in each lead in QRS area: Amax: maximal amplitude; RMS in area over 0.1Amax; RAZ: reduced area zone; KURT - kurtosis, statistical parameter of envelope. The mean over defined set of leads was analyzed. Results: The mean ± STD over healthy were 14.7±6.5 µV; 7.6±3.4 µV; 0.41±0.23; 7.1±1.2 for Amax, RMS, RAZ, KURT respectively. The values for CAD were 9.3±4 µV; 4.7±2 µV; 0.58±0.25; 5.7±1.7 for Amax, RMS, RAZ, KURT respectively. Differences between healthy and CAD are highly significant, the P is below 0.00001 for all presented parameters. Maximal differences are for RMS ($P<10e-11$), minimal for RAZ ($P<10e-5$). Significant correlation exists between Amax and RMS, independent parameters are KURT and RAZ, the correlation is below 0.5. Discussion: Healthy subjects have significantly higher Amax, RMS, KURT and significantly lower RAZ than CAD. Diagnostic limitation is high inter-subject variability and diagnosis based on measurement only in rest has low specificity and sensitivity. ROC area based on all presented parameters is 0.732. The course of parameters during heart excitation should be considered to improve sensitivity and specificity.

86-132 **Potential Solutions for Managing Real-Time ECG/Arrhythmia Monitoring Alarms - A Review**

John Wang*

Electrocardiographic monitoring, which allows for continuous non-invasive detection and documentation of cardiac arrhythmia, is one of the most frequently used monitoring procedures for managing in-hospital patients. The most often cited issue of using these systems is the large number of alarms generated by these systems. These alarms include both false alarms and repetitive non-actionable true alarms. Device based solutions for false alarm reduction include a) providing more specific information in assisting users to identify the root cause of the false alarms, and b) continuing the development of more robust algorithms. In this presentation, useful information that could be provided by the device in supporting root cause identification will be discussed. In addition to the enhancement of existing ECG based algorithms, the devevelopment should also include multi-parameter algorithms that incorporate simultaneous analysis of both ECG and non-ECG signals, such as blood pressure and pleth. Frequent repetitive non-actionable alarms can be reduced and managed by developing a more robust alarm generation structure. While a large amount of work to develop better algorithms has been reported, there have been very limited discussions on the development of a more robust alarm generation structure. This presentation will provide an overview of the key features/components of a robust alarm generation structure and show how such a system could be used to manage and reduce the repetitive non-actionable alarms. Computerized Electrocardiographic monitoring was introduced for clinical use in the 70s. Based on continuous users' feedback and advancement in computing technologies, commercial systems have improved significantly over the years. As before, it is expected that the identified issues will be the main focus of future development for commercial systems. As discussed, the improvement will come from better user support tools for trouble-shooting, more accurate analysis algorithms including both ECG and multi-parameter based, and better alarm generation structures.

87-118 **Comparison of Spatial QRS-T Angle in Different Healthy Racial Groups**

Elaine Clark* and Peter Macfarlane

Aim: A wide spatial QRS-T angle has been associated with higher risk of cardiac death. The aim of the present study was to compare the normal limits of the spatial QRS-T angle in four cohorts of different apparently healthy racial groups to determine if there were any significant differences due to age, gender and race. Methods: The University of Glasgow ECG Analysis Program was used to derive X, Y and Z leads from the 12 lead ECG and hence obtain the spatial QRS-T angle. The analyses were carried out on apparently healthy male and female Black (Nigerian), Caucasian (Scottish), Chinese (Taiwanese) and Indian cohorts. Statistical analysis of the angles was undertaken using SPSS and MedCalc packages. Results: In total, 4223 ECGs were analysed. 37 ECGs were excluded for technical reasons leaving 2542 males and 1644 females aged between 18 and 87 in the study. The mean spatial QRS-T angle for males in Black, Caucasian, Chinese and Indian populations was 66±26°, 69±29°, 59±26 and 72±33° respectively. The mean for Chinese males was significantly lower than for all other groups ($P<0.001$). For females, the corresponding mean values were 42±23°, 57±25°, 40±22° and 41±25°, with the Caucasian mean being significantly higher than the others ($P<0.001$). In all ethnic groups, the mean spatial QRS-T angle was higher in males than females, with an overall mean difference of 21°. Mean spatial QRS-T angle generally decreased as age increased in males while the opposite was true for females. The age independent upper limits of normal (98th percentile) were 128°, 145°, 141°, 157° for males and 101°, 119°, 85°,104° for females for Black, Caucasian, Chinese and Indian groups respectively. Conclusion: Race and gender in particular require to be considered when assessing the spatial QRS-T angle.

88-500 **SCP-ECG V3.0: An enhanced Standard Communication Protocol for computer-assisted Electrocardiography**

Paul Rubel*, Danilo Pani, Alois Schloegl, Jocelyne Fayn, Fabio Badilini, Peter Macfarlane and Alpo Varri

Several authors and task forces have repeatedly emphasized the need for open communication and interlinking of various types of ECG devices and systems and the difficulty of overcoming the lack of interoperability and limitations of different standards and proprietary solutions. In this paper, we will report about the progress made by our Project Team in revising and markedly extending the scope of the so called SCP-ECG “Standard communication protocol - Computer-assisted electrocardiography” Norm (EN:1064 ISO 11073-91064). The main goal of the SCP-ECG standard is to address ECG data and related metadata structuring, semantics and syntax, with the objective to facilitate interoperability and thus to support and promote the exchange of the relevant information for unary and serial ECG diagnosis. The standard will now also provide support for the storage of continuous, long-term ECG recordings and afford a repository for selected ECG sequences and the related metadata to accommodate stress tests, drug trials and protocol based ECG recordings. The global and per-lead measurements sections have been extended and three new sections have been introduced for storing beat-by-beat and/or spike-by-spike measurements and annotations. The used terminology and the provided measurements and annotations have been harmonized with the ISO/EEE 11073-10102 Annotated ECG standard. Emphasis has also been put on harmonizing the Universal Statement Codes with the CDISC and the categorized AHA statement codes and the drug and implanted devices codes with the ATC and NASPE codes. Another important feature of the SCP-ECG standard is to provide a protected format including self-control capabilities of the content and preserving confidentiality during the exchange on account of its dedicated binary representation. The latter also yields for files of smal size, compliant with mHealth scenarios for an early detection of cardiac diseases, anywhere and anytime.

S55 **ECG Imaging I**

Chairs: Remi Dubois and Dana Brooks

Room: Shaughnessy II

89-239 **Noninvasive Localization of Premature Ventricular Activity Using Different Equivalent Point Sources**

Jana Svehlikova* and Milan Tysler

The aim of the study was to compare localization errors of inverse estimations of the origin of premature ventricular contraction (PVC) using three different formulations of transfer matrix between the equivalent source and the surface potentials. Body surface potential maps (BSPMs) provided in EDGAR database by Karlsruhe Institute of Technology were used. The ECG signals were measured in 63 precordial leads during nine spontaneous PVCs in one patient. From the ablation procedure two reference points were known: PVC1– the site where the earliest activation time was recorded and PVC2– the site of the latest successful ablation. The geometry of patient's heart and torso were provided together with the transfer matrices for epicardial potentials (EPs) and transmembrane voltages (TMVs) on the joined endo-and-epicardial surface. The transfer matrix for dipoles (DIPs) situated in the mesh within the myocardial volume was also computed. The only constraint for the inverse solution was the assumption that at the beginning of the PVC only very small area is depolarized and it can be represented by a single point source. The inverse solution was computed for all available positions of the sources and the best source was chosen according to the criterion of the smallest relative residual error (RELDIF) between the input BSPM and the map generated by the equivalent source. The localization error (LE) of the inverse solution was evaluated with respect to both reference points. For all nine considered PVCs the locations of the inverse results were very stable – for particular transfer matrix they resulted in the same point or in adjoining points for all cases. Mean LEs with respect to PVC1/PVC2 were 22mm/15mm for EPs, 26mm/16mm for TMVs and 25mm/25mm for DIPs. The LEs of the PVC origin obtained by inverse solution supposing single point source were similar regardless of the source formulation.

90-434 **Noninvasive Epicardial and Endocardial Electrocardiographic Imaging of Scar-Related Ventricular Tachycardia**

Linwei Wang, Omar Gharbia, Sandesh Ghimire*, Milan Horacek and John Sapp

Background: Ventricular tachycardia (VT) is a major cause of morbidity and mortality in patients with heart disease. Many life-threatening VTs involve a “short circuit” sustained by heterogeneous scar substrates. To treat VT and prevent its recurrence, it is effective to interrupt the VT circuit by catheter ablation. Critical components of the circuit, ideally, can be delineated during VT using a combination of VT and entrainment mapping. To do so with invasive catheter mapping, however, requires the VT to be stable over a period of time. This unfortunately is only possible in a small percentage of patients. A noninvasive approach to quickly map VT has the potential to allow the mapping of more VTs and to improve the success rate of catheter ablation. Methods: In the presented workflow, patients first undergo a standard axial CT scan. 120-lead ECG mapping is then obtained during the initial induction of clinical VTs at the beginning of an ablation procedure. Patient-specific biventricular model and body-surface electrode positions are obtained from CT images. Noninvasive ECG imaging then computationally reconstructs electrical signals in the heart using 120-lead ECGs obtained during induced VT. Post-analysis is carried out to derive the activation time, conduction velocity, and phase maps for visualizing the resulting reentry circuits. Results & Conclusions: Experiments were conducted on three patients who underwent ablation of scar-related VT. In a retrospective study, inverse results computed from 120-lead ECGs were analyzed to examine the re-entry rotation, exits, and entrances of the VT circuits. These results were shown to be consistent with the region of scar and critical VT sites identified from ablation procedures (Figure 1). This pilot study shows that noninvasive ECG imaging has the potential to provide fast VT mapping for stable and unstable VTs. It may allow a better understanding of VT mechanisms and improve ablation efficacy

91-198 **A Comparison of Discretization Methods for the Inverse Problem of Electrocardiography**

Laura Bear*, Leo Cheng, Remi Dubois, Denis Loiselle and Bruce Smaill

Aims: The inverse problem of electrocardiography reconstructs cardiac electrical activity from torso potentials. Here we compare the two most common methodologies used for this problem; the boundary element method (BEM) and the method of fundamental solutions (MFS). Methods: Torso and epicardial potentials were recorded simultaneously in closed-chest pigs (n=5), during sinus rhythm, epicardial, and endocardial pacing (70 records in total). Post-mortem MRI was used to construct experiment-specific torso and epicardial meshes and to determine electrode locations. Three inverse methods were examined for each animal: 1) a BEM inverse using a refined torso mesh, with kriging interpolation to map potentials from torso electrodes to nodes, 2) a standard MFS inverse (MFSstand) using torso electrodes as direct inputs, and 3) an MFS inverse using the refined torso mesh and interpolated signals (MFSfull). In each case, potentials were reconstructed using Tikhonov regularization and CRESO criteria. Reconstructed electrograms and activation time (AT) maps were compared to their recorded signals using relative errors (RE) and correlation coefficients (CC). Results: Potential magnitudes were significantly underestimated by BEM (RMSvoltage=1.81±0.51 mV) compared to those measured (RMSvoltage=4.47±1.03 mV; $p<0.0001$). The general shape of electrograms were captured (CC=0.54±0.10) as was the spread of activation (CC=0.73±0.12 for AT Maps), though the total activation duration was underestimated (41±12 ms; $p<0.001$) and pacing sites were not localized reliably (27±21 mm; $p<0.001$). MFSfull improved potential magnitudes (RMSvoltage=2.07±0.46 mV; $p<0.0001$), though there was no significant difference in electrogram shape. There was also a significant improvement in localization of pacing sites (LE=19±10 mm; $p=0.01$). There was no significant difference in any metric between MFSfull and MFSstand. Conclusion: The BEM and MFS demonstrate similar accuracy for reconstructing epicardial potentials, with minor improvements by the MFS. Considering this, in addition to the advantage of being meshless, MFS is the preferred approach for inverse problems.

92-431 **The Consortium on Electrocardiographic Imaging**

Jaume Coll-Font*, Dana H Brooks, Peter M van Dam, Jwala Dhamala, Olaf Dössel, Maria de la Salud Guillem Sánchez, Rob MacLeod, Danila Potyagaylo, Walther Schulze, Jess D Tate and Linwei Wang

ElectroCardioGraphic Imaging (ECGI) has received increasing academic, clinical, and industrial attention recently. However, for ECGI to be more widely adopted in clinical practice, it is necessary to address the problems of reproducibility, cross-lab validation, and cross lab cooperation. This challenge is difficult given that each group uses separate datasets, algorithms, software, and, often, different validation metrics. It is thus necessary to establish a generally accepted infrastructure that allows shared access to datasets, methods, and experimental knowledge. We created the Consortium on Electrocardiographic Imaging (CEI) in 2015 for this purpose and are working to attract all research groups exploring ECGI. CEI has two main infrastructure components to tackle these challenges: a public collection of datasets, called EDGAR, and workgroups organized around common interests. Datasets from 6 groups from 3 continents are currently available from EDGAR in a standardized format including data from realistic simulations, large animal models, and experimental and clinical human subject data. The workgroups tackle validation of forward problems and inverse solutions, localization of first activation site in Premature Ventricular Contractions (PVCs), and imaging of Atrial Fibrillation (AF). The first workgroup aims to identify sources of uncertainty in forward models by comparing results at every step of the pipeline from segmentation of anatomical scans to computation of the forward matrix. The second workgroup aims to generate validation benchmarks for inverse solutions to test accuracy and utility of inverse solutions to localize initial activation sites of PVCs. The third group aims to establish benchmarks for imaging of atrial activity and AF. CEI also organizes international meetings and hackathons, either standalone or in conjunction with existing meetings such as Computing in Cardiology. The CEI is continuing to develop infrastructure to facilitate collaboration and foster reproducibility within the ECGI community. For more information about CEI, visit www.ecg-imaging.org or join the mailing list info@cei.org.

93-426 **Temporal Dilation of Animal Cardiac Recordings Registered to Human Torso Geometry**

Karli Gillette, Jess Tate*, Brianna Kindall, Wilson Good, Jeff Wilkinson, Narendra Simha and Rob MacLeod

Introduction: Data attained in electrophysiology studies of animals is useful to understand the mechanisms of cardiac diseases, particularly if adjusted to fit within human torso geometries. However, when large animal heart geometries are registered to a human torso model, timing of the electrograms must be adjusted to avoid an apparent increase in conduction velocity resulting from increased heart size. We developed a time dilation technique to ensure that adjusted cardiac electrograms were physiologically similar to human recordings after registration. Methods: We acquired electrograms from ten exposed canine hearts using an epicardial sock and registered a triangle mesh of the electrode locations to a single human torso geometry. We then calculated a global temporal scaling factor from the median change in length for each triangular mesh edge. Linear dilation was performed on the cardiac recordings for each data set using the calculated scaling factor. We validated the results with conduction velocity, QRS width, and QT interval for the dilated electrograms compared to literature values in humans. Results: Linear temporal dilation of the canine cardiac recordings yielded signals resembling human recordings. The mean temporal scaling factor, weighted based on the number of data sets per geometry, was 1.73$\pm$0.02. Wave morphologies of dilated cardiac recordings resembled human recordings and were also quantitatively comparable. The conduction velocity of 31.3$\pm$1.5 cm/s before registration and dilation increased to 39.6$\pm$2.5 cm/s after. The original canine cardiac recordings showed a QRS width and QT interval of 43.8$\pm$0.6 ms and 175$\pm$8 ms, respectively. After registration, the predicted values were 76$\pm$10 ms and 310$\pm$10 ms. Conclusions: Temporal correction of canine epicardial recordings can be used to generate signals similar to human recordings. Epicardial potential mapping of dilated canine signals allows the investigation of human-like arrhythmias and other disease states that can not be readily induced or measured in humans.

94-122 **Patient-Specific Time-Varying Association between Spatial and Temporal Variability in Repolarization and High Sensitivity Troponin I**

Larisa Tereshchenko* and Albert Feeny

Introduction: Fast cell-to-cell uncoupling in response to acute myocardial injury is adaptive as it prevents the spread of chemical mediators of injury from severely affected areas to less affected areas and therefore decreases damage to the heart. Cell-to-cell uncoupling is characterized by increasing repolarization lability (RL). Hypothesis: We hypothesized that the RL, quantified by spatial TT' angle, is associated with the degree of myocardial damage, quantified by the level of high sensitivity troponin I (hsTnI), in acute coronary syndrome (ACS) and acute decompensated heart failure (ADHF). Methods: Spatial TT' angle on resting 12-lead ECG (transformed to vectorcardiogram) and hsTnI were measured simultaneously every 3 hours during a 12-hour observation period in a prospective cohort of emergency department patients (n=379; age 57.8±13.2y; 54% female, 64% black), diagnosed with ACS(n=28), ADHF(n=35), or a non-cardiac condition(n=316). Random-effects linear regression assessed the association of spatial TT' angle and myocardial injury, with adjustment for demographics (age, sex, race), prevalent cardiovascular disease (myocardial infarction, history of revascularization, stroke, HF), risk factors (diabetes, smoking, hypercholesterolemia, hypertension, cocaine use), and left bundle branch block. An adjusted multinomial logit model was used to characterize differences between ACS, ADHF and non-cardiac conditions. HsTnI and TT' angle variables were log-transformed to normalize distribution. Results: As compared to acute non-cardiac conditions, ADHF was characterized by significantly higher baseline RL (adjusted relative risk ratio (RRR) for TT' angle 5.6(95%CI 1.2-25.4); P=0.027). Baseline RL in ACS did not differ from non-cardiac conditions (RRR 0.8(95%CI 0.2-4.0); P=0.770). A 10-fold increase in hsTnI was associated with a 1.14(95%CI 0.16-2.11) degrees increase in spatial TT' angle (P=0.022). High (above median) HsTnI in ACS was characterized by significantly larger TT' angle (12±8 vs 5±2 degrees; P=0.01) 12 hours after admission, but not earlier. Conclusion: Spatial TT' angle is associated with the level of hsTnI in ACS and ADHF.

Tuesday, September 13, 2016 **12:30**

P61 **Medical Informatics and Technology**

Room: Pinnacle I

95-351 **An Adaptive Organization Index to Characterize Atrial Fibrillation using Wrist-Type Photoplethysmographic Signals**

Sibylle Fallet*, Mathieu Lemay, Philippe Renevey, Célestin Leupi, Etienne Pruvot and Jean-Marc Vesin

Introduction: Photoplethysmography (PPG)-based wrist monitors have gained a lot of popularity as portable heart rate monitors. However, their ability to diagnose cardiac arrhythmias, such as atrial fibrillation (AF), is still unexplored. This study aims at quantifying the level of organization of PPG signals during electrophysiology procedures and to assess its potential to characterize atrial fibrillation (AF) episodes. Methods: The database includes 11 adult patients undergoing cathete ablation of cardiac arrhythmias. PPG signals were recorded using a wrist-type sensor, also including an accelerometer. A 12-lead ECG acquired simultaneously with the PPG waveforms was used as gold standard. ECGs were annotated by experts and selected segments were divided into 4 categories: sinus rhythm (SR), regularly paced rhythm (RPR), irregularly paced rhythm (IPR) and AF. The PPG adaptive organization index (AOI), defined as the ratio of the power of the fundamental frequency and the first harmonic to the total power of the pre-processed PPG signal, was computed using adaptive band-pass filters. The AOI was averaged on 10-second epochs (50% overlap). Accelerometer signals were used to remove epochs with motion artifacts. Results: A total of 1779/256/852/268 epochs were considered for AF/SR/RPR/IPR classes. The following mean AOI values were measured: 0.48±0.12 for AF, 0.66±0.23 for SR, 0.78±0.20 for RPR and 0.62±0.19 for IPR classes. Importantly, the AF AOI was significantly smaller than that of the other categories (p<0.001), indicating a higher degree of disorganization. After binary logistic regression, the AUC of the ROC was 0.82 between AF and the other classes. Conclusion: These preliminary results suggest that AF is characterized by a higher degree of disorganization of PPG signal similarly to that of ECG signals. PPG-based wrist monitors appear as promising diagnostic tools for the screening of AF in large populations.

96-236 **Imaging Photoplethysmography: What are the Best Locations on the Face to Estimate Heart Rate?**

Sibylle Fallet*, Virginie Moser, Fabian Braun and Jean-Marc Vesin

Purpose: The potential of imaging photoplethysmography (iPPG) for cardiovascular monitoring applications has been highlighted these last years. Different processing schemes have been proposed to extract heart rate (HR) from a defined region of interest (ROI) on the face. However, the reasons that motivate the choice of the ROI are often unknown. This study aims at comprehending the spatial distribution of the HR-related information on the subject face. Methods: The database is composed of six 4-minute video-sequences, from three subjects performing handgrip test or modulating their respiration according to a given protocol. For each video-sequence, a rectangle was manually fitted around the whole face and divided into 260 rectangular ROIs. For each ROI, the iPPG signals were obtained by averaging the pixels, in each frame. The resulting signals were band-pass filtered (0.6-4 Hz). The reference HR was derived from the ECG acquired simultaneously with the video-sequences. A power spectral density (PSD) analysis was performed to determine the amount of HR-related information in each ROI. For this purpose, a 10-second sliding-window (50% overlap) was used to compute the PSD of the iPPG signals. For each window, the percentage of the total power in a defined frequency-band centered at the local true HR was calculated and then averaged for each subject (PPow). Results: Normalized color maps were used to visualize the spatial distribution of the HR-information and clearly showed that color fluctuations due blood volume changes are always more pronounced on the forehead region. After face segmentation, for the R/G/B channels, averages PPow of 27%/43%/27% for the forehead, 17%/28%/18% for the cheeks and 16%/24%/16% for the whole face regions were obtained. Conclusion: Numerical results showed that the forehead part is the most relevant region to estimate HR, followed by the cheekbones. These regions should be tracked in priority in iPPG applications.

97-140 **Real-Time Approaches for Heart Rate Monitoring using Imaging Photoplethysmography**

Sibylle Fallet*, Leila Mirmohamadsadeghi, Virginie Moser, Fabian Braun and Jean-Marc Vesin

Purpose: Imaging photoplethysmography (iPPG) has gained a lot of popularity as a contactless heart rate (HR) monitoring technique. However, most of the existing approaches are based on block-wise processing, which is not optimal for real-time applications. In this study, three different algorithms suitable for almost real-time HR estimation are proposed and evaluated on a database composed of video-sequences acquired in different experimental conditions. Methods: The database is composed of 46 4-minute video-sequences recorded in visible light using an RGB camera or in darkness with a near-infrared camera and appropriate illumination. In order to induce changes in HR, the subjects were asked to perform handgrip exercise or to modulate their respiration according to a given protocol. The iPPG signals were obtained by averaging the pixels within a fixed region of interest selected on the forehead. Three algorithms for continuous HR estimation are investigated: 1) an algorithm based on adaptive sliding-window singular value decomposition (SWASVD), 2) an approach based on an adaptive band-pass filter (OSC-ANF-W), 3) a notch-filter bank (NBF) estimation method. In addition, a confidence index was developed to eliminate motion artifacts. The ground-truth HR was derived from the ECG signal acquired simultaneously with the videos. Results: For the visible/dark sequences, average absolute errors (AAE) of 3.42/5.25, 3.14/4.21 and 3.98/6.02 bpm were obtained for the SWASVD, the OSC-ANF-W and the NFB algorithms, respectively. The corresponding averaged estimation delays, estimated using the cross-covariance between true and estimated HR, were 4 seconds (SWASVD and OSC-ANF-W) and 3 seconds (NFB). Conclusion: Although the proposed algorithms are based on different mechanisms, they lead to similar results. Moreover, the HR fluctuations induced by the modulation of the breathing rate or the handgrip were correctly tracked. These results highlight the potential of iPPG for real-time HR monitoring applications, both in visible light and darkness using near-infrared light.

98-179 **Missing Data Imputation for Individualised CVD Diagnostic and Treatment**

Sitalakshmi Venkatraman, Andrew Yatsko, Andrew Stranieri and Herbert F Jelinek*

Cardiac health screening standards require more and more clinical tests consisting of both blood, urine and anthropometric measures as well as an extensive clinical and medication history. Extensive screening requires diagnostic determinants to be highly accurate to reduce false positives and ensuing stress to the individual patients. In addition, it requires algorithms that allow imputing missing variables on an individual basis. The current study provides a unique imputation algorithm that can be applied to personalised cardiac health screening The algorithm is based on dynamic clustering centred around cardiovascular disease (CVD), diabetes mellitus and hypertension, conditions. The DiabHealth database containing 6800 records with 20(attributes was used for testing the experimental validity of our algorithm. Our results for predicting CVD showed a high accuracy with a sensitivity and specificity 92% and 99% respectively using the Info-Neighbour method. Naïve Bayesian performed less accurately (80% and 84% respectively) and identified Framingham cardiac risk as the best predictor. Removing variables that define cardiac events and conditions available from the medical history left age followed by use of anti-hypertensives and anti-cholesterol medication, especially statins as the best predictors. The missing values algorithm is an important addition to patient-centred healthcare in the current population screening environment since it allows the prediction of CVD in individual patients who do not provide all the required cardiac health predictor variables.

99-135 **A Heuristic Gene Regulatory Networks Model for Cardiac Function and Pathology**

Armita Zanegar, Peter Vamplew, Andrew Stranieri and Herbert F Jelinek*

Genome-wide association studies (GWAS) and next-generation sequencing (NGS) has led to an increase in information about the human genome and cardiovascular disease. Understanding the role of genes in cardiac function and pathology requires modeling gene interactions and identification of regulatory genes as part of a gene regulatory network (GRN). Feature selection and data reduction not sufficient and require domain knowledge to deal with large data. We propose three novel innovations in constructing a GRN based on heuristics. A 2D Visualised Co-regulation function. Post-processing to identify gene-gene interactions. Finally a threshold algorithm is applied to identify the hub genes that provide the backbone of the GRN. The 2D Visualized Co-regulation function performed significantly better compared to the Pearson's correlation for measuring pairwise associations (t=3.46, df=5, p=0.018). The F-measure, improved from 0.11 to 0.12. The hub network provided a 60% improvement to that reported in the literature. The performance of the hub network was then also compared against ARACNe and performed significantly better (p=0.024). We conclude that a heuristics approach in developing GRNs has potential to improve our understanding of gene regulation and interaction in diverse biological function and disease.

100-371 **A Novel Algorithm for Fast Ballistocardiogram Cycle Extraction in Ambulatory Scenarios**

Joan Gomez-Clapers, Ramon Casanella* and Ramon Pallas-Areny

Aims: The ballistocardiogram (BCG) is the recording of forces in the body as a result of cardiac ejection and can be obtained from modified weight scales to deliver cardiovascular information in ambulatory scenarios. However, such BCG recordings are burdened by artifacts whose effect is often minimized by ensemble-averaging techniques that rely on reference signals such as the electrocardiogram (ECG), not easily available in non-clinical settings. This work presents a novel algorithm (JDet) for BCG cycle extraction intended for fast generation of ensemble averages in ambulatory scenarios. Methods: The sensitivity and positive predictivity of JDet were evaluated for recordings from 14 healthy subjects standing on a modified weight scale and the results compared to those from BSeg++, a BCG cycle-extraction algorithm that does not require any reference signal either. Afterwards, the signal to noise ratio (SNR) was calculated for ensemble averages synchronized from fiducial points obtained from JDet, BSeg++, and the ECG for different recording durations. Results: The sensitivity of JDet is better than that of BSeg++ (0.87 vs. 0.57) whereas their positive predictivities are similar (0.92 and 0.87). The SNR for ensemble averages generated from JDet are similar to ECG-generated ensemble averages for short recordings due to its higher sensitivity compared to BSeg++. For long durations, SNR is limited by false positives and trends towards a value similar to that of BSeg++. SNR for ensemble averages generated from JDet can be close to that of those synchronized to the ECG, the only cost being a 25 % longer recording time whereas BSeg++ needs recordings about 100 % longer. Conclusions: The JDet algorithm enables faster and more reliable measurements of cardiovascular parameters from the BCG in ambulatory scenarios without any ancillary reference signal. The results provide guidelines for further improved algorithms intended for short recordings.

101-513 **A Non-rigid Electro-anatomic Map and CT Surface Registration Method**

Lixia Shu* and Changyan Lin

Aims: Electro-anatomical map (EAM) and CT surface registration is widely used for catheter navigation in atrial fibrillation (AF) ablations. However, few studies have done on the registration algorithm. Furthermore, these methods are inaccurate for precise navigation. The reason is that the transform models they use, rigid or affine transformation, can't accurately describe the large elastic atrial deformations. Therefore, in this study, we applied an Incremental Free Form Deformations (IFFD) model, and proposed an IFFD based non-rigid method for accurate EAM and CT surface registration. Methods: Firstly, using rigid transform and pricipal axes based approach, EAM and CT surface were coarsely aligned. EAM was the float point set; CT surface was the reference set. Secondly, using Sum of Squared Differences (SSD) as the similarty measurement and cubic B-spline based local IFFD as the tranform model, EAM and CT surface were finely aligned. Different from the coarse step, EAM was the reference point set, and CT surface was the float set. Those IFFD parameters that minimized the objective function, the sum of SSD and a smoothness term, were the final registration result. Results: Using Carto-Merge, stochastic approach and IFFD based method, we registered a simulated EAM/CT pair and a real EAM/CT pair. Root Mean Squre Error (RMSE) of the gold-standard points was applied for evaluating simulated data registration accuracy; average distance between the two point sets was applied for evaluating real data registration accuracy. The RMSE of Carto-Merge, stochastic approach and IFFD based method were 30.297mm, 11.762mm, and 1.525mm. The average distance of Carto-Merge, stochastic approach and IFFD based method were 10.815±7.8371mm, 7.6249±4.7337mm and 2.3152±1.7035mm. For both simulated and real data, IFFD based method obtained much more accurate results than the other two appraches. Conclusion: Compared to the traditional methods, IFFD based method is much more accurate for precise catheter navigation.

102-150 **Photoplethysmography as Primary Tool for Progressive Haemorrhage Assessment During Progressive Lower Body Negative Pressure**

Kian Davoudi Rad* and Bozena Kaminska

Lack of a precise index to identify degree of hemorrhage prior cardiovascular collapse is being considered a driving cause of fatality in patients experiencing progressive hemorrhage. The traditional clinical hemorrhage assessment consists of conventional beat-to-beat heart rate and arterial blood pressure measurement. But, as shown in [1][2], prior cardiovascular collapses, these indexes continue projecting no significant shift in their status. Hence, Convertino and Tavakolian have shown that Seismocardiography (SCG) and Photoplethysmography (PPG) indeed provide such a window to alarm cardiovascular collapse prior radical projection on conventional measurements. Hence, as author has shown in [3], a mechanically flexible PPG sensor was designed and optimized for continuous monitoring of cardiovascular and respiratory performance. But, the reliability of this sensor for calcification of stages of hemorrhage, was not assessed. Thus, goal of this dissertation was to resolve this issue, by conducting Lower Body Negative Pressure (LBNP) to stimulate hemorrhage in 10 awaked patients and compared the reliability of PPG signal captured from mechanically flexible sensor, with conventional PPG captured from FDA approved pulse oximeter. Results from Bland and Altman (BA) analysis showed all data points from PPG were close to the mean value and between the upper and lower limit of standard deviation BA analysis. The BA between flexible PPG and Nasal respiratory sensor, showed, 0.2 Mean, -2.37 and 2.78 for lower and upper boundaries respectively. Thus, the results demonstrate that the flexible PPG sensor is reliable for detection of respiration rate from PPG sensor during progressive hypovolemia on awaked patients.

103-245 **Automatic Classification and Prediction of Congenital Heart Disease based on Hybrid Neural Network System**

Wenping Pan*, Kuanquan Wang, Henggui Zhang, Cunjin Luo, Qince Li and yongfeng yuan

Introduction: Clinical study found that in the treatment of congenital heart disease (CHD), the physiological indicators, including B-type natriuretic peptide (BNP), ventricular end diastolic diameter (VEDD), ventricular ejection fraction (VEF) and the size of the hole of congenital heart defects (SHCHDs), have great relevance to each other. Currently, a valid model is needed to be established to predict SHCHDs, indicating the severity of patients concerned, using BNP, VEDD and VEF. Methods and Results: Three different networks, including BP neural network, RBF neural network and Hopfield neural network, were used to process the same clinical data sets respectively Then, Hybrid Neural Network (HNN) was built to integrate the three outputs produced above by weighted average method decided by the respective average errors. The clinical data sets had covered three types of CHD: ventricular septum defect (VSD), atrial septum defect (ASD) and patent ductus arteriosus (PDA). We had 51 training samples and 20 test samples for VSD, 39 training samples and 32 test samples for ASD, and 31 training samples and 32 test samples for PDA. The average SHCHDs prediction errors of BP, RBF, Hopfield and HNN respectively were as followed (unit is mm):
VSD（4.3980，3.2205，3.9491,3.0203），ASD（4.2572，4.1318，4.0167，3.7 274），PDA（4.1318，4.2129 3.8592，3.6658）。
Conclusion: The results suggest that HNN significantly improves the generalization ability, and improves the accuracy of automatic diagnosis in the SHCHDs prediction of congenital heart disease.

104-358 **Validation of the Heart-Rate Signal Provided by the Zephyr BioHarness 3.0**

Daniele Nepi, Agnese Sbrollini, Angela Agostinelli*, Elvira Maranesi, Francesco Di Nardo, Sandro Fioretti, Paola Pierleoni, Luca Pernini, Simone Valenti and Laura Burattini

The Zephyr BioHarness 3.0 (BH3) is a popular wearable system specifically designed for training optimization of professional athletes. If clinical reliable cardiac signals were provided, BH3 could also be used as a practical tool for clinical cardiac-risk evaluation. Thus, the aim of the present study, which is part of larger project on BH3 validation, is to evaluate the reliability of the heart-rate signal (HRS) provided by BH3. To have some levels of heart-rate variability, 10 healthy subjects (age: 34±17 years) were monitored during a 5-min rest. BH3 recorded the electrocardiogram and then applied unknown algorithms in order to obtain and provide HRS (HRS_BH3). Since the tachogram represents the standard signal for studying heart rate and heart-rate variability, we analyzed the electrocardiogram provided by BH3 in order to get the tachogram (HRS_TG). HRS_BH3 and HRS_TG were then compared in terms of mean heart rate (MHR), heart-rate standard deviation (HRSD) and HRSD error (here defined as the difference between HRSD values provided by HRSD_BH3 and HRS_TG, respectively). HRS_BH3 and HRS_TG provided comparable MHR (73.07±15.53 bpm vs 72.86±15.57 bpm, respectively; $P=0.1299$) while HRSD by HRS_BH3 (4.51±2.28 bpm) was significantly lower than HRSD by HRS_TG (5.63±2.99 bpm; $P<0.0043$). HRSD error was always positive (from 0.20 bpm to 3.00 bpm), and thus significantly greater than zero ($P=0.0043$); moreover, it was strongly correlated to HRSD by HRS_TG ($\rho=0.82$, $P=0.0036$). Thus, according to our results, BH3 provides reliable MHR estimations while significantly underestimates heart-rate variability (here measured as HRSD). Specifically, the level of the underestimation linearly grows with the amount of variability. Consequently, the use of BH3 is appropriate to sport applications relying on MHR estimations, but not to clinical evaluations based on heart-rate variability measurements. A larger number of subjects monitored under different conditions will be used in future studies to confirm these results.

105-309 **An Evaluation of Different Coating for TiN Microelectrode Chambers Used for Neonatal Cardiomyocytes**

Ondrej Svoboda*, Josef Skopalik, Larisa Baiazitova, Eva Gabrielova, Vratislav Cmiel, Ivo Provaznik, Zdenka Fohlerova and Jaromir Hubalek

INTRODUCTION: Neonatal myocytes are widely used model for modern in-vitro pharmacological screening and tissue engineering of cardiac tissue. However, the recording of neonatal myocyte morphology and electrophysiology in real time is still not ideally optimized. The aim of this study was to evaluate the impact of using different substrates in culture chamber on the surviving and functiona electrophysiological activity of the myocytes in first 5 days. METHODS: Cardiomyocytes were isolated from 2-day neonatal rat, plated at 6×105 cells/cm2 density on 12×12 ITO microelectrode chamber and cultured for 3 days at 37°C and 5% CO2. Two chamber designs were used: i) 30 µm electrode diameter with 100 µm electrode spacing and ii) variant 30/10 µm. Four surface treatment methods were used: i) collagen IV; ii) poly-L-lysine (PLL); iii) poly-D-lysine (PDL); iv) poly-D-lysine+fibronectin. Cell adhesion, morphology and electrical response were monitored with Olympus IX73 (Calcein AM were used for viability staining). For electrical monitoring 120 channels MEA2100 system were used. Signal baseline were recorded in 0,09% glucose buffer for 300 seconds, thereafter 0,9% glucose buffer were replaced and recorded for spontaneous activity. After tha 200 µs duration biphasic electrical pulse was applied with different amplitudes and frequencies. Records were than analysed in point of shape, frequency and amplitude. RESULTS: The PDL+fibronectin treatment display the highest cardiomyocyte adhesion to the electrodes (20% of cells) and developing of contractible cells with measurable electrical response. In these type of samples, cells can be desensitized with 500 mV pulses at 16.67 mHz frequency and recovered after 10 minutes in 0.9% glucose buffer. Pure PDL also provides good electrode adhesion (16%) and lower cell responses can be recorded. Colagen IV and PLL display due to the weak interactions with surface very low cell adhesion (0.5~5%). Cell response cannot be recorded in these Colagen IV and PLL samples.

106-324 A Context-aware, Predictive and Protective Approach for Wellness Monitoring of Cardiac Patients

Abdur Rahim Mohammad Forkan and Weichih Hu*

Cardiovascular diseases are major cause of deaths throughout the world. In this work, we develop a context-aware system for wellness monitoring of older adults who leave alone in home and suffers from cardiac disease. The focus here is the integration of social networking services with conventional remote monitoring services by utilizing a scalable cloud platforms. The goal here is to expand patient's social linkage by identifying similarity in his/her cardiac conditions. Here we build a cloud-oriented context-aware model that captures health parameters such as heart rate, ECG, activity, calories burned using modern fitbit device and ECG sensors. The raw data are sent the cloud platforms provided by Amazon Web Service (AWS) where data is converted to high level context. Using social networks this high level context information is send to patient's friends, family and doctors who are interested to know about his/her health condition. The interested parties get notified by Facebook when the context-aware system detects any changes. That is, using this platform a cardiac patient who live alone and need continuous monitoring is always get connected with virtual community by means of his/her health information. To retain the privacy context data is only sent to the people of known virtual community. This is a new model that utilizes the context data generated by wearable sensors to create interesting social networking services. The system is also designed to promote cardiac patients to interact with their community of interest using various context-aware social services. The results obtained for this innovative model show a new approach of wellness monitoring using social networks.

107-460 **Fully-Textile Polymer-Based ECG Electrodes: Overcoming the Limits of Metal-Based Textiles**

Danilo Pani*, Andrea Achilli, Pier Paolo Bassareo, Lucia Cugusi, Giuseppe Mercuro, Beatrice Fraboni and Annalisa Bonfiglio

In recent years, there has been a particular interest in wearable electronics with applications in various fields as fashion, fitness or medical devices. The ultimate goal is the integration of sensors and electronics in clothes and garments. For ECG signals acquisition, the disposable Ag/AgCl gelled electrodes are still the gold standard for clinical and short-term recordings. However, their short operation time and low comfort limit their use in wearable applications. In order to overcome these limitations, several groups have been working in the development of dry electrodes using electro-conductive textiles. The development of textile electrodes, typically exploits finished fabrics, woven or stitched with fine metal wires, or silver-coated fibers. Beyond the limited comfort due to the presence of a metallic material in contact with the skin, the skin-electrode interface is less efficient than gelled Ag/AgCl electrodes, motivating the use of solid hydrogel membranes in some studies. In this work, textiles electrodes for ECG are obtained by treating finished fabric with the conductive polymer poly-3,4- ethylenedioxythiophene doped with poly(styrene sulfonate) (PEDOT:PSS). The intrinsic ionic conductivity of the PEDOT:PSS coated fabrics eliminates the need of liquid electrolytes and solid hydrogel for acquiring bioelectrical potentials directly from the human skin, improving both comfort and signal quality. Different procedures for the electrodes fabrication are compared, including a novel printing technique able to achieve good definition and control over the quantity of deposited polymer as valuable alternative to the treatment of the whole tissue. The electrodes have been characterized and then tested on voluntary subjects. A comparative analysis from a clinical perspective reveals that these electrodes can be effectively used to acquire ECG signals with an acceptable quality, highlighting virtues and vices of the proposed technology.

108-168 Design and Implementation of a Tool for the Analysis and Management of Cardiac Parameters

Jorge Aguilera Perez* and Rene Ivan Gonzalez-Fernandez

The aim of this paper is to discuss the main features of a desktop application designed to study the evolution of heart diseases in the community based on the evolution of a group of electrocardiographic parameters. Periodically, a rest ECG is acquired from persons prone to suffer a heart disorder or who have already had a heart attack. Cornell and Sokolov indexes are computed to study ventricular hypertrophy; spatial dispersion of QT interval is calculated to predict malignant arrhythmias and the Selvester score is computed for persons who have suffer a myocardial infarction. Trend charts are updated for each parameter and physicians can analyze the evolution of these cardiac disorders. Also each ECG can be displayed in different formats in order to be checked by the physicians. The Qt Creator platform, a SQL database engine and C++ language were used to develop the proposed application. Several graphical tools were developed to study the ECG and for data representation. Also, a wide set of PDF reports can be generated or printed directly using a printer. A simple protocol designed by the authors is used in the communication process among Cuban ECG machines and the proposed application. The protocol is composed by different types of blocks with the following format: one-byte identification, data bytes, a one-byte checksum and an ending code. The proposed application has been preliminary tested with thirteen healthy voluntaries and two cardiac patients; ten ECGs were acquired for each person and stored in the database. The communication among the proposed application and the ECG machines never failed and all data were reliable stored and processed. Data recovery for physician analysis was easy and according to the expert using the proposed application, it seems a useful tool to predict cardiac disturbances in the community.

109-493 **An Interactive Clinician-friendly Query Builder for Decision Support During ECG Interpretation**

Ronald Cloughley, Raymond R. Bond*, Dewar D. Finlay, Daniel Guldenring and James McLaughlin

Aims: This study aimed to address the problems faced by clinicians reading and interpreting electrocardiograms (ECGs). Research into ECG interpretation methods and on-line ECG databases were conducted with a view to creating a web based intuitive query builder and decision support tool that would assist diagnostic decision making. Methods: A dataset constructed from on-line ECG library databases was used to create an open source MySQL database of 38 ECG features (e.g. QRS interval, ST amplitude etc. for each lead where appropriate). The Bootstrap framework together with (PHP, HTML) and JavaScript code was used to create a web application. Bootstrap's responsive design enabled the web application to be used across heterogeneous devices (PC desktop/tablet/mobile phone). Controls were created to allow clinicians to intuitively build queries to search the database. The SELECT fields and a dynamic table control for the WHERE criteria were developed. WHERE criteria were specified in a new table row and consisted of drop down controls and text boxes to speed up data entry. A Run Query button enabled query execution and returned the result-set (diagnoses) in a drop down control. Additional ECG details were displayed in HTML tables consisting of features, causes and background information together with an example ECG image for suggested diagnoses. Results: Queries were easily created and diagnoses were promptly returned within milliseconds. Choosing a diagnosis returned further details within milliseconds that assisted in speeding up the decision making. Conclusion: Modern web development and database technologies provided a user-friendly means of querying an ECG database to assist in the diagnostic decision making process. No SQL knowledge is required by the clinician to build and execute the query. The web application was successful across a number of devices and operated within acceptable response times which has the potential to expedite and improve the decision making process.

Tuesday, September 13, 2016 **12:30**

P62 **ECG**

Room: Pinnacle I

110-136 **Optimization of Organ Conductivity for the Forward Problem of Electrocardiography**

Laura Bear*, Remi Dubois and Nejib Zemzemi

Aims: The relationship defined between epicardial and torso potentials is fundamental to the inverse problem, and is influenced by the organ conductivities within. Here we present a proof of concept for an empirical approach to define these conductivities. Methods: Epicardial potentials were recorded in a closed-chest pig during ventricular pacing. Post-mortem MRI were used to localize electrodes and construct a finite element model, including lungs (l), fat (f), skeletal muscle (m) and cavity (c) volumes. Torso potentials (UT) at 180 “electrodes” were computed from the measured epicardial potentials using conductivities σl=0.05, σf=0.04, σm=0.40, σc=0.22 mSmm-1. For the optimization problem, torso potentials were computed using initial conductivities of σl=σm=σc=0.3 mSmm-1, while σf was kept constant. Optimal conductivities were estimated by minimizing the relative error (RE) between forward computed potentials and UT using a standard gradient-based approach. The gradient of the cost function was approximated using 1) finite differences over electrodes (GradFD), and 2) an adjoint method over mesh nodes (Gradadj). Sensitivity of optimizing conductivities was tested by varying levels of torso electrode location error and Gaussian noise on UT. Results: All conductivities were accurately estimated (<10% difference in value) with up to 1.28 and 0.64cm electrode error and for up to 0.51 and 0.02uV noise for GradFD and Gradadj respectively. RE increased linearly with increasing electrode error (R2=0.964,0.989) and signal noise (R2=0.997,0.993) for GradFD and Gradadj respectively, with little difference (0-5%) between the methods. Gradadj took <20 iterations for all error levels, while GradFD took 70-90 iterations. Conclusion: Given experimental data with simultaneous epicardial and torso recordings, conductivity within the torso could be accurately estimated. While Gradadj is more computationally efficient, the GradFD is more robust to any noise in the data. Optimizing conductivities would provide not only a more accurate forward model, but also potentially more robust inverse solutions.

111-200 **Detection of Incomplete Left Bundle Branch Block by Noninvasive Electrocardiographic Imaging**

Laura Bear*, Ruben Coronel, Peter Huntjens, Olivier Bernus, Corentin Dallet, Richard Walton and Remi Dubois

Aims: While complete left bundle branch block (LBBB) can be easily identified in a 12-lead ECG, incomplete LBBB often goes undetected. Non-invasive electrocardiographic imaging (ECGi) may support diagnosis in these cases. This study sought to use a novel ex-vivo porcine model of incomplete LBBB in an experimental torso-tank set up to evaluate ECGi for LBBB detection. Methods: LBBB was induced in Langendorff-perfused pig hearts by radio frequency ablation (n=3) or ligation (n=3) of parts of the left bundle branch. A flexible electrode sock was placed over the epicardium to record 108 electrograms. The level of electrical dyssynchrony was compared to baseline recordings using: 1) The total duration of activation (TAT) and 2) the ventricular electrical uncoupling (VEU), that is the mean LVAT minus the mean RVAT. Five of the hearts were suspended in the human anatomical position in a man-shaped torso-tank filled with Tyrode's solution and fitted with 256 surface electrodes. Epicardial and surface potentials were recorded during sinus rhythm. Post-experiment MRI provided the epicardial geometry and electrode (epicardial and surface) locations. Epicardial electrograms were calculated using the method o fundamental solutions and Tikhonov regularization, and the derived reconstructed values for electrical dysynchrony were compared to those obtained directly from recorded electrograms. Results: Ablation established complete LBBB in one heart (VEUpre-ablation=0 ms,VEUpost-ablation=49 ms with a 47 ms increase in TAT), was ineffective in 2 (VEUpost-ablation=-3,8 ms). Incomplete LBBB was accomplished in the remaining 3 hearts (VEUpost-ligation=21-24 ms, 7 34 ms increase in TAT). ECGi correctly identified the presence/absence of dyssynchronous activity in 4/5 cases analyzed. Overall, there was nc significant difference in VEU (R2=0.86,p=0.42), or TAT values (R2=0.53,p=0.08) between calculated and measured electrograms. Conclusion: ECGi reliably identifies dyssynchronous activation including incomplete LBBB, also without increased TAT. Our results are relevant for fine tuning of resynchronization therapy.

112-190 **Reduced QT Variability and increased QT/RR slope in ECG signals of Depressed Patients with Suicidal Ideation**

Ahsan Khandoker*, Veena Luthra, Yousef Abouallaban, Muhammac Hasan, Nayeefa Chowdhury and Herbert Jelinek

Major depressive disorder (MDD) is associated with a number of comorbidities including cardiovascular disease (CVD), with an increased risk of death after myocardial infarction. Globally, suicidal behaviour is the third most common cause of death among depressed patients (fifteen precent of depressed patients die by suicide). However, its biological understandings of the phenomena remain ill-defined. The aim of this study was to investigate if parameters for ventricular repolarization variability and dynamics in ECG signals are different in MDD patients with/without suicidal ideation and healthy volunteers. Sixty-one ECG recordings (10 minutes) were acquired and analysed from control subjects (44 CONT), 20 MDD subjects with (MDDSI+) and 21 without suicidal ideation [SI] (MDDSI-) for a case-control analysis at a psychiatric clinic in the UAE. Diagnoses of MDD were made by the Mini-International Neuropsychiatric Interview (MINI) and the severity was assessed using the Hamilton Depression Rating Scale (HAM-D). The subscale for SI consists of 19 items, which was used to evaluate the patients' suicidal intensions [0 to 38]. Then heart rate-corrected QT interval (QTc) (by following the Bazett's formula), QT/RR slope [from QT = α[RR] + β; where α is the slope and | is the y-intercept], QT variability (QTV) [from standard deviation of QT intervals], QT variability index (QTVI) [by using QTVI = ⟦log⟧_10 [⟦QT⟧_v/⟦QT⟧_m^2)/(⟦RR⟧_v/⟦RR⟧_m^ ^2)], Median T wave amplitudes and Twave variability [from standard deviation of T-wave amplitude]. Results are summarized in Table 1. MDD patients with suicidal ideation displayed increased QT/RR slope and reduced QT variability, which may reflect abnormal ventricular repolarization liability and lead to higher risk of cardiac arrhythmia and future cardiovascular diseases. These findings could assist in identifying patients with suicidal ideation in order to provide effective treatment by restoring ventricular repolarization dynamics of MDD patients with suicidal ideation and decrease risk of fatal arhythmia.

113-151 **Respiratory Rate Estimation from Multilead ECG Delineation using VCG Directions on Fiducial Points**

Maikel Noriega, Ennis Carcases, K Duran, Enrique Marañón, Juan Pablo Martínez* and Rute Almeida

Introduction: Estimating the instantaneous respiratory rate (Rr) from the electrocardiogram (ECG) is of interest as respiration direct measurement in clinical situations is often cumbersome. Several studies have developed signal processing techniques to extract respiratory information from the modulation of the ECG morphology. However, the single lead R-peak amplitudes (RPA) was shown not to yield accurate Rr estimates, which is in part because the suitability of a given ECG lead to represent the respiratory influence is subject dependent. For this reason, the Rr estimation from ECG with multi lead algorithm becomes more important. Methods: In this study, the Rr was estimated from the beat-to-beat series of "Final Directions" (FD) obtained in a previously proposed multilead ECG delineator. Those FD are obtained as those presenting maximal projection of the wavelet-transform loop for QRS complex main peak (Rp), T wave peak (Tp) and T wave end (Te). The series are subject to power espectral analysis to estimate Rr. To validate the proposed algorithm, a control database (40 subjects, 12 leads) recorded at University of Zaragoza was considered. The Frank leads were synthesized using the inverse Dower transformation. Additionally, Rr was estimated from the single lead RPA series. Results: The average of mean absolute error (MAE) across files in terms of breaths-per-minute was 2.99, 3.03 and 3.01 for estimates from the FD series of QRS complex main peak and T wave peak and end, respectively. The average MAE of single lead RPA estimates was between 3.30 bpm (lead V4) and 5.22 bpm (lead aVF). Conclusions: The proposed strategy based final direction of maximum projection outperform the best results obtained from the single lead RPA series, representing an alternative for Rr estimation. Additionally, the beat-to-beat estimation of Rr can be obtained as an extra output of multilead delineation with almost no extra effort.

114-226 **Comparison of Four Recovery Algorithms Used in Compressed Sensing for ECG Signal Processing**

Zhimin Zhang*, Shoushui Wei, Dingwen Wei, Liping Li, Feng Liu and Chengyu Liu

Background: Compressed Sensing (CS) has been widely used for ECG signal processing with the rapid development of real-time dynamic ECG applications. Reconstruction process is essential in CS and many recovery algorithms were reported in the last decades. However, the comparative study for the performances of different recovery algorithms for CS-based ECG signal processing lacks, especially for the real-time applications. This study aimed to investigate these issues and provide useful information. Methods: Thirty-six 10-s ECG recordings from MIT-BIH Normal Sinus Rhythm Database were used for the CS analysis. All ECG data were firstly compressed using a Gaussian random matrix and then were reconstructed by four typical recovery algorithms, i.e., compressed sampling matching pursuit (CSMP), orthogonal matching pursuit (OMP), expectation-maximum-based block sparse Bayesian learning (BSBL_EM) and bound-optimization-based block sparse Bayesian learning (BSBL_BO). The evaluation criterion for a successful recovery was that the percentage of root-mean-square difference (PRD) was less than 9%. PRD, as well as compression ratio (CR) and reconstructing time (RT), were calculated. Each recovery algorithm was executed for 100 times for each recording, for the purpose of removing the influence of random factor in the compression matrix. Results: The results of evaluation indices for CSMP method were PRD=8.02%, CR=69.44% and RT=8.7 s, for OMP methods were PRD=8.99%, CR=57.78% and RT=2.2 s, for BSBL_EM method were PRD=8.75%, CR=41.11% and RT=1.3 s, and for BSBL_BO method were PRD=8.41%, CR=31.11% and RT=1.5 s. Conclusion: With the setting of PRD<9%, among the four recovery algorithms, BSBL_BO method had the best compression ratio while BSBL_EM achieved the shortest reconstructing time. By contrast, CSMP method had the worst compression ratio. Meanwhile, the long running time of 8.7 s in CSMP for 10-s ECG analysis indicated that it was not suitable for real-time applications.

115-295 **Myocardial Ischemia Events Detection based on Support Vector Machines using QRS and ST Features**

Rudys Magrans, Pedro Gomis* and Pere Caminal

Introduction: ST-segment deviation and QRS-derived indices have been individually used to detect acute myocardial ischemia. The aim o this study was developing a nonlinear (Gaussian kernel) support vecto machine (SVM) model to detect ischemic events based on a dataset o QRS-derived and ST indices from non-ischemic and acute ischemic episodes. Methods: Sixty-seven patients who underwent elective percutaneous coronary intervention (PCI) with balloon inflation periods of mean 4.7 minutes were studied. Twelve lead continuous ECG before and during PCI were obtained and signal-averaged. Fifty-four indices were initially considered from each episode. The dataset was randomly divided into training (80%) and testing (20%) subsets. A pre-filtering stage was applied on the training subset to select only statistically significant changing indices between both episodes. Then the training subset was used to optimize the SVM parameters algorithm and for determining the most important statistically significant indices, by using k-fold cross-validation (k=5). Cross-validation procedure was repeated 25 times to quantify the variation of predictions from different splits of the subset on training. The final model was constructed using the total training subset for optimal combination of parameters and indices, and assessed by means of the testing subset. The whole procedure was run on 25 randomized training/testing subsets to assess the average performance. Results: On average, the most important indices were the QRS-vector difference and the ST segment level at J-point + 60 ms computed from the synthesized vector magnitude, and the summed high-frequency QRS components of all 12 leads at 150 – 250 Hz band. The performance of testing was: classification error = 12.5(8.3-16.7)%, sensibility = 83.3(75.0-91.7)%, specificity = 91.7(83.3-91.7)%, positive predictive value = 90.9(83.0-92.3)% and negative predictive value = 85.7(80.0-91.7)%. Conclusions: The method used to construct the SVM model is robust enough and looks promising in detecting acute myocardial ischemia and myocardial infarction risk.

116-423 **Response of Ventricular Repolarization Parameters to Preload Changes in Isolated Working Heart**

Jakub Hejc*, Oto Janousek, Marina Ronzhina, Tibor Stracina, Veronika Olejnickova, Jana Kolarova and Marie Novakova

Aim: Heart rate dependency of ventricular repolarization (VR) parameters is well known phenomenon since many years ago. Other factors that can contribute to VR regulation are still under investigation. One of possible control mechanism is so-called mechanc electric coupling; electrophysiology changes induced by mechanical stretch. We investigate step response of VR parameters to abrupt changes in mechanical end-diastolic load. Methods: Ten New Zealand white rabbit hearts were isolated and perfused in working heart mode Each heart was kept at constant heart rate by permanent left atrial pacing. Changes in preload were induced by abrupt increase in perfusion apparatus water column level in range of 8–11 cmH2O within step of 1, 2 and 3 cmH2O. Electrical activity was recorded at sampling frequency 10 kHz by seven non-contact unipolar leads equally positioned around left ventricle in range of angles from 0° to 180°. To obtain global view on ventricular repolarization, singular value decomposition was used to reconstruct one global lead in which four VR parameters (QT, QTPeak, RT and RTPeak) were detected by custom made algorithm. Results: Response of VR parameters to mechanical load is highly subject specific including non-responders or non-detectable changes due to low rate of increase in preload or signal to noise ratio of delineated intervals. On this account, RT and RTPeak are less sensitive to delineation errors and thus more reliable for an analysis. In responding subjects, step response of VR parameters has three different phases: (1) gradual prolongation up to 2–5 ms; (2) temporarily stable state and (3) slow adaptation back to baseline value. Total time of the process reaches up to 40–50 seconds

117-442 **Dynamic Coupling Between Ventricular Repolarization Duration and RR-Interval Phase-Rectification Analysis in Chagas Disease**

Paulo Roberto Benchimol-Barbosa*, Olivassé Nasario-Junior, Jurandir Nadal and Roberto Coury Pedrosa

Dynamic ventricular repolarization duration (VRD) vs. RR-interval coupling relates to tachyarrhythmia vulnerability, particularly in chronic Chagas dis-ease (ChD). Phase-rectification of RR-interval series separates acceleration (AC) and deceleration (DC) phases (Figure 1), reflecting sympathetic and parasympathetic influences on heart rate, respectively. This study investigat-ed VRD and phase-rectification-driven RR-interval coupling to assess dy-namic repolarization adaptation in healthy and chronic ChD subjects. Healthy sedentary (Control, n=11) and ChD (n=11) groups were studied. All were in sinus rhythm and underwent 60 min head-up tilt table test. ChD group were submitted to MIBG scintigraphy to assess cardiac sympathetic innervation. Histogram of RR-interval series was calculated, with 100 ms class, ranging from 600 ms to 1200 ms. For each class, mean of normal RR-intervals (MRR) and mean of the peak-to-peak R-to-T wave interval (MRT), representing VRD, were calculated and analyzed in the whole series (T), and in DC and AC phases. Linear regression model of MRT vs. MRR were com-puted for each group, and respective slopes calculated (sMRT-T, sMRT-DC and sMRT-AC). Correlation coefficients were tested before analysis, and Student t-test compared groups ($\alpha<0.05$). MRT-T, MRT-AC and MRT-DC significantly increased as a function of MRR in all groups, and slopes were significantly different between groups in phase-matched comparisons (Table 1). All ChD subjects presented reduced cardiac MIBG uptake. In a linear model of VRD RR-interval coupling, average RT-interval increases as a function of RR-interval, in both ChD and healthy subjects during tilt-table test. However, in ChD subjects showing sympathetic denervation, average RT-interval is long-er and exhibited a flatter slope in a linear RR-interval coupling model. Table 1 – Slopes of MRT vs. MRR regression lines and intervals duration per group (mean ± SD): Group sMRT-T sMRT-DC sMRT-AC MRR(ms) MRT(ms) Control 0.156±0.005* 0.161±0.007* 0.158±0.005* 806±72.4 265±11.6 ChD 0.115±0.009* 0.110±0.010* 0.132±0.002* 906±51.6 273±10.6 *p<0.05 intergroup comparison

118-278 **Automatic Detection of the Wolff-Parkinson-White (WPW) Syndrome from Electrocardiograms (ECGs)**

Hassan Adam MAHAMAT*, Sabir Jacquir, Cliff Khalil, Gabriel Laurent and Stéphane Binczak

The Wolff-Parkinson-White (WPW) syndrome is a cardiac conduction trouble associated with reentry tachycardia and may even be responsible for sudden cardiac death. This congenital abnormality corresponds to a “short circuit” between atria and ventricles due to the presence of an accessory pathway (AP). In Europe, the prevalence of the WPW syndrome is about 0.15 to 0.31%, it is the second most common cause of paroxysmal supraventricular tachycardia. When patent, the WPW syndrome can be diagnosed on a 12-lead standard ECG as it usually produces a PR interval, a prolonged QRS duration due to the presence of a so called delta wave. Aside from medical anti-arrhythmic drugs, the main treatment is based on the physical eradication of the AP by applying radiofrequency energy with a dedicated lead on its precise location by endovascular techniques. To date its precise location around tricuspid or mitral annulus is based on non-practical algorithms that have been published over the years. Those methods are mainly based on the identification of delta wave morphologies on 12 lead-ECGs. We have developed a completely new method based on the whole complex QRS morphology analysis as opposed to previous algorithms based on delta wave patterns only. Therefore we have used the continuous wavelet transform, the detection of P waves, QRS complexes and T waves. Duration of those waves has been computed after determination of the boundary location (onset and offset of the P, QRS and T waves). Based on the whole QRS complex upstroke and morphology the analysis has been performed on 12 lead-ECGs of patients who have been efficiently treated by endovascular techniques. This new automated algorithm has been tested on the physionet Ptbdb database in order to confirm its robustness. This method should help physicians in their daily clinical practice.

119-391 **Classification of Multiform Ventricular Extrasystole Using Morphology Match over the Reconstructed Phase Space of Electrocardiogram**

Hsiao-Lung Chan*, Chun-Li Wang, Shih-Chin Fang and Yi-Sheng Lee

Ectopic electrical activity in the ventricle usually causes an extrasystole, typically as a premature ventricular contraction (PVC). The presence of multiform PVC reflects complex electrocardiographic abnormality. Patients with multiform PVC were shown to have a higher incidence of adverse event than patients with uniform PVC. In addition, the mortality rate in the multiform group was also higher compared to the uniform group. Therefore, characterization of multiform PVC is beneficial for prognosis of cardiovascular disease whereas classification of multiform PVC is an essential procedure for the characterization. Here, we propose a new morphology matching o heartbeats over the reconstructed 3-dimensional phase space from single-lead electrocardiogram. A similarity measure, the spatial correlation (SC) is defined as the incident rate of phase space trajectories on the divided M×M×M cube. Another dissimilarity measure, the mutual nearest point distance (MNPD) is obtained by calculating point-to-nearest-point distances between two phase space trajectories. An unsupervised heartbeat classification is developed based on cluster separation and cluster merging using similarity or dissimilarity measure. The assessment based on the MIT/BIH arrhythmia database demonstrated the classification based on MNPD had higher accuracies in distinguishing PVC from normal heartbeats and separating PVC with different morphology compared to that based on the SC.

120-281 **Auto-Cropping of Phone Camera Color Images to Segment Cardiac Signals in ECG Printouts**

Fernando Lozano-Fernández*, Inmaculada Mora-Jiménez, Margarita Sanromán-Junquera, Sergio Muñoz-Romero, Arcadio García-Alberola and Jose Luis Rojo-Alvarez

Digital analysis of the bio-electrical signals allows us to obtain valuable information for clinical and research purposes. Despite current devices record and store the digital signal, in some cases only a printout version is available. Previous scientific research has proposed algorithms to digitize the printed signal from a scanned image. Nowadays, it is possible to obtain an image of the printouts by just taking a color photograph with the digital camera of a cell phone. Most of the current algorithms to digitize the signals start from images containing just one signal, which is manually selected. We propose a procedure to automatically crop the image as many sub-images as signals in the printout. Then, different signal extraction methods available in the literature can be used to digitize every individual signal. We particularize our procedure for ECG printouts. A preprocessing stage is required to correct the perspective and prepare the image for the auto-cropping procedure. After perspective correction, chromatic components are extracted in the YCbCr color space. The Cr component is selected for red grids. For other colored grids, a new image is obtained from the relative color difference. This image, I, mainly contains the grid. The grayscale image, G, and I are both processed with morphological operators to emphasize both signal and grid in G, and grid in I. Both images are subtracted and the horizontal projection is computed. Boundaries among contiguous signals are found by applying morphological operators such as closing, reconstruction and maxima extinction filters to the projection. These boundaries are used to obtain the sub-image associated to each signal. Thirty phone camera color images of continuous and discontinuous grid ECG printouts were used for evaluation. Images were taken from a distance of 15cm to cover 3 leads. Our procedure worked correctly when consecutive lead sub-images were not overlapped.

121-290 **Do we need to enforce the homogeneous Neumann condition on the torso for solving the inverse electrographic problem?**

Judit Chamorro-Servent*, Laura Bear, Josselin Duchateau, Mark Potse, Remi Dubois and Yves Coudière

INTRODUCTION: Robust representation of the forward problem of non-invasive electrocardiographic imaging (ECGI) may require accurate specification of boundary conditions at the torso and cardiac surfaces. In the method of fundamental solutions (MFS), the potentials are expressed as a linear combination of fundamental solutions of Laplace’s equation over a discrete set of virtual sources placed outside the domain of interest. An objective function allows the determination of the solution that better approximates the Dirichlet and homogeneous Neumann conditions (HNC) at the torso surface. HNC requires accurate computation of normal directions at torso electrodes positions and Laplace fundamental solution derivatives. However, we hypothesize that these derivatives at torso locations are inherently close to zero, and the cost and difficulty to compute HNC is negligible. METHODS: First, for a simulated data set built with complex three-dimensional models of propagation of electrical activity, we studied the effect of weighting the MFS objective function in consideration of the Dirichlet and Neumann conditions respectively, and compared it to standard MFS (where both conditions are equally weighted). Afterwards, we reconstructed epicardial potentials for five activation sequences, using the standard MFS and the MFS without HNC (both by zero-order Tikhonov and CRESO regularization parameter). Finally, we compared the electrograms and activation times to the reference epicardial signals. RESULTS: A small ratio between the norms of the HNC part of the MFS matrix and its respective Dirichlet part was found (~10-2-10-3), indicating the negligibility of the HNC. Reconstructed electrograms not including HNC had significantly higher CCs ($p<0.0001$), and lower REs ($p<0.0001$) than including them. Activation times not including HNC results showed CCs ~0.002 to 0.004 greater ($p<0.001$), and RE values 1.6-1.9% lower ($p<0.0001$). CONCLUSION: We provide results showing the negligibility of HNC for the MFS problem. This finding reduces the computational burden to solve the forward and inverse problem.

122-223 Empirical Mode Decomposition Template Matched Filter for Detection and Estimation of T-Wave Alternans

Asim Bakhshi, Muhammad Latif, Sajid Bashir and Hafiz Munsub Ali*

Introduction: T-wave alternans (TWA) is a well recognized marker for sudden cardiac death. It involves beat-to-beat periodic variations in amplitude of ECG ST-T complexes, showing stationary as well as non-stationary temporal characteristics. TWA analysis becomes a challenge under the presence of process noises, transient outliers and physiological artifacts. Targeting detection of distributed alternant energy rather than peak amplitude, we propose a template matched filter based detection theoretic approach (EMF). Empirical Mode Decomposition (EMD) is used for alternant waveform trend estimation to construct the matched-filter template. Unlike classical implementations in a similar context, the varying nature of the constructed template better estimates the non-stationary and transient TWA episodes. Methods: After QRS and T-wave delineation, even and odd ST-T complexes are segregated. For each even-odd pair, the difference being the alternant waveform is matched against a corresponding dynamically generated template through decomposition into intrinsic mode functions and subsequent reconstruction. Finite impulse response implementation of the classical energy detector maximizes SNR at the output, providing the required energy estimate. Generalized likelihood ratio decision statistic, obtained using receiver operating characteristics curves, is used for TWA detection test. Results: Proposed detector outperforms correlation method (CM) and static median template based matched filter for complete range of SNR (-15 to 30 dB) and all noise types. Attained performance is also comparable to spectral method (SM) and its EMD based improvement (EMD-SM) for electrode and motion artifacts. Estimation bias of EMF approaches that of SM for SNR ≥ 20 dB and remains better than MMAM throughout. Observed relative bias of EMF approaches SM for alternans magnitude > 20 µV with both real noise types. Efficacy of EMF is vindicated for dynamic TWA tracking where it is compared against other detectors under variety of TWA episodes.

123-394 **Is There Any Association Between Ventricular Ectopy and Falls in Community-dwelling Older Adults?**

Saman Parvaneh*, Bijan Najafi, Nima Toosizadeh, Irbaz Bin Riaz and Jane Mohler

Background: Falls are common in older adults, one in three older adults age 65 years and older falls every year. Over 700,000 US patients a year are hospitalized after a fall, most often due to a head injury or hip fracture. Dizziness is one of factors that is associated with higher risk of falling. Frequent ventricular ectopic (Premature Ventricular Contraction, PVC) beats can cause dizziness due to the reduced ability of the heart to pump blood in systemic circulation. Therefore, the main goal of this study was to study the prevalence of PVC in community-dwelling older adults with, and without, history of falling. Method: A four hour uni-channel ECG was recorded using an FDA-approved wearable-sensor in 45 elders aged 65 and above. Participants were categorized as non-fallers (n=22) and fallers (n=23) based on historical report of falling in the last 12 month. The number of self-reported falls ranged from zero and six. For data analysis, PVC beats were extracted using a Matlab code, and reviewed by an expert to ensure accuracy. Number of PVCs per hour was extracted as the parameter of interest in this study and compared between fallers and non-fallers using independent sample t-test with p= 0.05 as statistically significant level. Results: Number of PVC beats was not significantly different (p>0.05) between non-fallers (41.65±74.22) and fallers (43.62±59.48). When the number of PVCs was compared between non-fallers and fallers with just one fall an increasing trend in prevalence of PVC was observed (non-fallers: n=22, PVC=(41.65±74.22); fallers with one fall: n=13, PVC=63.15±73.69). Discussion: In this study, no relationship between prevalence of PVC and falls was found. A high standard deviation in PVC was observed in the studied population, and may be associated with the wide diversity of participants.

124-512 **Classification Methodology of CVD with Localized Features Analysis Using Phase Space Reconstruction Targeting Personalized Remote Health Monitoring**

Naresh Vemishetty, Amit Acharyya, Saptarshi Das, Shivteja Ayyagari, Soumya Jana*, Koushik Maharatna and Paolo Emilio Puddu

According to the survey conducted by WHO, CVDs are the primary drivers for the high mortality rate all over the world among all the non communicable diseases. To detect, monitor and diagnose CVD remotely in personalized manner, affordable and reliable devices for remote health care monitoring devices need to be developed that would classify even the minute abnormalities of the heart apriori. Accounting this, we propose here a real-time CVD classification methodology based on the localized features analysis of individual ECG-PQRST complexes using Phase Space Reconstruction (PSR) technique. Recently, PSR technique has shown prospect of offline-detection of Ventricular Arrhythmias when analyzed statistically on large dataset of many samples. However, the existing PSR technique works on several stored PQRST complexes,the classification of CVD would not be accurate in fragmented QRS complexes or ECG in absent of P wave or any small desynchronization in the individual ECG beats due to missing of some important and interesting diagnostic features. Therefore the proposed classification methodology uses the localized features (QRS interval,PR interval) of individual ECG beats from our already proposed Feature Extraction (FE) block(Fig.1) and detect the desynchronization in the given intervals after applying the PSR technique. Considering the QRS interval, if any notch is present in the QRS complex, then the corresponding contour(Fig.2) will be appear and give the variation in the box count indicating a notch in the QRS complex. Likewise, the contour and the disparity of box count due to the variation in the PR and ST interval localized wave have been noticed using the proposed PSR technique. MIT-BIH and PTBDB database has been used to verify the proposed CVD methodology on various abnormalities like fragmented QRS complexes,myocardial infarction, Hyperkalemia and atrial fibrillation. The design have been successfully tested for diagnosing various disorders with 98% accuracy on all the specified abnormal databases.

125-116 **Adaptive Modulation Spectral Filtering for Improved Electrocardiogram Quality Enhancement**

Diana Tobon* and Tiago Falk

Advances in wearable electrocardiogram (ECG) monitoring devices ha: allowed for new cardiovascular applications to emerge beyond diagnostics, such as stress detection, sleep disorder characterization, mood recognition, activity surveillance, or fitness monitoring, to name a few. Such devices, however, are prone to artifacts, particularly due to movement, thus rendering heart rate and heart rate variability metrics useless. To address this issue, this paper proposes a new ECG quality enhancement algorithm based on filtering in the so-called spectro-temporal domain. That domain characterizes the rate-of-change of ECG spectral components, which differ from artifacts components. Our experiments show that this new signal representation accurately separates ECG signal and noise components thus allowing for adaptive filtering to improve signal quality even in extremely noisy settings. For testing, we used synthetic signals with heart rates between 50 and 180 bpm to cover tachycardia, bradycardia, and different activity levels such as sitting, walking, and running. Also, low frequency to high frequency ratio was randomly sampled between 0.5 and 8.9 to cover light-to-deep sleep, wakefulness, myocardial infarction, and rapid eye movement. The synthetic signals were contaminated with artifacts taken from MIT-BIH Noise Stress Test Database at five different signal-to-noise (SNR) levels (i.e., -10, -8, -5, 0, and 5 dB). Experimental results show the proposed algorithm outperforming a state-of-the-art wavelet-based enhancement algorithm in terms of SNR ratio improvement, as well as ECG kurtosis. We found an average SNR improvement for noisier signals of 9 dB compared to 4 dB with the benchmark. Further, an average kurtosis increase over the noisy signal of 4 was obtained, thus outperforming the subtle increase of 0.1 obtained with the benchmark. These findings suggest that the proposed algorithm can be used to enhance the quality of wearable ECG monitors even in extreme conditions, thus can play a key role in athletic peak performance training/monitoring.

126-255 **Automatic Location of Sources of Electrical Activation from Electroanatomical Maps**

Fernando Barber, Miguel Lozano, Ignacio Garcia-Fernandez and Rafael Sebastian*

Motivation: The activation of the myocardial muscle is triggered by Purkinje-myocardial junctions (PMJs), which are the terminal sites of the specialised cardiac conduction system (CCS). The CCS coordinates and dictates the sequence of activation in the ventricles, and can be interfered by ectopic activity or late activated areas triggered by slow conduction channels. Obtaining the location of the PMJs and other sources of endocardial ectopic activity would be desirable for build computer models of cardiac electrophysiology and planning ablation interventions. Aims: This study aims to estimate the location and activation time of all relevant endocardial sources of electrical activity from a discrete set of endocardial measurements obtained by an electro-anatomical mapping system (EPM). Given the proportion of EPM samples versus trigger points the system will locate trigger points with an error in the order millimetres. Methods: From the set of EPM samples (location and time) a Delaunay triangulation is used to create an annotated mesh. Considering a constant circular propagation velocity on myocardial tissue a solver is used to determine the theoretical source of activation of each triangle. After processing all the triangles, the sources that activate at least two tringles are considered true sources. The residual triangles point out areas whose source cannot be determined due to low mapping density. Synthetic CCS with different branching pattern and PMJ density were built (see figure 1, left) to generate activation maps. Results: Activation maps were sampled at random locations (see crosses in Figure 1, right) with increasing density to evaluate the number of real sources detected. The percentage of sources recovered depended their area of influence and inter-spacing, since in clustered configurations (figure 1, left C) sensed locations inside the cluster were too few. When right spacing and proportion of sources/sensors was reached, the exact location of PMJs was obtained.

127-482 **Study of New Criteria Based on Eigenvalue Decomposition to Assist Arrhythmogenic Cardiomyopathy Diagnosis**

Santiago Jiménez-Serrano, Jorge Sanz Sánchez, Antonio Cebrián, Begoña Igual, Raquel Cervigón, Jose Millet*, Esther Zorio and Francisco Castells

Arrhythmogenic Cardiomyopathy (ACM) is a heritable cardiac disease, characterized by fibro-fatty infiltration of the ventricular myocardium, being a main cause of sudden cardiac death in young people. Its clinical diagnosis includes major and minor criteria based on alterations of the surface electrocardiogram (ECG). On the other hand Principal Component Analysis (PCA) has been used successfully in ECG Signal Processing in different applications. The aim of this study is to propose and evaluate new criteria based on PCA applied to 12-lead ECG signals and find differences between individuals affected and unaffected by ACM. Datasets consists of 12-lead ECG recordings from 34 patients diagnosed with ACM, and 37 relatives of those affected, but without gene mutation. In order to reduce high frequency noise and baseline wandering, signals were pass-band filtered between 1Hz and 45Hz. We extracted 8 eigenvalues from each recording. First proposed criteria (C1) represents the percentage of energy of eigenvalues in not-dipolar components. Second proposed criteria (C2) represents the level of energy contained at the third eigenvalue respect the first and second one. Results show that the most significant indicator was C1, with values of 0.025 ± 0.015 in ACM patients and 0.014 ± 0.009 in not affected by ACM individuals (p <10e-3). Second criteria C2, contains values of 0.049 ± 0.035 and 0.028 ± 0.023 (p <10e-2) in the same groups. The results of this study show significant differences in the indicators proposed between the group affected by ACM and the control group, indicating that the degree of information contained in the not-dipolar leads is higher in the first group. Besides, the level of information contained at the third dimension is also higher in the ACM group. All this suggest more heterogeneity of the electrical activation in patients with ACM.

128-529 **Comparison of General Purpose ECG Analyzers in Patients Implanted with a CRT Device.**

Jaime Yagüe-Mayans, Santiago Jiménez-Serrano, Pau Alonso Fernandez, Raquel Cervigón, Conrado J. Calvo, Francisco Castells, Joaquin Osca Asensi and Jose Millet*

The literature proposes numerous algorithms for automatic QRS boundary detection that have proven to perform well with common ECG databases (QT, MIT-BHI arrhythmia database...). In this study we tested two of such algorithms, one based on empirical mode decomposition (EMD) and one relying on curve length transform (CLT) against a database formed by registers from patients implanted with a CRT device. The aim was to determine if general purpose algorithms were still useful in scenarios where QRS morphology is altered and in the presence of stimulation artefacts. The database contained 22 12-lead ECG, half of them with the device switched off and half with the device switched on. QRS complexes were automatically detected and QRS patterns for each register and lead were obtained through coherent averaging. The algorithms were applied to these patterns, which were also manually annotated by a clinician to serve as reference. Both methods failed to accurately determine QRS duration tending to overestimate it. QRS duration estimated by both methods showed significant differences ($p<0.05$) respect to the expert annotations, with an average error of 15.64±17.9ms in the case of the EMD based method and 27.56±15.32 ms with the CLT based one. No significant differences were observed in the performance of the methods between stimulated and non-stimulated registers or between the different leads ($p>0.05$). Results indicate that general purpose algorithms are not suitable for more specific situations, especially if aberrant or unusual QRS morphologies are present as in the case of studies involving CRT devices, where slow dynamics in the late QRS and the presence of the stimuli were identified as the main sources of error. In those cases, ad-hoc algorithms development or supervised annotation are still required.

129-408 **Serial ECG Analysis after Myocardial Infarction: When Heart Failure Develops, the ECG Becomes Increasingly Discordant**

Marjolein C. De Jongh, Arie C. Maan, Enno T. Van der Velde and Cees A. Swenne*

Introduction. After myocardial infarction (MI), patients have an increased risk of developing chronic heart failure (HF). Early HF detection/therapy is important to limit HF-induced cardiac remodeling. Here, we address the hypothesis that the ECG of patients with a healed MI without HF becomes less concordant when later HF develops. If true, periodic ECG monitoring of post-infarction patients on concordance could help to early detect emerging HF. Methods. We checked in patients who presented with new HF if they had previously been admitted to our hospital because of acute MI. Patients were selected if they had recovered from their MI without any sign of heart failure. Patients with non-sinus rhythm and patients with a paced rhythm were excluded. In the remaining patients we compared the ECGs made six months after acute MI (“baseline ECG”) with those made at initial presentation with HF (“HF ECG”). ECG were analyzed by our vectorcardiographically-oriented computer program LEADS. The spatial QRS-T angle (SA) was taken as a measure of concordance (the smaller SA, the more concordant the ECG). Results. As a pilot, we studied 12 patients (10/2 male/female, mean±SD age at the time of acute MI 65±10 years, time between acute MI and first HF presentation 4.4±2.5 years). SA in HF ECGs was larger than SA in baseline ECGs (127°±32° vs. 103°±36°, P=0.015). Only 3/12 patients had an SA in the HF ECG that was smaller (10°, 8°, and 1°, respectively) than SA in the baseline ECG. Discussion. Our results show that ECGs of patients with a healed MI presenting for the first time with HF are less concordant than previous reference ECGs. This suggests that SA could be a suitable monitoring variable for early ECG-based detection of HF in the post-MI period. At the conference, results of the entire study population will be presented.

130-174 **A Genetic Algorithm-Neural Network Wrapper Approach for Bundle Branch Block Detection**

Ragheed Allami, Andrew Stranieri, Herbert F Jelinek* and Venki Balasubramanian

A Bundle Branch Block (BBB) is a delay or obstruction along electrical impulse pathways in the heart. The automated detection and classification of BBB is important for prompt, accurate diagnosis and treatment of many heart conditions. This work proposes a new technique for the detection of BBB that uses Genetic Algorithm (GA) ir combination with Artificial Neural Networks (ANN). Nineteen tempora features and three morphological features are extracted for each heart beat and the normalization is performed. A GA guides the searcl for the best subset of features to present to the ANN in order to improve the generalization performance. This wrapper approach compares favourably with a Principal Component Analysis (PCA) – ANN Hybrid method on the MIT-BIH Arrhythmia database. The GA-ANN Hybrid results in sensitivity, specificity and accuracy of 98%, 98% and 99% respectively on the MIT-BIH Arrhythmia database, above that of 55%, 97% and 77% respectively, for the PCA-ANN method. Indeed, results have been illustrated that the performance of the classifier is improved with the help of the optimized features.

131-503 **Multiscale Principal Component Analysis to Predict Atrial Fibrillation Reversion to Sinus Rhythm**

Raquel Cervigón*, Javier Moreno, Francisco Castells and Jose Millet

Introduction: Recent articles dealing with long-term outcomes of catheter ablation in patients with atrial fibrillation (AF) has confirmed the success rates obtained in the short period. This work studies the capability of Multiscale Principal Component Analysis (MSPCA) to extract information to predict recurrence outcome, from intracardiac recordings, which contain contributions from electrical activity whose behaviour changes over time and location, an indicator for recurrence outcome. Methods: Intra-atrial recordings from 41 AF patients were registered previously to an ablation procedure. Four electrodes were located at the right atrium (RA) and four more at the left atrium (LA). In a 3 months follow-up, 26 of them remained in sinus rhythm, whereas the other 19 turned back to AF. MSPCA was applied to different atrial areas. MSPCA computes the PCA of wavelet coefficients at each scale, followed by combining the results at relevant scales. Results: Results showed 5.05±1.29 Hz in non recurrent AF patients vs. 5.92±1.12 Hz the AF recurrent group (p=0.02) for a dipole located in the right atrium, moreover the quality of reconstruction given by the relative mean square errors in percentage of 99.21±2.72 in non-recurrent AF patients vs. 88.01±32.13 in recurrent AF patients (p=0.04). Moreover, electrical activity from dipoles located in both regions showed differences in non-recurrent AF patients, nevertheless in the recurrent AF patients only it was possible to find differences between dipoles of the LA, with a differences of frequencies between two dipoles of the LA of 5.86±1.50 Hz and 5.02±1.74 Hz (p=0.03). Conclusion: High frequency values and not differences in main atrial frequency along the RA may indicate that AF reversion to sinus rhythm is more difficult.

Tuesday, September 13, 2016 **12:30**

P63 **Cardiac Imaging**

Room: Pinnacle I

132-389 **Analysis of Tissue Characterization from Myocardial Lesions, Autonomic Denervation, and Vascular Dysfunction evaluated through MRI and SPECT images**

Gustavo Barizon*, Marcus Vinícius Simões, André Schmidt, Leonardo Gadioli and Luiz Otávio Murta Junior

The relationship between the myocardial tissue damage, microvascular dysfunction and autonomic innervations defects is still poorly understood. This paper addresses imaging methods capable of providing an integrated visualization and evaluation of tissue injuries through MRI, autonomic innervations and myocardial perfusion through SPECT images. Thirteen patients with Chagas disease underwent to MRI (late enhancement) and SPECT (^{123}I-MIBG and ^{99m}Tc-MIBI) exams. We segmented and quantified areas of fibrosis, ischemia and denervation and percentage rates regarding myocardium through image registration and segmentation to establish relations between these tissue injuries. To perform the segmentation of left ventricular myocardium, we used the technique of Geodesic Active Contour. The nonrigid registration was performed based on B-Spline method. From the results obtained of apical, middle and basal short axis, it was verified the correlation between tissue damages. We used the non parametric Spearman correlation test to infer about relationship between different area measurements. We found a moderate correlation between fibrosis and denervation and a moderate correlation between ischemia and fibrosis. Our findings indicates a strong relationship between ischemia and denervation, and suggests a joint mechanism affecting both ischemia and denervation. We can conclude that the developed tool provides an integrated analysis of information, enabling a better understanding of the relationship between tissue damage, perfusion defects and autonomic denervation. Thus, this software can help elucidating relevant information about the underlying mechanism of Chagas disease.

133-396 **Autocorrelation Kernel Support Vector Machines for Doppler Ultrasound M-Mode Images Denoising**

Cristina Soguero-Ruiz*, Alicia Guerrero-Curieses, Francisco Javier Palancar, Javier Bermejo, José Carlos Antoranz and Jose Luis Rojo-Alvarez

Doppler ultrasound M-mode images are routinely used in clinical echocardiography, and their use has been proposed to estimate non-invasively the intracardiac pressure gradients, which has been shown to be sensitive to spline interpolation. In this work, we scrutinized the effect of interpolation with a new support vector machine (SVM) for estimation using autocorrelation Mercer kernel. The SVM algorithm was modified to provide estimation of a whole image in terms of a reduced set of pixels as training data set. The autocorrelation of the Doppler M-mode image was estimated with conventional cross-correlation, and used as Mercer kernel, by considering the total image Several subsampling strategies were scrutinized, namely, a heuristic approach, a uniformly random approach, a criterion based on the amplitude of the absolute gradient and of the absolute laplacian of the image. Also, different combinations of criteria were explored. To evaluate the proposed methods, we analysed a previously proposed Doppler image synthetic model, as well as a real image. Results in terms of mean absolute error showed that the minimum error is obtained when information from the edges is considered, yielding MAE of 7.37 for radial basis function SVM, 2.80 for double sigmoid radial basis function SVM, and 0.80 for autocorrelation kernel. Considering the amplitude, errors increased to 21.79, 3.57 and 0.74, respectively. Independently of the criteria to select the samples, the autocorrelation kernel provided withthe best results. We conclude that utocorrelation kernel provides an accurate estimation of the spatiotemporal distribution of flow velocity within the heart using CDMM images. This methodology can be further exploited for of noninvasive cardiovascular diagnosis.

134-409 **A Left Ventricular Segmentation Method on 3D Echocardiography Using Deep Learning and Snake**

Suyu Dong*, Gongning Luo, Guanxiong Sun, Kuanquan Wang and Henggui Zhang

Background: Segmentation of left ventricular (LV) endocardium from 3D echocardiography (3DE) is important for clinical diagnosis because it not only can provide some clinical indices (e.g. ventricular volume, ejection fraction) but also can be used for the analysis of ventricular anatomic structure. Thus, this challenging task, which has to handle many problems inherent to ultrasound imaging, such as low signal-noise ratio, edge dropout and artifacts, has attracted much attention. In this work, we proposed a new full-automatic method, combining the deep learning and snake, for the segmentation of LV endocardium. Methods: The proposed method consists of three parts: the location of the region of interest (ROI) containing the LV endocardium, the inference of LV initial shape and segmentation. Firstly, the convolutional neural networks are trained to generate a binary cuboid to locate the ROI. And then, using ROI as the input, we train stacked autoencoders to infer the LV initial shape. At last, we adopt snake model initiated by inferred shape to segment the LV endocardium. The inferred shape is a good initialization, as well as the energy constraint item, avoiding the leak or shrink around edge. We use 3DE data from CETUS challenge 2014 for training and testing by following evaluation metrics: segmentation metrics (mean surface distance dM, hausdorff surface distance dH), clinical indexes (the correlation (corr) and bias of end-diastolic volumes (EDV), end-systolic volumes (ESV) , and ejection fractions (EF)). Results: Evaluation metrics are compared with the ground truth (ED: dM=2.20±0.60mm, dH=8.34±2.87mm; ES: dM=2.56±0.92mm, dH=8.46±3.02mm; EDV: corr=0.82, bias=2.3±11.2ml; ESV: corr=0.79, bias=-7.6±10.35ml; EF: corr=0.8, bias=-5.8±6.7ml). Conclusions: The results demonstrated that the proposed method, which combines the deep learning and deformable model, is accurate and boost.

135-495 **Spatial-Frequency Approach to Fibrous Tissue Classification in Intracoronary Optical Images**

Maysa M G Macedo*, Pedro FG Nicz, Carlos M Campos, Pedro A Lemos and Marco Antonio Gutierrez

Aims: Acute coronary syndromes are associated with atherosclerotic plaque rupture, caused by inflammation, thinning and disruption of a fibrous cap covering a lipid pool. However, increased understanding about the mechanisms of coronary thrombosis in humans has been limited by the lack of imaging modalities with resolution sufficient to characterize fibrous cap tissue and determine its thickness in vivo. Intravascular optical coherence tomography (IVOCT) provides images with micrometer axial and lateral resolution (10-15um), enabling detailed visualization of micro-structural changes of the arterial wall. This article describes a fully automated method for identification and quantification of fibrous tissue in IVOCT human coronary images. Methods: For each A-line scan of an IVOCT slice in polar coordinates, the short-time Fourier transform was performed with a Hanning window of size 64 pixels, resulting in a spectrum for each depth. Features were extracted from these spectra such as maximum power and mean frequency. The technique Forward Regression Orthogonalization Least Squares (FROLS) was used to select the set of features that best characterizes the fibrous tissue. Based on this set of features, each pixel was classified and a fibrous tissue contour detected automatically. For each degree of the coronary wall the fibrous cap thickness was measured. A validation was performed by comparing results from automated analysis with an expert manual assessment of fibrous tissue. Results: An evaluation of the proposed method was performed using 40 slices containing different plaque types from 9 in vivo patients. Automated and manual fiber areas were compared, achieving Dice metric 76%, Hausdorff 0.39 mm, RMSE 0.12 mm, Sensitivity 81% and Specificity 98%. Conclusion: The proposed spatial-frequency method is a promising technique for identification of fibrous tissue, and the quantification of fibrous cap thickness represents important information for vulnerable plaque analysis from an OCT dataset.

136-393 **An Approach to New Methods for Digital Processing on Optical Mapping Sequences and Electrical Mapping**

Sergio Muñoz-Romero, Margarita Sanromán-Junquera, Cristina Soguero-Ruíz, Inmaculada Mora-Jiménez*, Raúl Caulier-Cisterna, Javier Moreno-Planas, Jorge García-Quintanilla, Arcadi García-Alberola and Jose Luis Rojo-Alvarez

Optical Mapping (OM) sequences are usually preprocessed with conventional filtering and masks. We addressed the usefulness of other techniques for providing high quality, both itself and when combined with electrical mapping. First, we scrutinized the usefulness of Principal Component Analysis (PCA) for separating signal from noise from different sources. We analized 2 movies from OM during sinus rhythm in Langerdoff conventional procedure in an animal model (guinea pig). A trend was found from the first largest eigenvalues components to convey optical structure and boundary effects. We removed those components whose singular values was smaller than mean +- standard deviation of all the eigenvalues which yielded a roughly estimated normalized signal to noise ratio of 21.9% and 22.0%. Second, we analyzed 5 OM sequences in which a lasso catheter (10 electrodes) was fixed to the heart surface in order to provide with simultaneous optical and electrical recordings. Optical signals were estimated in the same locations as the electrical electrodes, by following these steps: (a) lasso region was manually segmented (for the first frame and then reused), as far as it was shown sensitive to automatic basic segmentation methods; (b) PCA noise cancelation, which can be done before or after the segmentation; (c) signal extrapolation inside the lasso mask, with Gaussian Processes methods (GPatt algorithm). The quality of the extrapolation was validated by reconstructing a known square in the video (instead of the lasso region) and then extrapolating those pixels, and it was sensitive to previous correction of the dynamic range (normalized mean absolute error 0.85% +- 0.37%) or not (2.04%+-0.49%). This way, electrodes positions were located, and signals in the pixels from each electrode were averaged to provide with an estimated optical signal, which could be syncronized with the electrical signals recorded in these points.

137-406 A Deep Learning Network for Right Ventricle Segmentation in Short-Axis MRI

Gongning Luo*, Ran An, Kuanquan Wang, Suyu Dong and Henggui Zhang

Aims: The segmentation of the right ventricular (RV) myocardium on MRI is a prerequisite step for the evaluation of RV structure and function, which is of great importance in the diagnose of most cardiac diseases, such as pulmonary hypertension, congenital heart disease, coronary heart disease, and dysplasia. However, RV segmentation is considered challenging, mainly because of the complex crescent shape of the RV across slices and phases. Hence this study aims to propose a new approach to segment RV endocardium and epicardium method based on deep learning. Methods: The proposed method contains two subtasks: (1) localizing salient regions (SR), the biventricular region which contains more meaningful features and can facilitate the RV segmentation, and (2) segmenting the RV myocardium based on the localization. The two subtasks are integrated into a joint task learning framework, in which each task is solved via two multi-layer convolutional neural networks. The parameters of the two networks are optimized unitedly via back propagation. Additionally, the SR are denoted by the latent variables and trained to contain biventricular region properly. Furthermore, to avoid the ambiguity of objects mask, trainings of segmentation of endocardium and epicardium are independent. The deep learning network was trained and validated on cardiac MRI datasets from MICCAI 2012 right ventricle segmentation challenge including 48 patients (16 train patients and 32 test patients). At last, the proposed method was evaluated by the recognized criterions, including Dice metric (DM), Hausdorff distance (HD), correlation coefficient (R) and mean errors (ME) for end-diastole volumes (EDV), end-systole volumes (ESV) and ejection fraction (EF). Results: The results by comparison with ground truth are as following: Endocardium: DM=0.86±0.09, HD=6.9±2.6mm; Epicardium: DM=0.84±0.13, HD=8.9±5.7mm; EDV: R=0.89, ME=7.1±4.5ml; ESV: R=0.84, ME=9.6±6.7ml; EF: R=0.86, ME=7.5±5.3%. Conclusion: The proposed RV segmentation method based on deep learning has been proved effective and accurate.

138-327 Reconstruction of 3D Dense Cardiac Motion Field from Cine and Tagged Magnetic Resonance Images

Soo Kng Teo*, Sarayu Parimal, Like Gobeawan, Smita Sampath, Chih-Liang Chin and Yi Su

We developed a method to reconstruct 3D dense motion field of the left ventricle (LV) over one cardiac cycle from a fusion of cine and tagged car-diovascular magnetic resonance (CMR) images. The inputs to our methods are (i) a set of short-axis (SA) and long-axis (LA) tagged CMR images of the LV over one cardiac cycle, and (ii) a set of border-delineated cine CMR images of the LV at end-diastole. A hexahedral mesh of the LV myocardium is reconstructed from the border-delineated cine images and used for the dense motion field reconstruction. First, 2D in-plane deformations from both the SA and LA tagged images are computed using the Harmonic Phase (HARP) data analysis tool. These 2D in-plane deformations are then mapped onto the hexahedral mesh to pro-duce a sparse 3D motion field on the mesh as inter-slice deformations are not available. In order to compute the inter-slice deformations, a finite-element method (FEM) model is used. The sparse 3D motion field from SA and LA tagged images is imposed as prescribed boundary conditions in the FEM model, and the unknown inter-slice deformations are solved for each frame in the cardiac cycle. The novelty of our approach is the combination of both sets of in-plane deformations from the SA and LA tagged images, which yields more accu-rate motion quantification as opposed to using solely the SA or LA. Fur-thermore, compared to the conventional interpolation approach, our method produces a 3D dense motion field that is physically realistic and prevents displacement of adjacent points from intersecting. A future extension of this work includes the application of our method to characterize LV cardiac functions for normal and pathological conditions in clinical settings.

139-312 **Directional Analysis of Cardiac Motion Field based on the Discrete Helmholtz Hodge Decomposition**

John Sims, Marco Gutierrez and Maysa M G Macedo*

Aims: Diagnosis of cardiovascular diseases can be assisted by left ventricular (LV) motion analysis. However, the analysis of these complex fields, as a whole or in LV regions, is a difficult task for the physician. This paper proposes an automated method of motion field decomposition to analyse LV deformation over the cardiac cycle. Method: Synthetic motion fields were created from position vectors output by the 4D Extended Cardiac-Torso (XCAT) Phantom (v2.0). The 3D Discrete Helmholtz Hodge Decomposition (DHHD) computes field potentials from a smooth complex motion field, allowing curl-free (CF) and divergence-free (DF) motion field components to be found. The following investigations were performed with the DHHD: (i) Variation of decomposition error with input field smoothness. DF and CF components were generated on a uniform grid by applying differential operators to Gaussian potential fields with varying degrees of smoothness. Complex 3D fields were formed by component addition and decomposed to produce component estimates. Error measures were applied to quantify DHHD performance. (ii) Radial and rotational components of XCAT motion were presented as separate fields to simplify the visualisation. Results: Measured error in the DHHD decreased with increasing variance of Gaussian potentials, reaching a minimum normalised RMSE of 0.87% and 1.01% for CF and DF components. Component fields were visualised after decomposing the XCAT motion field. Visualisation of short axis (SAX) slices through the DF component of the XCAT motion field in systole show anti-clockwise LV rotation when viewed from base to apex. LV apical rotation was clockwise during systole. Conclusion: CF (radial) and DF (rotational) components can be presented simultaneously, offering a new quantitative and qualitative method to visualise LV motion over the cardiac cycle.

Tuesday, September 13, 2016 **12:30**

P64 **Cardiovascular Modeling and Analysis**

Room: Pinnacle I

140-345 **Fuzzy Logic SBP and RR Modelling Evaluated under Parasympathetic Blockade**

Sonia Gouveia*, Andreia O. Pinheiro, Susana Brás and Luciana A. Campos

Our previous work proposed fuzzy logic (FL) models to describe tachogram values as a function of systolic blood pressure levels, i.e. RR=f(SBP) where f is not restricted to be sigmoidal (e.g. non-stationary invasive experiments) nor linear (e.g. spontaneous time domain methods for baroreflex sensitivity quantification). In this work, FL-models are evaluated under parasympathetic autonomic blockade, which difficult the modelling task once RR variability is dramatically decreased whereas no SBP changes are observed. Beat-to-beat intrafemoral SBP and RR series were obtained from 7 freely moving rats. Parasympathetic blockade was achieved by intravenous administration of peripheral muscarinic methyl-atropine (MeA,0.5 mg/kg), and consecutive 512-beats were chosen before (baseline) and after blockade (MeA). The blockade was confirmed by baseline-MeA changes in spectral markers of sympathetic/vagal activity (LF and HF powers and transfer function gain). The FL-models performance was quantified from the mean absolute percentage error (delta, %) between estimated and original RR values, where lower delta indicates higher model performance. The statistical significance for each of the 14 models (7 subjects times 2 conditions) was evaluated with isodistributional random data (100 replicas generated by original RR shuffling, supporting the hypothesis of no SBP and RR relation). For all cases, delta evaluated in original data was lower than that evaluated for the replicas. Also, there were no significant differences in performance between conditions ($p=0.58$). Finally, pairwise differences between delta in both conditions were correlated with differences in SBP LF power (baseline,$r=0.97$,$p<0.01$;MeA,$r=0.88$,$p=0.02$) and not with differences in RR HF power (baseline,$r=0.60$,$p=0.21$;MeA,$r=0.09$,$p=0.87$), respectively sympathetic and vagal activity markers. The results support that FL-models are statistically significant and its performance is stable over conditions with different sympathetic and vagal activities, with similar relations with spectral markers of autonomic activity. Our future evaluation of the FL-models will also include conditions activating the sympathetic branch of the autonomic nervous system.

141-254 **The Effect of Cardiac Filling on Heart Rate Variability in Rabbit Isolated Heart**

Oto Janousek*, Marina Ronzhina, Jakub Hejc, Tibor Stracina, Veronika Olejnickova, Marie Nováková, Ivo Provazník and Jana Kolarova

Aims: Presence of heart rate variability (HRV) in isolated hearts is widely recognized; however, its mechanisms are still subject of debate. One of the possible explanations is that mechanoreceptors in cardiac tissue affect HRV. This hypothesis is supported by the fact that mechanical stimulus can induce changes of heart rhythm. In order to evaluate possible dependence of HRV on heart mechanoreceptors activated during left ventricle filling, the HRV parameters in two perfusion modes of isolated heart were compared: according to Langendorff and according to Neely (working heart mode). Methods: Ten New Zealand rabbit isolated hearts were perfused (Krebs-Henseleit, 37 °C, 85 mmHg) in Langendorff mode and consecutively in working heart mode (8 cmH2O preload, 60 cmH2O afterload). RR series of 5 minutes duration were obtained from electrograms by custom made R wave detector. A total of 95 HRV parameters in time, frequency, geometric, and non-linear domain were computed, including the time (RR mean, SDNN, RMSSD, NN50, pNN50), geometric (TI, TINN), frequency (areas, peaks and ratios of VLF, LF, HF computed by Fourier transform, Welch periodogram and Burg autoregressive model), and non-linear (sample entropy, fluctuation slopes, Poincaré diagram's SD1 and SD2) parameters. Results: No significant differences (Wilcoxon signed rank test, $p < 0.05$) were found among all studied HRV parameters, as calculated from electrograms during perfusion in two different modes. The study confirms the presence of heart rate fluctuation in isolated hearts in both Langendorff and working heart modes. Results of statistical analysis show that heart rate fluctuation is irrespective to mechanical stimulation of heart during atrium and ventricle filling. It can be concluded that either heart mechanoreceptors´ contribution to HRV is insignificant, or the heart compensatory mechanisms work in the same manner both in Langendorff as well as in working heart modes.

142-498 **Casual Interactions between Blood Pressure and Cardiac Inter-beat Intervals in Older People with Orthostatic Intolerance**

Marcos Hortelano, Richard B. Reilly and Raquel Cervigón*

Orthostatic hypotension (OH) is a frequent cause of Orthostatic Intolerance (OI) and related symptoms associated with the occurrence of syncope. Baroreflex function is usually assessed from spontaneous oscillations of blood pressure (BP) and heart rate (HR) assuming the unidirectional influence from BP to HR. However, the interaction of BP and HR is bidirectional. The aim of our study was to analyze the proportion of both casual directions between RR and BP during six minutes walking distance test between symptomatic and asymptomatic participants of OI. The database included a total of 65 participants, aged over 70 years of age (70.11±5.85), of whom 65% were females. There were not significant differences in age and gender between symptomatic and asymptomatic OI participants, 44.6% (n=29) had symptoms of OI and 55.4% (n=36) did not. The participants underwent a supine to stand orthostatic test with non-invasive beat-to-beat systolic and diastolic blood pressure (SBP and DBP) and heart rate (R-R) monitoring. Hemodynamic parameters were registered during different phases: pre-exercise, starting of exercise, exercise, recovery and post-exercise phase. Transfer entropy (TE) method was applied to identify relationship between hemodynamical variables. The directionality index quantifies the preferred direction of information flow from difference between both directional couplings. The directionality index from SBP to R-R interval showed statistically significant differences in the descent phase (p=0.042) between symptomatic OI patients 0.219±0.057 and asymptomatic OI patients 0.039±0.065. Moreover, this index from DBP to R-R interval showed statistical differences during the descent phase (p=0.043) showing changes during active and passive phases in the preferred direction of flow information. TE is a useful tool to quantify the causal interaction between blood pressure and heart rate. These results show that SBP affects heart rate; nevertheless directional coupling between these cardiovascular signals is altered depending on changes in autonomic control introduced by the orthostatic test.

143-531 **Sample Entropy Analysis of Hemodynamic Parameters in elderly with Orthostatic Intolerance Symptoms**

Marcos Hortelano*, Richard Reilly and Raquel Cervigón

This study focuses on examining the hemodynamic profile in older people with symptoms of orthostatic Intolerance (OI) undergoing an active stand and to investigate if their dynamic cardiovascular profile during a six-minute walk would be different to those of controls. The database included a total of 65 participants, aged over 70 years of age (70.11±5.85), of whom 65% were females. There was no significant differences in age and gender between symptomatic and asymptomatic OI participants, 44.6% (n=29) had symptoms of OI and 55.4% (n=36) did not. The participants underwent a supine to stand orthostatic test with non-invasive beat-to-beat systolic and diastolic blood pressure (SBP and DBP) and heart rate (R-R) monitoring. Hemodynamic parameters were registered during different phases: pre-exercise, starting of exercise, exercise, recovery and post-exercise phase. Sample entropy (SE) method was calculated at each phase. Results showed differences during phases in both groups. SE values of SBP showed differences in the phase 3 with statistically signification (p=0.023) between symptomatic OI 1.06±0.22 and non-symptomatic OI group 0.89±0.35. In addition, the R-R values showed statistically significant differences during the ascent phase (p=0.015), between symptomatic OI patients 0.75±0.46 and non-symptomatic OI patients 0.52±0.35 and in the descent phase (p=0.024) between symptomatic OI group 0.71±0.40 and non-symptomatic OI group 0.50±0.38. We also observed statistically significant differences in the descent phase (p=0.027) symptomatic OI patients 0.55±0.33 and non-symptomatic OI group 0.40±0.27. This study emphasizes the importance of entropy analysis to extract information of of cardiovascular signals.

144-481 **Short-term Hemodynamic Variability in Supine and Tilted Position in Young Women**

Gerard Cybulski*, Edward Koźluk, Agnieszka Piątkowska, Ewa Michalak, Anna Strasz, Anna Gąsiorowska and Wiktor Niewiadomsk

Aims The analysis of cardiovascular system response to a orthostatic head-up tilt test might bring diagnostic data on autonomic control and help to predict the occurrence of orthostatic syncope. Cardiac rhythm variability is intensively studied in supine and other body positions in humans. However, limited data are available regarding fluctuations of hemodynamic parameters during orthostatic tests. The aim of the study was to evaluate short-term changes in hemodynamic parameters observed in supine and tilted positions. Methods Six young women (age: 21-25) participated in the study. Impedance cardiography (ICG) and electrocardiographic (ECG) signals were recorded continuously in supine and after 60 degrees head-up tilt manoeuvre. Hemodynamic variability was determined using standard deviation, coefficient of variation and quartile deviation of impedance cardiography (ICG) derived stroke volume, ejection time and pre-ejection period. Analysis was performed over two six minutes periods recorded in supine position and 10 minutes after tilting manoeuvre. Results In supine position it were observed the following parameters presented as mean, standard deviation, coefficient of variations, quartile deviation. For stroke volume: 66 ml, 17ml, 11.3%, 8 ml. For RR intervals: 878 ms, 100, ms, 11.2%, 55 ms. For ejection time: 292 ms, 32 ms, 11.4%, 24 ms. For pre-ejection period: 115 ms, 15 ms, 13.4%, 9.5 ms. In tilted position it were observed the following parameters: For stroke volume: 53 ml, 10 ml, 19.8%, 6.7 ml. For RR intervals: 736 ms, 88, ms, 11.8%, 37 ms. For ejection time: 252 ms, 30 ms, 11.7%, 12 ms. For pre-ejection period: 134 ms, 12 ms, 9%, 6.7 ms. Conclusions Preliminary results shows that relative measures of hemodynamic parameters variability were different after tilting in comparison to supine position, however the pattern of those modifications is not uniform.

145-271 **Changes in Amplitude Characteristics of Heart Sound Signals during External-cuff-inflation Procedure: A Pilot Study**

Xinpei Wang*, Yuanyang Li, Chengyu Liu, Changchun Liu, Lizhen Ji and Haibin Zeng

Changes in amplitude characteristics of the first heart sound (S1) and second heart sound (S2) have been confirmed to be linked with the physiological or pathological changes of cardiovascular system. Earlier studies have also documented that these changes in amplitudes of S1 and S2 were correlated with blood pressure (BP) factor. External-cuff-inflation-deflation (ECID) is a standard procedure for BP measurement and will certainly influence the BP state in the arterial trees. However, no existing studies report whether this ECID procedure will change the amplitude characteristics of S1 and S2. This study aimed to provide insight into this information. Thirty-one healthy volunteers were enrolled. Heart sound and cuff pressure signals were recorded synchronously for each subject during a resting state and then followed by a external-cuff-inflation (ECI) state and a external-cuff-deflation (ECD) state. The BP measurements included two patterns: cuff wrapped on the left upper arm and cuff wrapped on arms and legs. Thus, there were six measurement states in this study: two resting states, a ECI on the left upper arm (ECI_lua) state, a ECD on the left upper arm (ECD_lua) state, a ECI on arms and legs synchronously (ECI_als) state and a ECD on arms and legs synchronously (ECD_als) state. The amplitudes of S1 (S1_amp) and S2 (S2_amp), as well as their ratio (S1/S2_amp), were calculated for each beat signals and then were averaged for each state. These three indices were compared between resting and ECI state, also between resting and ECD state using paired-t test. The results showed that S2_amp had significant differences between resting and ECI_als state ($p<0.01$). To conclude, this pilot study suggested that the applied ECI_als procedure during BP measurement significantly influences the amplitude characteristics of S2.

146-192 **Effect of Autonomic Cardiac Modulation on Speech Perception in Noise**

Kang Pei, Fei Chen and Dingchang Zheng*

The impact of environmental noise on human health has been widely recognized. Noisy environment may cause hearing loss and many cardiovascular diseases. Speech perception in noise (SPIN) is associated with many physiological, psychological and environmental modulation mechanisms. This study aimed to examine the effect of autonomic cardiac modulation on SPIN. More specifically, this work aimed to investigate how cardiac activity with increased heart rate influence SPIN. Ten young subjects with normal-hearing participated in the experiment. They were given 5 mins rest for recording baseline heart rate. They were then asked to recognize a list of 20 sentences corrupted by 2-talker babble masker at -10 dB signal-to-noise ratio to have the SPIN score. Heart rate was recorded during the process to reflect the influence of noise on cardiac activity. Next, each subject was asked to ride on bicycle for 5-7 mins to experience a moderate amount of exercise, and then given at least 10 mins of recovery to achieve the normal resting heart rate. After the exercise and recovery, the SPIN scores were measured for each subject and compared with those before exercise. Experimental results showed that immediate exposure to noise did not significantly increase heart rate ($p>0.5$). However, after moderate exercise of bicycle-riding, most participants had significantly better SPIN scores compared to those measured before exercise (49.7+/-4.1% vs 42.5+/-4.2%). After the recovery to a normal resting cardiac activity, the SPIN performance of 49.9+/-4.7% was significantly better than the normal level at resting cardiac activity (i.e., before the exercise). This study scientifically demonstrated the improved SPIN performance immediately after exercise and recovery. Sympathetic cardiac modulation increases heart rate and expedites blood flow in human body, which might contribute to improved SPIN performance after moderate exercise. However, the underlying mechanism for the improved SPIN after recovery needs further investigation.

147-433 **Hemodynamic Modelling in the Calf – A Pilot Study**

Magdalena Matejkova*, Pavel Jurak, Ladislav Soukup, Josef Halamek, Ivo Viscor, Peter Langer and Vlastimil Vondra

With increasing age, the cardiovascular system loses its efficiency. The goal of this work was to investigate the hemodynamic system response to a head-up tilt test in two groups of different aged people. We used a model for describing this response in the right calf based on a non-invasive, non-occlusive, bioimpedance signal measurement technique. A decrease in the bioimpedance value in the calf during the head-up tilt test is associated with the accumulation of blood in the calf, which can be expressed by a model parameter. Subjects were examined in both a head-up tilt test and a supine position. 50 healthy non–smoking volunteers were divided into two groups according to age. The impedance signal during the tilt test for each subject was fitted by a model exponential function: Z0 model EF(t) =A*exp(-t/B)+C where Z0 model EF(t) is the calculated model of electrical impedance in the calf by an exponential function, A is the amplitude of impedance change, B is the time constant of the impedance decrease, C is the value of the steady state after the tilt test and t denotes time. A lower time constant B shows a faster filling of the vascular system in the investigated part. The Mann-Whitney test (p-value<0.005) revealed that the time constant B for the older group was significantly lower than for the young group (145.24± 80.28 vs. 239.23±136.59 sec.). A lower time constant value means a faster response to blood filling in the lower limbs and directly reflects decreased vessel elasticity. This time constant was faster in the older group. The results show increased vessel stiffness in old age and could lead to a non-invasive evaluating the cardiovascular system state.

Tuesday, September 13, 2016 **12:30**

P65 **Baroreflex Sensitivity and Autonomic Regulation**

Room: Pinnacle I

148-349 Effect of Exercise on Baroreflex at Different Altitudes

Sasan Yazdani*, Nicolas Bourdillon, AltitudeOmics Group and Jean-Marc Vesin

Purpose: This work is part of a series titled "AltitudeOmics", representing a group of studies that explore the mechanisms controlling human acclimatization to hypoxia. This work aims at analyzing the baroreflex sensitivity (BRS) at rest and during incremental exercise stages, at sea level and high altitude. Methods Twenty-one healthy subjects [age: 20.8 (19–23 yrs.)] underwent experimental trials near sea level (SL; 130 m; barometric pressure 749 mmHg) and twice at high altitude (5,260 m, Mt. Chacaltaya, Bolivia; barometric pressure 409.1 and 410.4 mmHg) on the 1st and 16th day at high altitude (ALT1 and ALT16, respectively). The subjects laid down in a room dedicated to the insertion of an arterial catheter (20–22 gauge) into a radial artery. They were then seated on an electrically-braked cycle ergometer. The protocol consisted of a three-min resting baseline in pedaling position, followed by four 3-min stages at 70, 100, 130 and 160 Watts. To analyze the baroreflex responses at rest and during exercise, we studied BRS using the sequence method (spontaneous trends of three or more consecutive RR-intervals and systolic blood pressure). Results: The calculated BRS (in ms/mmHg) for the twenty-one subjects at rest were respectively (10.57±5.34), (7.73±4.24), (4.98±1.98) for SL, ALT1 and ALT16. During exercise (70W 160W) BRS continuously decreased from (3.64±2.35), (1.48±0.7), (2.36±1.37) to (1.73±0.83), (1.25±0.77), (1.19±0.54) respectively for SL, ALT1 and ALT16. Finally, by performing an exponential fit to the calculated rest-exercise BRS, main decay constants of -1.8, -3.6, -1.3 were computed respectively for SL, ALT1 and ALT16. Conclusions: Preliminary results suggest that BRS exponentially decreases during exercise at SL, in acute and chronic hypoxia. The BRS decays much faster in ALT1, indicating that chemoreflex activation in acute hypoxia impairs the baroreflex behavior. At ALT16, the evolution of BRS during exercise has the same behavior as at SL, indicating acclimatization to altitude.

149-347 **Effect of Hypoxia and Hyperoxia on Baroreflex Sensitivity**

Sasan Yazdani*, Nicolas Bourdillon, AltitudeOmics Group and Jean-Marc Vesin

Purpose: This paper is part of a series titled “AltitudeOmics” that together represent a group of studies that explore the basic mechanisms controlling human acclimatization to hypoxia. This study aims at analyzing the baroreflex sensitivity (BRS) at sea level, in acute and chronic hypoxia and test whether hyperoxia reverts the hypoxic effects. Methods: Twenty-one young, healthy, sea-level residents [age: 20.8 yrs. (range 19–23 yrs.)] underwent experimental trials near sea level (SL; 130 m; barometric pressure 749 mmHg) and two times at high altitude (5,260 m, Mt. Chacaltaya, Bolivia; barometric pressure 409.1 and 410.4 mmHg) on the 1st and 16th day at high altitude (ALT1 and ALT16, respectively). After insertion of an arterial catheter (20–22 gauge) into a radial artery, recordings were made with the subjects sitting on a bike at rest, breathing either room air or hyperoxic mixture (inspired oxygen pressure of 250 mmHg). We studied BRS using the sequence method (spontaneous trends of three or more consecutive RR-intervals and systolic blood pressure), frequency methods (autoregressive spectral power of RR-intervals and systolic blood pressure in low and high frequency bands), and the standard deviation method (standard deviation of RR-intervals divided by that of systolic blood pressure). Results: The calculated BRS for the twenty-one subjects using the sequence method (in ms/mmHg) at rest in SL were respectively (10.57±5.34), (4.48±2.53), for room air and hyperoxic conditions. These values respectively decreased (7.73±4.24), (5.09±2.91) for ALT1 and (4.98±5.34), (3.04±1.57), for ALT16. The changes in the standard deviation and the frequency methods were consistent with that of the sequence method. Conclusions: As awaited, preliminary results show a decrease in BRS with hypoxic exposure, however hyperoxic exposure exacerbated this effect. Knocking off the oxygen chemoreceptors with hyperoxia seems to impair the control of baroreflex in all conditions.

150-111 **Instantaneous Response Patterns of Baroreflex Sensitivity, Respiratory Sinus Arrhythmia Sensitivity and Vagal Activity to Cold Face Test and Active Orthostatic Test**

Salvador Carrasco-Sosa, Alejandra Guillén-Mandujano* and Aldo R. Mejía-Rodríguez

Recently, in two different studies we reported that baroreflex sensitivity (BRS) is functionally related to vagal activity and heart rate, and that the active orthostatic test (AOT) produces a sympathetic activation seven times greater than that of cold face test (CFT). To further support the aforementioned relations and to establish if AOT and CFT produce opposite effects in BRS and sympathovagal balance, we examined the instantaneous dynamics of BRS and of spectral measures of autonomic activity, as well as the correlations among them. Twenty-five healthy volunteers underwent 1-min control, 1-min maneuver (CFT, AOT) and 2-min recovery stages. From their ECG and arterial pressure recordings, R-R intervals (RR) and systolic pressure (SP) time series were obtained. Time-frequency spectra of these series were estimated to compute the low-frequency powers of RR (LFRR) and SP (LFSP), high-frequency power of RR (HFRR) and the LFRR/HFRR ratio. Instantaneous BRS was obtained by alpha index in the low-frequency band. Instantaneous values of BRS, HFRR and RR displayed distinctive patterns in response to each maneuver: overshoot for CFT and undershoot for AOT. While pooled means of BRS, HFRR and RR were 2.4±2.3, 3.1±3.0 and 2.0±1.4 times greater ($p<0.001$) in CFT than in AOT, those of LFRR/HFRR and LFSP were 7.2±6.2 and 5.1±5.0 times smaller ($p<0.001$) respectively. Correlations of BRS with HFRR, RR and LFSP were 0.82±0.14, 0.87±0.11 and -0.77±0.13 respectively. In a beat-to-beat format, BRS, HFRR, LFSP and RR: exhibit great dynamism, show strong correlations between them, and follow distinctive opposite patterns in response to each maneuver. While in CFT the greater values of BRS allow amplifying the vagal activity and minimizing the sympathetic one, in AOT the lower values of BRS determine the opposite autonomic effects. Our findings support that BRS presents a direct relationship with vagal activity and an inverse relation with the sympathetic one.

151-155 **Adaptation of QT and PR Intervals to Heart Rate Changes**

Katerina Hnatkova, Peter Smetana, Martina Sisakova, Georg Schmidt and Marek Malik*

In healthy subjects, both QT and PR intervals are heart rate dependent, shortening at fast heart rates. Following abrupt heart rate changes, neither QT nor PR intervals change immediately but adapt with a lag. This hysteresis of the adaptation has been repeatedly studied for QT interval but little is known on PR/RR hysteresis. Individual QT/RR and PR/RR hysteresis profiles were studies and compared in 52 healthy females aged 35.8±13.6 years and 57 healthy males aged 34.3±12.1 years (p=NS between sexes). In each subject, repeated measurements of QT and PR intervals were made preceded by both stable and variable heart rates. These were used to derive exponential decay profiles of the influence of RR sequences preceding the QT and PR measurements. From these, the time constants were derived during which 95% adaptation of QT and PR intervals was achieved in individual subjects. As expected, QT/RR dependency was substantially steeper (curve-linear slopes of 0.155±0.035 and 0.135±0.028 in women and men, respectively, p=0.001 between sexes) than the PR/RR dependency (curve-linear slopes of 0.033±0.021 and 0.038±0.033 in women and men, P=NS between sexes). QT/RR hysteresis showed little differences between sexes (95% adaptation in 116.8±22.6 and 119.9±13.7 s in women and men, respectively, p=NS between sexes). On the contrary, PR/RR hysteresis was substantially slower in women compared to men (95% adaptation in 110.4±79.4 and 59±60.9 s in women and men, respectively, p=0.0003 between sexes). Moreover, while QT/RR hysteresis was marginally slowing with advancing age (logarithmic slopes of 18.7 and 13.8 in women and men, respectively), PR/RR hysteresis was strongly accelerating with advancing age (logarithmic slopes of -79.4 and -76.7 in women and men, respectively). The QT/RR and PR/RR hysteresis time constants correlated in neither women nor men. Thus the PR and QT adaptation to heart rate is governed by completely different physiologic regulatory processes.

152-344 **Reflection of Autonomic Regulation Behaviour Using Short-Term Cross-Spectral Analysis on RR and QT Intervals**

Ping Zhan*, Chenxi Li, Hongduoer Liu and Yi Peng

The balance of autonomic nervous system (ANS) is of great significance for regulating normal physiological functions of heart and avoiding risk of cardiac diseases. This project is aimed to reveal the regulation state of ANS by analyzing the linear relationship between RR interval (RRI) and QT interval (QTI). The data for this analysis were provided by the Telemetric and Holter ECG Warehouse (THEW), among which database Normal was selected as normal controls (n=189) and database ESRD as typical subjects of ANS dysfunction with high risk for cardiac arrhythmias and sudden cardiac death(n=43). A causal cross-spectral approach based on the autoregressive model was applied to distinguish the directional effect from RRI to QTI. And the causal cross-spectral analysis used here was focused on 2-minute-length series. Firstly, the validity of the short-term indices was verified Then the relevant indices, such as cross-spectral energy in both low frequency (LF) and high frequency (HF) bands, as well as transfer function G, were calculated. Inner-comparison for the same index between day and night and inter-comparison between Normal and ESRD were made. Results showed that: 1) For Normal, there were significant differences between daytime and nigh-time results of GLF, GHF and LF/HF. However, no significant diurnal variation of the corresponding indices existed in ESRD; 2) GLF-d/GLF-n and (LF/HF)d/(LF/HF)n were significantly smaller in ESRD than that in Normal. The above results suggest the loss of circadian rhythm in ESRD. Furthermore, there is no statistic difference of GHF-d/GHF-n between Normal and ESRD. Since HF band mainly reflect the influence of vagal tone, it was revealed that loss of circadian rhythm in ESRD was primarily caused by the overactivity of sympathetic branch. Our study confirmed the feasibility of very short series based analysis and provided an approach for investigating ANS activity.

153-486 **Management of Lower Extremity Oedema Using a Novel Smart Compression System**

Mahan Rahimi*, Malcom F. Tremblay, Farzad Khosrow-Khavar, Kouhyar Tavakolian, Andrew P. Blaber and Carlo Menon

Objectives: Excessive swelling of the legs is prevalent in the elderly, spinal cord injury patients, and pregnant women. This condition can be associated with varicose veins and orthostatic hypotension, and may lead to stroke volume (SV) decline and syncope. The efficacious role of compression therapy in management of such disorders has been the subject of numerous studies. The shortcomings of the existing compression therapy products motivated us to develop an adaptive compression system (ACS) for prevention of lower leg oedema during stasis or ambulation. The proposed device is a motorized compression garment which is capable of delivering pressure in continuous and intermittent modes and adapts to physiological changes based on the interface pressure feedback from flexible Force Sensing Resistors® (FSRs). Methods: Previous studies have shown that there exists a positive correlation between left ventricular ejection time (LVET) and SV. We used this concept to conduct a study on 12 healthy participants and investigate the performance of the ACS in pumping blood back to the heart by monitoring its capability of preventing LVET fall, hence SV decline. We created the needed shift in blood volume by graded lower body negative pressure (LBNP) and throughout testing continuously monitored beat-to-beat blood pressure, and electrical and mechanical activities of the heart via electrocardiography (ECG) and seismocardiography (SCG), respectively. Each subject completed two sets of experiments with and without ACS application. Results: A two-way repeated-measures analysis of variance revealed a significant reduction in the mean cardiovascular changes to LBNP including LVET and heart rate (HR): {absolute change from baseline ± standard error: no ACS: LVET=-64.5ms±9.1, HR=19bpm±2; with ACS: LVET=-51.9ms±8.9, HR=14bpm±2; $p<0.05$}. These results indicate less cardiovascular stress with the ACS. Conclusion: This study showed that our device is capable of hindering LVET fall by facilitating blood circulation through the compression of lower extremities.

P66 **Physionet Challenge I**

Room: Point Grey

154-268 **Abnormal Heart Sounds Detected from Short Duration Unsegmented Phonocardiograms by Wavelet Entropy**

Philip Langley*

The automated detection of abnormal heart sounds from electronic stethoscope recordings remains a significant challenge particularly when recordings are obtained outside the clinical environment by novice users. Classification algorithms generally require segmentation of the characteristic heart sounds and intervals. The aim of this study was to assess the potential of a computationally efficient algorithm to detect abnormal heart sounds from short unsegmented recordings, ie without detection of S1/S2 and diastolic/systolic intervals. The algorithm is based on the hypothesis that abnormal heart sounds have more uniform temporal energy distribution compared to normal heart sounds. Normal recordings have discrete energy peaks corresponding to S1 and S2, whereas abnormal recordings have additional energy components, for example due to heart murmurs. Continuous wavelet transformation was used to describe the time/frequency energy distribution of heart sound recordings classified as normal/abnormal for the Computing in Cardiology/PhysioNet Challenge 2016. Analysis was limited to the first 5 s of recording. Wavelet entropy was used to quantify the temporal energy distribution at different scales. Based on 3125 recordings of the training set (630 abnormal recordings), across all scales considered wavelet scale 1.7 (corresponding to a frequency of approx. 600 Hz) and entropy threshold of 7.8 provided the highest classification score with sensitivity (Se) = 95%, specificity (Sp) = 60% and overall score = 78%. Abnormal recordings had significantly reduced entropy compared to normal recordings at this scale (median (interquartile range) 6.3 (1.8) vs 8.0 (1.8) $p<0.0001$) suggesting the presence of discrete high frequency energy components. Applied to a subset of recordings from the independent test set similar results were obtained with Se = 95%, Sp = 58%, overall score = 76%. The algorithm shows promise for computationally efficient detection of abnormal heart sounds from short duration recordings.

155-182 **Improving the Classification of Heart Sound Recordings**

Juan L. Domínguez-Olmedo* and Jacinto Mata Vázquez

The 2016 PhysioNet/CinC Challenge aims to encourage the development of algorithms to classify heart sound recordings collected from a variety of clinical or nonclinical environments. The automated classification of pathology in heart sound recordings still presents challenges. Starting from the method employed in the sample submission code, some variations have been developed and tested by using an ensemble of classifiers and different signal features One of the entries submitted in phase I obtained an overall score of 0.78.

156-329 **Automated Classification of Normal and Abnormal Heart Sounds using Support Vector Machines**

Anthony Bouril, Darya Aleinikava, Maria de la Salud Guillem Sánchez* and Grace Mirsky

While a number of researchers have attempted to develop algorithms for automated classification of heart sounds over the last five decades these studies have been inadequate in terms of clinical utility due to a number of important limitations. These limitations are primarily a result of data that is not representative of the variety of data that may be obtained due to various recording positions and/or the amount of noise present, as well as lack of robust evaluative procedures of the algorithms such as validation on independent test sets. The PhysioNet/Computing in Cardiology 2016 Challenge seeks to facilitate the development of highly robust algorithms to perform automatic classification of heart sounds in a manner which overcomes the limitations of previous studies. The dataset consists of over 3000 phonocardiogram recordings, taken from several locations on the body, from both healthy and pathological adults and children. The classification task requires the algorithm to determine if a recording is normal, abnormal or cannot be scored (due to excessive noise/corruption of the signal). An implementation of a state-of-the-art segmentation algorithm has been provided by the Challenge organizers, leaving the primary focus of the Challenge on the classification task. For this task, we selected a number of features in both the time and frequency domains. We determined the top features and used them to train a Support Vector Machine (SVM) to perform the classification. For Phase I, our best overall score for the hidden test set was 0.78 (Sensitivity = 0.70, Specificity = 0.87). For Phase II, we plan to further investigate additional machine learning techniques to determine if performance may be improved by exploiting the tradeoffs of alternative methods as well as to continue to refine the selection of attributes used for those techniques.

157-485 **Machine Learning Based Identification of Pathological Heart Sounds**

Tanmay Gokhale*

Aims: Auscultation of heart sounds is a critical component of the physical exam and can lead to the identification of serious medical conditions. However, identification of pathological hearts sounds by ear is challenging in the most ideal environments, and become exponentially more difficult with ambient noise and other sounds, making the automated classification of heart sounds a powerful tool. Existing algorithm for this purpose work well with clean, idealized recordings but fail in recordings from realistic settings. In this work, we describe a machine learning-based approach to classify heart sound recordings as pathological or normal. Methods: Five existing databases of heart sounds comprising 3,126 unique recordings obtained under varied conditions were used for training. All databases contained both normal and abnormal recordings, with the composite set containing 80% normal recordings. Recordings were segmented using a provided, pre-trained hidden Markov model. A pre-designated feature set of segment durations and relative amplitudes was used. Additional features were obtained by considering the shapes of the Hilbert envelopes of each segment, as well as the continuous wavelet transform of the signal using the Coifman fifth order wavelet. Several machine learning classification models (boosted decision trees, support vector machine, and neural networks) were trained and validated using 10-fold cross validation. Preliminary Results: Boosted decision trees using the logitboost scheme obtained the highest cross-validation accuracy, as well as sensitivity and specificity on the provided validation set. The resulting model obtained an overall score of 0.68 on the hidden test set, with high specificity (0.98) but low sensitivity (0.39). Modification of the model to predict 'unsure' in borderline cases resulted in reduced specificity but improved sensitivity.   Conclusions: Automated analysis of heart sounds is able to match expert classification with moderate accuracy, and further tuning of feature extraction and learning algorithms will likely allow for improved, expert-caliber classification.

158-401 **Using Spectral Acoustic Features to Identify Abnormal Heart Sounds**

Nicholas Singh-Miller* and Natasha Singh-Miller

Using the Physionet challenge database we aim to determine whether a heart sound recording is “normal”, “abnormal”, or "uncertain." Using the Physionet challenge database we aim to determine whether a heart sound recording, a phonocardiogram (PCG), corresponds to a ``normal'' or ``abnormal'' physiological state. Our goal is to augment the information available to a physician during auscultation of a patient's heart, ultimately assisting with clinical decision making. To that end, we first produce spectral features of the PCG, for varying windows and frequency bands. We use the resulting spectral information to identify a variety of features based on means, variance, and activity at different frequency bands. We find that much of the information corresponding to abnormalities is captured in these features, with particular good performance on murmurs. Finally, we build a discriminative model, specifically a random forest regressor, to classify new samples based on the aforementioned features. Our final performance on the challenge data received a combined score of 81%.

159-187 **Recognition of Abnormalities in Phonocardiograms for Computer-Assisted Diagnosis of Heart Failures**

Simon Hofmann*, Volker Groß and Andreas Dominik

Examination of heart sounds by use of a binaural stethoscope is a common part of almost every medical check-up. Bedside monitoring of ICU patients, however, is still mainly focused on continuous ECG, ignoring valuable infor- mation from easily detectable heart sound recordings. We present an algorithm to identify abnormal heart sounds by mimicking the decision making process of a human listener. The focus of our study there- fore lies on rhythm (such as total frequency, regularity, spectral power of heart rate etc.) and recognition of additional or missing sounds. The first step of the algorithm is the detection of heart beats, resulting in a time series from which rhythm-related parameters can be derived. For fur- ther analysis only the intensity of the signal, estimated as Hilbert amplitude envelope, is considered. In a next step, windows comprising single beats are extracted from the recording, superimposed and averaged. The final idealised beat is cleaned from random noise as well as from background noise and short- term disturbances. Descriptors derived from this single beat by binning are examined with self- organising maps (SOM) and used for training of predictive models by applica- tion of learning vector quantisation (LVQ) and artificial neural networks. First results with a preliminary descriptor set show a sensitivity of 0.40 and a specificity of 0.85 (score=0.63). Following Implementations will consider extra beats and features from heart murmurs in sections between S1 and S2.

160-186 **Heart Sound Classification Using Deep Structured Features**

Michael Tschannen*, Thomas Kramer, Gian Marti, Matthias Heinzmann and Thomas Wiatowski

Introduction: Current state-of-the-art methods for automated classification of pathology in heart sound recordings often suffer from poor generalization capabilities because they were trained and/or evaluated on small and/or carefully selected data sets. We propose a novel method for heart sound classification and evaluate it on the Physionet/CinC 2016 challenge data set, the largest public collection o labeled heart sound recordings available to date. Method: Our method (see figure below) consists of a feature extraction stage and a classification stage. In the former stage, two types of features are extracted from the raw heart sound recording, namely ``summary features'' that describe the entire recording, and ``deep features'' that provide a robust characterization of the shape and morphology of each heart beat in the recording. The raw heart sound recording is firs segmented into the four states of the heart cycle. First and second order statistics of amplitude and duration associated with these states as well as a power spectral density estimate of the entire (unsegmented) heart sound recording serve as summary features. Deep features are extracted by feeding each heart beat to a tree-like multi-layer convolutional neural network that is based on Haar wavelet filters, ReLU non-linearities, and max-pooling. The feature vector characterizing a heart beat is then constructed by stacking the corresponding deep features and the summary features into a single vector. In the classification stage, each heart beat (i.e., its feature vector) is finally classified into ``normal''/``abnormal'' (and possibly ``unsure'') using an L2-SVM, and the prediction for the entire recordin is obtained as the majority vote over all heart beats. Results: The parameters of our method were selected using 5-fold stratified (by patient) cross-validation on the Physionet/CinC 2016 challenge data set. The optimal parameter configuration yielded a cross-validation challenge score, sensitivity, and specificity of 0.87, 0.90, and 0.83, respectively.

161-228 **Classification of Acoustic Physiological Signals Based on Deep Learning Neural Networks with Augmented Features**

Te-Chung Yang* and Haowei Hsieh

Feature extraction and classification of one-dimensional digital signals, such as acoustic waveforms sampled at discrete time instances, is traditionally performed with several commonly known techniques, namely discrete Fourier transform, digital filter, and first, second, or higher-order statistics, i.e. mean, variance, and/or kurtosis. More advanced techniques which consider signals as stochastic processes are also utilized. Those include Principal Component Analysis, Independent Component Analysis and Kalman filter. With features extracted via the aforementioned techniques, a waveform, or its temporal domain segment, can be classified into pre-defined categories. However, such extracted features are not easily understood and could not capture all information embedded in the signals. As two-dimensional signals, i.e. images, are classified with high success rate by deep learning neural networks, which has been better than manually crafted and selected features, attempts to utilize such techniques to classify one-dimensional signals have been made. However, like speech recognition or nature language process, one-dimensional signal still a challenge to deep learning neural networks and there are still areas to improve. In this paper, we present a way to process acoustic physiological signals in order to extract their features with modern deep learning neural networks, a combination of recurrent and convolutional neural networks. The extracted features, represented as weights inside networks, work with other augmented features from the same signals to detect abnormality inside the signals with probabilities. A final decision-making layer in the network classifies the acoustic physiological signal from the probability distribution of abnormality. With training data provided in this challenge, our network is capable of achieving 84% overall accuracy, with 77% sensitivity and 92% specificity, during Phase I submission. As the network is flexible in depth of layers and breadth of connection parameters, we expect the network could achieve better results with more available data and long training time.

162-229 **Classification of Phonocardiogram Signals with Support Vector Machines Using Waveform and Power Spectral Features**

yatao Zhang*, Shoushui Wei, feifei Liu and yan wang

An method to classify the normal and abnormal heart sounds is described, and enter in the PhysioNet/Computing in Cardiology Challenge 2016 (CinC 2016). Firstly, 49 features of phonocardiogram (PCG) were extracted, and the features included 20 features derived from RR, S1, S1, systole and diastole intervals, 15 power spectral density (PSD) features derived from different PCG frequency range (i.e. 10-100, 0-600, 0-100, 100-300, and 300-600) and the ratios between the PSDs, and 14 amplitude features (i.e. the maximum and the minimum amplitude of S1, S2, systole and diastole period, and the difference between the maximum amplitude and the corresponding minimum). Then the proposed method employed kernel support vector machine (KSVM) and the matrix for the classification of PCG. Using training data set a, b c, d and e provided by CinC 2016 the proposed method was trained and obtained the cross validation classification accuracy 87.3001%，and 99.34% on validation set (provided by sample.zip). At last the score was 51% on a random test dataset on submitting system of the PhysioNet.

163-189 **Time-Frequency Analysis of Phonocardiogram for Classifying Heart Disease**

Rohan Banerjee, Swagata Biswas, Snehasis Banerjee, Anirban Dutta Choudhury*, Tanushyam Chattopadhyay, Arpan Pal, Kayapanda M Mandana and Parijat Deshpande

Objective: Analysis of heart sound is a popular research area for non-invasive identification of several heart diseases. The Physionet Challenge 2016, aims to classify normal or abnormal heart sounds based on features of phonocardiogram (PCG) signal. Dataset: Five datasets containing a total of 3,126 heart sound recordings, lasting from 5 seconds to 120 seconds, collected from different locations on chest were provided for training. Another dataset, containing a small portion from each training set was also provided for validation. The final entry is tested on a hidden test dataset for evaluation. Methods: State of the art approach is adopted for identifying the four ‘states’ of a cardiac cycle namely first and second heart sounds, systole and diastole from a PCG signal using Hidden Markov Model (HMM). Our contribution lies on finding of new features for a better classification accuracy. Several time and frequency domain features were explored. The time domain features contain information regarding time intervals between different ‘states’ and their intermediate ratios. Further, the diastolic portion is sub segmented into overlapping windows of 50 ms and each window is modeled with a 10th order autoregressive (AR) model. Magnitude of first 4 AR-poles were explored as features. Spectral features of the diastolic portion of PCG signal within of 0–100 Hz was also included for analysis. Artificial neural Network (ANN) is used for classification. Results and Conclusions: our approach yielded sensitivity and specificity and modified accuracy of 0.81, 0.78 and 0.8 respectively in one of our entries in the unofficial phase. Due to uncontrolled environment, few signals in the dataset are noisy in nature and hence impossible to classify. Currently, we are trying to mark them as ‘uncertain’ via signal quality checking as well as low confidence score of the classifier.

164-530 **Time and Frequency -Based Approach to Heart Sound Segmentation and Classification**

Jarno Mäkelä and Heikki Väänänen*

Introduction: Phonocardiography is a noninvasive and cost efficient method for evaluating the audible function of the heart; cardiac valves, blood flow and such. In this study, we propose a decision tree classifier of heart sound signals. Methods: We divided the training set (N = 3126) into three subsets: the cases with distinct electrocardiogram (ECG) available (N = 278), the cases used in iterative algorithm development (N = 278 + 2223), and the cases for method evaluation (N = 903). First, we defined dominant heart sound (S1, S2) segments based on ECG trigger and on adaptive auto correlation of the sound signal. Based on the segments, we estimated S1 and S2 frequency contents and created a set of filters for cardiac cycle enveloping and decomposition, and for decision tree parametrization. Using the set of filters and inter-segment timings, we created three sets of markers: a set utilizing both S1 and S2 identification (N = 1431), a set where only one sound (assumed to be either S1 or S2) is identified (N = 1205), and a set without any repetitive envelope (N = 473). A subset (N = 17) was discarded due to signal quality. Individual classification tree was trained for each marker set. For each case the tree with the biggest possible marker set was used. The resulting classifier was evaluated with cross-validation techniques. Concurrent iterations were executed to achieve more precise segment extraction and markers. Results: After three iteration cycles with the smallest marker set our classifier attained sensitivity (Se = 0.56) and specificity (Sp = 0.95) and overall score of 0.75 for a random subset. Conclusion: The proposed classifier shows potential in heart sound analysis even with low data quality and limited computational resources. Further potential of the study lies in heterogeneous computing used in signal analysis.

165-215 **Can Electrocardiogram Classification be Applied to Phonocardiogram Data? -- An Analysis Using Recurrent Neural Networks**

Christopher Schölzel* and Andreas Dominik

A phonocardiogram (PCG) is a sequential measurement of heart activity used to distinguish normal from abnormal heart function. In this respect it is similar to an electrocardiogram (ECG). There are already several studies about the classification of PCGs, but they are overshadowed by the vast amount of scientific studies performed with ECGs. Is it possible to use this large amount of knowledge about ECG classification to improve the current state of PCG classification techniques? A prerequisite for this would be to transform the PCG into an artificial ECG that can be interpreted by ECG-related methods. Apart from all technical problems involved in this transformation, such an approach can only be useful if the resulting representation can still carry the information necessary for the classification between normal and abnormal PCG. Our first step therefore is to train a set of recurrent neural network on the task of the physionet challenge 2016 using (a) only PCG data, and (b) only ECG data. It turns out that the challenge score of 0.74 is lower for net (b) than net (a), which achieved a score of 0.82. As expected, we lose information, if we only consider the ECG data, but net (b) is still able to correctly classify 74% of the samples in the dataset. This suggests that our transformational approach may be viable. Unfortunately, however, we could not build a neural network that was able to transform a PCG to an artificial ECG. We tried several structures, including long short-term memory networks (LSTM), bidirectional LSTM (BLSTM), autoencoders, and Evolino networks. It seems that both the ECG and PCG signal int the dataset have too many unpredictable qualitative difference due to the placement of the electrodes and the transducer.

166-307 **Classification of Noisy Heart Sound Recordings Using Hidden Markov Models**

Paria Rashidinejad* and Yusuf Bugra Erol

The automated classification of pathology in heart sound recordings has been performed for over 50 years, but still present challenges. Researches so far have used a variety of methods including threshold-based methods, neural networks, support vector machines (SVM), k-nearest neighbors, and so forth. Accurate segmentation of heart sound as an important step, is done in a hidden Markov model, to extract useful features for the classifier. Encouraged by PhysioNet 2016 challenge, this paper develops an algorithm to classify short and noisy PCG recordings collected from a single precordial location. First, we implemented a hidden Markov model for accurate segmentation of primary heart sounds. The parameters of the model are learned by expectation maximization (EM) algorithm and emission probabilities are modeled as a mixture of multivariate Gaussians. The Viterbi algorithm is finally used to find the most likely sequence of states. Second, features are extracted from each segment of the recordings and the performance of various classifiers, namely k-nearest neighbors, logistic regression, SVMs, and bagging are compared to each other. Applying this method to the validation set of 309 PCGs gives us a score of 0.82 and the score on physionet website is 0.64.

167-535 **Normal / Abnormal Heart Sound Recordings Classification Using Convolutional Neural Network**

Tanachat Nilanon*, Sanjay Purushotham and Yan Liu

Aims: Automatic classification of phonocardiogram (PCG) recordings has demonstrated potential to accurately detect heart pathology. The aim of the classification is to quickly identify subjects that need further expert diagnosis. PCG automatic classification is useful in both nonclinical and clinical environments, such as patient's residence where only rudimentary equipment is available, or emergency ward where fast and undemanding triaging is vital. Dataset: The PhysioNet/Computing in Cardiology Challenge 2016 maintains a public training set and a hidden test set. The training set consists of PCG recordings from six databases, totaling 3,240 recordings. Two unseen databases are retained and included in the hidden test set. The length of the recordings ranges from 5 seconds to over 120 seconds. The training set and the test set are divided such that they are two sets of mutually exclusive populations. Methods: The PCG recordings were first normalized by their root-mean-square power. To improve the robustness of the classifiers by increasing the number of training samples, the recordings were then windowed into 5 seconds segments and our classifiers were trained to classify these segments. Each recording classification was then generated using a voting scheme from classification results of its segments. Our features include spectrograms and Mel-frequency cepstrum coefficients. The training data was split in two ways: traditional stratified five-fold cross validation and a manual split that contains unseen test databases. Results: Our best submission result during the official phase (evaluated on a random 20% of the hidden test set) has a score of 0.813, with 0.735 sensitivity and 0.892 specificity. Three more submissions are still being evaluated. Discussion: In this task, we found that complex classifiers such as neural networks tend to overfit the training data. Proper regularization, data augmentation, and training set splitting would be key in improving the generalizability of the classifiers.

168-317 **Heart Sound Classification Based on Temporal Alignment Techniques**

Jose Javier Gonzalez Ortiz*, Cheng Perng Phoo and Jenna Wiens

The ability to accurately stratify patients at risk of adverse cardiovascular outcomes using heart sound recordings could result in earlier treatment and improved patient outcomes. However, there are several challenges associated with risk stratifying patients based on the phonocardiogram (PCG) alone. First, the data are subject to temporal variations due to variations in heart rate. Second, inter-patient differences can make it challenging to learn a model that generalizes well across patients. Finally, differences introduced by heterogeneity in the collection of the recordings can render a classifier trained on one population useless when applied to another. To address these challenges, we explore the use of temporal alignment techniques, in particular dynamic time warping (DTW). In our proposed approach, we combine state-of-the-art heart sound segmentation algorithms with DTW techniques to define a representative medoid heartbeat for each recording. Using this medoid as a reference point, we extract a number of statistical features from each recording (e.g. the amount of deviation from this medoid). These features, in combination with other temporal and spectral features, then serve as input to a non-linear SVM. When applied to a left out 10% (chosen randomly) of the provided data, our proposed approach led to significant improvements in classification performance. We achieved an overall sensitivity and specificity of 0.92 and 0.87 respectively, with an average score of 0.89. In comparison, on the same dataset, the challenge baseline achieved a score of 0.68. On the held-out challenge data, a completely unseen dataset, we achieved an overall score of 0.72. These results suggest that our proposed technique leads to more robust features and in turn better generalization. While we have shown that temporal alignment techniques can reduce the effects of inter-patient variability, we believe that further analysis is required to completely eliminate the effects of the heterogeneous data collection environments.

169-159 **Classification of Normal/Abnormal Heart Sound Recordings based on Multi-Domain Features and Back Propagation Neural Network**

Hong Tang*, Huaming Chen, Ting Li and Mingjun Zhong

This paper aims to classify a single PCG recording as normal or abnormal for computer-aided diagnosis. The proposed framework for this challenge has four steps: preprocessing, feature extraction, training and validation. In the preprocessing step, a recording is segmented into four states, i.e., the first heart sound, systolic interval, the second heart sound, and diastolic interval by the Springer Segmentation algorithm. In the feature extraction step, the authors extract 324 features from multi-domains to perform classification. A back propagation neural network is used as predication model. The optimal threshold for distinguishing normal and abnormal is determined by the statistics of model output for both normal and abnormal. The performance of the proposed predictor tested by the six training sets is sensitivity 0.812 and specificity 0.860 (overall accuracy is 0.836). However, the performance reduces to sensitivity 0.807 and specificity 0.829 (overall accuracy is 0.818) for the hidden test set.

170-318 **Heart Sound Classification from Wavelet Decomposed Signal Using Morphological and Statistical Features**

Tamanna Tabassum Khan Munia, Kouhyar Tavakolian, Ajay Verma*
Vahid Zakeri, Farzad Khosrow-Khavar, Reza Fazel-Rezai and Alireza Akhbardeh

Aims: The aim of this study is to assess a large database of heart sounds collected from a wide variety of clinical and nonclinical environments and classify them into normal and abnormal categories based on Support Vector Machine (SVM) classifier. Methods: A total of 3,126 heart sound recordings, collected from different locations of the body from both healthy and pathological subjects were provided by PhysioNet as a training dataset for 2016 Challenge. Individual cardiac cycles which include sound 1(S1), Systole, Sound 2(S2) and Diastole were extracted from all recordings by using Hidden Semi-Markov model (HSMM) based segmentation model provided by PhysioNet. After the segmentation, each cardiac cycle was further divided into four windows as follows: window 1-S1, window 2-Systole, window 3-S2 and window 4-Diastole. Daubechis-2 wavelet transform was applied to each window for each heart cycle at decomposition level 2. Along with seven timing features from each cycle, 36 statistica and morphological features were extracted from each window and were cross-averaged over the whole signal. Classification into normal and abnormal was based on SVM with polynomial kernel function. Results: The algorithm was trained by the heart sound recordings from all the training datasets (training set A to E). The performance of the system was evaluated on 20% of the hidden test data randomly selected by Physionet. Overall classification accuracy of 82% with a sensitivity of 76% and specificity of 88% was achieved during phase 1 submission of the challenge. Conclusion: Based on the current result, the proposed framework could be a possible solution for a robust and automatic classification of healthy and pathological heart sound recordings.

171-321 **Classification of Heart Sound using Time Domain Features**

Ajay Verma, Farzad Khosrow-Khavar, Alireza Akhbardeh, Vahid Zakeri, Reza Fazel-Rezai and Kouhyar Tavakolian*

Background: Phonocardiogram (PCG) is a graphical representation of heart sound. Heart sound quality often reflects quality of cardiovascular system functioning. Early detection of abnormal heart sounds provide physicians with ample of time to take corrective measures in order to counter the cause behind abnormal heart sound and thus, prevent cardiovascular system disruption. The goal of current research is to classify heart sound as a normal or abnormal from short term PCG recordings (5-120 seconds) obtained from clinica and home based settings. Methods: Phonocardiogram data was provided as a part of PhysioNet challenge 2016. Data consisted of 5 training set consisting of 3126 signals. Data label was also provided with each training set. Several time domain heart rate variability features were added to sample code provided on physionet website for this challenge. Application of non-linear features such as max layapunov exponent, sample entropy and detrending fluctuation analysis to classify heart sound were also explored. However, due to processing time constraints non-linear features were excluded to obtain initial score. For current preliminary work MATLAB's classification learner toolbox was used to check the performance of different classifiers on a set of features derived from training set by using 5 fold cross validation. A total of 29 features were extracted. The chosen classifier (support vector machine, Gaussian kernel) model was then used for classification purpose. A MATLAB package entry with variable containing all features and classifier model was uploaded on physionet website for its validation on a randomly selected test set. A score was provided after validation as a maker of classifier perfomance. Results: The performance of classifier was measured in terms of accuracy, sensitivity and specificity. An overall accuracy of 51% with sensitivity of 45% and specificity of 56% was obtained based on the entry score provided.

172-492 **Feature Selection for the Classification of Heart Sounds Recordings based on Entropy Measurements**

Pedro Quintana-Morales*, Antonio Ravelo-García, Eduardo Hernández-Pérez, Sofía Martín-González and Juan-Luis Navarro-Mesa

The automatic classification of pathology in phonocardiograms is still a challenge in the automated classification of cardiac pathologies. Although many works have been focused on this task, it exists enough space for new proposals of characterization and classification of heart murmurs. Entropy based measures can be a good option to study the heart sounds specially in presence of pathologies due to the noise added to the signal that is an indicator correlated to the disorders. Heart sound recordings used here were sourced from several contributors, collected at either a clinical or nonclinical environment, from both healthy subjects and pathological patients. The Challenge training set consists of five databases containing a total of 3,126 heart sound recordings, lasting from 5 seconds to just over 120 seconds. In our methodology we have started considering the segmentation, using Springer's improved version of Schmidt's method provided by the organization, where the fundamental heart sounds have been detailed which include the first (S1) and second (S2) heart sounds and then the systole and diastole interval. We have calculated entropy based measures over different kind of time series generated from the intervals defined by the limit of the segments like S1-S1, S1-S2, etc. Another set of features has been extracted from the time dynamic of the entropy based measures calculated over the segments of the phonocardiograms. An automated statistical classification based on logistic regression has reached accuracy over 74% and hope to improve the results in the following entrances to the challenge.

173-455 **Classification of Heart Sound Recordings via Recurrent Neural Networks**

Yusuf Bugra Erol* and Fahad Kamran

Aim: We aim to develop a new and robust classification algorithm that can accurately classify heart sound recordings -- phonocardiogram (PCG) . The proposed algorithm can handle diverse PCG recordings and poor signal quality. Methods: The task of learning patterns from sequential data is one of the most widely studied problems in machine learning. A recurrent neural network (RNN) can learn complex temporal patterns via its high-dimensional hidden state with nonlinear dynamics and can remember and process past information. RNNs have been used in the context of sentiment analysis, image/video captioning, word prediction and translation successfully. We are utilizing a long short term memory (LSTM) network with the many to one structure to classify heart sound recordings as normal or abnormal. Our approach is similar to the sentiment analysis framework where a given sentence is classified as expressing positive or negative sentiment. The training of the network is done by the stochastic optimization algorithm known as Adam, utilizing a binary cross entropy loss in order to steer the model towards the right direction. The training is done in keras-python, useful due to its flexibility with custom layers, deeper intermediate hierarchy, and ability to control dropout, a Bayesian-regularization feature designed in order to prevent over fitting. In our phase 1, our sensitivity score was .12 and our specificity score was .89. We plan to control our overall score in the future using a more sophisticated layering system for our LSTM model as well as a pre-processing our the input data, possibly leading to a multi-dimensional input system.

174-238 Cycle Selection and Neuro-Voting System for Classifying Heart Sound Recordings

Ali Ghaffari, Mostafa Abdollahpur, Shadi Ghiasi* and Mohammad Javad Mollakazemi

Background: Heart sound can reflect most of the heart valve disorders which can be detected by phonocardiogram signal (PCG) analysis. Sonic vibrations of heart and blood flow are recorded in PCG which can be useful for discriminating pathological heart sounds from normal ones. Aim: This study aims to discuss a new method to classify PCG signals col-lected from a variety of clinical or nonclinical environments. Methods: The raw PCG data was pre-processed by applying a bandpass finite-duration impulse response filter (FIR) and discrete wavelet transform (DWT). For PCG delineation, first (s1) and second (s2) heart sounds were detected based on local extremums and location of minimum slopes of (zero crossing) Shannon energy envelogram, with purpose of recognizing sound incidences and their boundaries. Afterwards, wavelet packet transform was applied to the resulted PCG. In this study, three analyses were used for fea-ture extraction. The first analysis was time-frequency domain analysis in which the energy of nodes of wavelet packet transform was extracted beside the features obtained from the two other analyses which were time domain and frequency domain analysis. Then, with analysis of the ROC curve for feature discrimination, twenty proper features were selected. For heart sounds classification, two classifiers of artificial neural network (ANN) and support vector machine (SVM) were implemented. To accomplish a precise classification, the output of both classifiers were employed in a fuzzy-logic algorithm. Results: The efficacy of the proposed method was evaluated by record-ings of the PhysioNet/CinC Challenge 2016 test dataset, and the sensitivity, specificity and overall score of 81.1%, 87.2% and 84.1% were obtained, respectively.

175-133 **Classification of Heart Sound Signals Based on AR Model**

Runnan He*, Kuanquan Wang, Qince Li, Zhiqiang Sheng, Na Zhao and Henggui Zhang

Heart sounds reflect information of the mechanical contraction of the heart in both of the physiological and pathological conditions. It is important to develop novel numerical algorithms to characterize the features of the heart sound as a helpful diagnostic tool of cardiovascular diseases. This study aims to develop an efficient algorithm for analyzing heart sound signals that can be used for cardiovascular disease monitoring. In the algorithms, wavelet analysis (coif5) with 5 decomposition levels was first applied to heart sound signals for noise eliminating by using a soft fixed threshold. Then, heart sound signals were decomposed by the wavelet method to reconstruct bands with different frequencies. Following this, the normalized Shannon energy of each frequency band within the same time duration was calculated to determine the position of the second heart sound (S2). Finally,the aortic valve closure (A2) of the S2 were extracted using the power spectrum analysis of Auto Regressive(AR) model, which were used to classify the normal and abnormal heart sound recordings. Results show that the modified Sensitivity (Se), Specificity (Sp) and overall score are respectively 0.87, 0.61, and 0.74.

176-230 **Monitoring Cardiac Stress Using Features Extracted from Heart Sounds**

Rajarao M. V., Jithesh M, Nebu George and Ravi Teja M. S.*

Aim: This study aimed to analyze the acoustic signals that are associated with the physiological changes of heart and categorize them as normal or abnormal with the help of Kohonen Self-Organizing Map (SOM). Method: The heart sound recordings were first passed through a bandpass filter to remove the unwanted acoustic information. S1 and S2 heart sounds were extracted from the filtered signal and features such as mean, variance, kurtosis and skew(these features are good indicators of whether the heart is under normal activity or cardiac stress) were examined. Apart from the signals available in the database(from physionet.org), 20 live recordings were taken from operating rooms, consisting of 12 normal patients and 8 patients under cardiac stress, to identify the features as well as to check the accuracy of the algorithm. The extracted features of these recordings were used to train the SOM, which has an unsupervised learning algorithm, which makes it self-learning after it converges. Results: The algorithm was tested against all the recordings in the database as well as the live recordings and accuracy of the results turned out to be 88%. Conclusion: The result is pretty good considering the fact that it's based on artificial intelligence and with newer recordings and subsequent training, the accuracy can be pulled up to a higher extent.

Tuesday, September 13, 2016 **14:15**

S71 **Physionet Challenge I**

Chairs: Gari Clifford and Roger Mark

Room: Pinnacle II

177-154 **Classification of Normal/Abnormal Heart Sound Recording: the PhysioNet/Computing in Cardiology Challenge 2016**

Gari Clifford*, Chengyu Liu, David Springer, Benjamin Moody, Qiao Li, Ricardo Abad, Jose Millet, Ikaro Silva, Alistair Johnson and Roger Mark

In the past few decades heart sound signals (i.e., the phonocardiogram or PCG) have been widely studied. Automated heart sound segmentation and classification techniques have potential to detect pathology accurately in a variety of clinical applications. However, comparative analyses of algorithms in the literature have been hindered by the lack of a large and open database of heart sound recordings. The PhysioNet/Computing in Cardiology (CinC) Challenge 2016 addresses this issue by assembling the largest public heart sound database, aggregated from six sources obtained by multiple research groups around the world. The database includes 2,051 heart sound recordings in total collected from 906 healthy subjects and patients with a variety of conditions such as heart valve disease and coronary artery disease. These recordings were collected using heterogeneous equipment in both clinical and nonclinical (such as in-home visits). The length of recording varied from several seconds to several minutes. Additional data are provided including subject demographics (age and gender), recording information (number per patient, body location, and length of recording), synchronously recorded signals, sampling frequency and sensor type used. Participants were asked to classify recordings as normal, abnormal, or not possible to evaluate. The overall score for an entry was based modified sensitivity and specificity scores with respect to manual expert annotations. A brief summary of the commonly used heart sound segmentation and classification methods is provided, including a description of open source code, which has been provided in association with the Challenge. The open source code provided a score of 0.75 (0.7 Sensitivity, 0.8 Specificity). During the unofficial phase of the competition, a total of 64 teams participated, with a highest score of 0.88 (0.75 Sensitivity, 1.0 Specificity). We conclude with a discussion o several potential benefits from this newly released public heart sounc database.

178-213 **PhysioNet/CinC Challenge: Normal/Abnormal PCG Classification using an Ensemble of Support Vector Machines**

Morteza Zabihi*, Ali Bahrami Rad, Serkan Kiranyaz, Moncef Gabbouj and Aggelos K. Katsaggelos

Objective: Phonocardiogram (PCG) signals are non-invasive recordings which potentially convey information about the malfunctioning of the cardiovascular system. The aim of this study is to develop the binary classification of the heart sound using novel and robust feature set in time-frequency domain and phase space representation. Method: The PCG dataset consists of 3427 (3126 training, and 301 validation) heart sounds recorded from both healthy and pathological subjects with sampling frequency of 2000 Hz. The length and recording region of these signals vary within the provided dataset. We propose two approaches to classify the data into normal and abnormal categories. In the first approach, the signals are denoised by applying K-SVD dictionary learning algorithm. Then, the positions of the first and second heart sounds (S1 and S2) are localized. Variation of the distance between S1 and S2 are used as features. Moreover, 24 other features are extracted from time-frequency domain and phase space representation of PCG. Once the features are extracted, they are fed into an ensemble of SVM classifiers. The second approach is to extract features and classify signals without considering the S1 and S2 segmentation. The main advantage of the latter approach is its relatively low computational complexity. Results: The highest overall score of the proposed approaches is 0.85, which is an unweighted average of sensitivity (0.79) and specificity (0.91). These results have achieved on a random subset of unseen test dataset. The ongoing work will attempt to increase the performance of the proposed approaches by extracting more significant features.

179-266 **DropConnected Neural Network Trained with Diverse Features for Classifying Heart Sounds**

Edmund Kay* and Anurag Agarwal

Introduction: A neural network-based approach is used for the 2016 PhysioNet/CinC Challenge, which aims to classify phonocardiograms (PCGs) as normal or abnormal. The ability to diagnose certain heart diseases accurately using a recording of the heart sound has the potential to reduce the number of inaccurate auscultatory diagnoses by GPs, and also provide better diagnoses in places where there is neither the expertise nor the resources to perform echocardiograms. Segmentation: The segmentation algorithm used is currently the same one as in the sample code. Features: The features are obtained from a continuous wavelet transform (CWT) using the Morlet wavelet. These are normalized, averaged into time and frequency bins, then averaged across well-correlated heart beats. Classifier: The classifier is a fully-connected, shallow (1 or 2 hidden layer), feed-forward neural network, trained using a gradient-based back-propagation algorithm. It uses a cross-entropy cost function, with regularization (to reduce overfitting), and a momentum factor (to mitigate convergence to local minima). In order to obtain results that reduce the chance of overfitting, the recordings from the validation data are removed from the training data. The best networks are then combined in an ensemble in which each network votes on the classification of each recording and the final classification is given by the majority. Results: Performance is initially analysed on the validation data before submitting the best results on the test data. The best result on the test data was 84%. Conclusions and Future Work: High classification accuracy has been obtained with a simple, fully-connected, shallow neural network trained on time-frequency features obtained using the continuous wavelet transform. Future work includes feature extraction using different time-frequency representations of the heart sounds (for example quadratic time-frequency distributions) and the use of deep networks consisting of many convolution and pooling layers.

180-399 **Hybrid Feature Aggregation for Detection of Abnormal Heart Sound**

Cristhian Potes*, Saman Parvaneh, Asif Rahman, Bryan Conroy, Daniel Schulman and John Ames

Background:Heart auscultation is the primary tool for screening and diagnosis in primary health care. Availability of digital stethoscopes and mobile devices provides clinicians an opportunity to record and analyze heart sounds for diagnosis purposes. The goal of 2016 PhysioNet/CinC Challenge is to encourage the development of algorithms to classify normal/abnormal heart sound recordings. In this article, a set of features was derived from a time-frequency analysis of the phonocardiogram (PCG) and then combined with another set of features automatically learned using a convolutional neural network (CNN) in order to find the best algorithm for classification of heart sounds as normal or abnormal. Method:The algorithm was trained on available training dataset (normal= 2575, abnormal= 665) and validated on a subset of blind test dataset. Data was first re-sample (1000Hz) and band-pass filtered (between 25-400Hz) and then segmented to the PCG components (S1, S2, Systolic, and diastolic) of each cardiac cycle using a Hidden Markov Model (HMM). Time (e.g. time differences of S1 onset) and frequency (e.g. power across different frequency bands) features were extracted from each PCG component of each cardiac cycle. Additional features were derived by running a CNN on each cardiac cycle of the PCG. The resulting time, frequency and CNN features were combined and input to an AdaBoost classifier. Sensitivity and specificity on training dataset were used for assessing the algorithm's performance. Results:The best results achieve at the official phase of the challenge on a test data set was sensitivity and specificity of 0.96 and 0.809, respectively (overall score=0.885). Discussion:In this study, we propose a novel approach that combines hand-crafted features with automatic features learned using a CNN to find the best classification method for distinguishing normal/abnormal heart sounds.The result of competition is promising, but further improvement should be made to increase the algorithm's performance.

181-214 **Using Deep Gated RNN with a Convolutional Front End for End-to-End Classification of Heart Sound**

Christian Thomae* and Andreas Dominik

Classifying heart sounds from different recording settings as normal/abnormal is the objective of the 2016 Physionet Challenge. Interpreted as a sequence classification problem, we use gated recurrent neural networks, like long short term memory (LSTM) and gated recurrent unit (GRU), to learn long-term dependencies hidden in the audio sequences. A shortage of promising new features leads us to a challenge entry in which we try to gain a correct method for end-to-end sequence classification. We replace the commonly used step of feature extraction with a convolutional front end to our recurrent neural network. The convolutional front end can be interpreted as a kind of wavelet transformation with a learnable wavelet. We use multiple filter lengths for the convolutions as is done at different decomposition stages in a wavelet transformation. The combination o convolutional layers with recurrent layers into a deep neural network is a promising approach for classifying abnormal/normal heart sounds. Whereas currently trending deep neural networks in speech recognition, machine translation and computer vision use up to a million samples, a restricted set of 3,125 heart sound recordings is available as training data for the challenge. We work around this limitation by augmenting the raw heart sound recordings with various noise sounds, like mixing with speech and motion artifacts, to artificially increase the available set of recordings. Using a moderately sized neural network, we can report a result of 0.87 on the training's data set, following the official challenge scoring, and a submitted phase one entry with an overall score of 0.81 (sensitivity 0.81, specificity 0.82).

182-315 **A Tensor Approach to Heart Sound Classification**

Ignacio Diaz Bobillo*

In the context of the PhysioNet/CinC 2016 Challenge, where a relatively large, labeled data set of phonocardiograms was made available, this work presents a mixed approach to the problem of its binary classification. Instead of laboriously selecting a set of PCG signa features that captures the fundamental differences between healthy and unhealthy heart sounds, a rather exhaustive set of time and frequency domain features is generated for each heart beat segment and represented in a 4-way tensor form. In a second stage, such tensor representation is decomposed and compressed, to determine only a few of the most discriminating resulting parameters, which are then fed to an otherwise standard classifier.This results in an accurate, compact and fast algorithm, that can effectively classify noisy PCG signals of different duration, achieving an overall balanced accuracy of 92% in a random, 10-fold cross-validation setting.

S72 **ECG Signal Processing I**

Chairs: Peter Macfarlane and Marianna Meo

Room: Pinnacle III

183-142 **A Novel Preprocessing Tool to Enhance ECG R-wave Extraction**

Sasan Yazdani* and Jean-Marc Vesin

Purpose: Various approaches have been proposed to detect the R-waves in the ECG. From the derivative-based to more complicated wavelet transform approaches, the main goal of these approaches is to extract the R-waves from the perturbations present in the ECG. Our study aims at proposing a simple preprocessing tool that suppresses perturbations and enhances the R-waves in the ECG by means of a relative short- and long-term energy ratio. Methods: Using two sliding windows, short and long-term signal energy powers are calculated for each sample in the ECG. A coefficient signal is created as the ratio between the corresponding short- and long-term energies. The enhanced ECG is then calculated by multiplying the coefficient signal and the original ECG. Since QRS complexes have relatively higher energy compared to P-/T-waves and the noise in the signal, the coefficient signal values are close to one where QRS complexes take place in the ECG. The MIT-BIH database was used to assess the improvement of R-wave detection. Also, the approach was tested against synthesized white and EMG noises. Results: For the 116137 existing R-waves in MIT-BIH arrhythmia database, using the proposed method as a preprocessing tool to the classic Pan-Tompkins approach lead to a detection rate of 99.7% with 144 false positive and 162 false negative beats. This corresponds to a false positive and false negative beat reduction of respectively 71% and 41% Pan-Tompkins alone. Conclusions: preliminary results suggest the relative ratio between short- and long-term energies can efficiently enhance R-wave detection in the ECG. Importantly, the approach is easily implementable in near real-time. It can be used as a preprocessing tool for the already well known approaches with low computation cost which makes it a suitable approach for online scenarios.

184-403 **Phase-Rectified Signal Averaging for Automatic Detection of QRS Fragmentation**

Griet Goovaerts*, Bert Vandenberk, Carolina Varon, Rik Willems and Sabine Van Huffel

Introduction: Fragmented QRS complexes (fQRS) are defined as QRS complexes that contain one or more deflections, notches or slurs. The presence of QRS fragmentation is a known indicator for myocardial scarring, and has been shown to predict cardiac events in patients witl coronary artery disease and (non-)ischemic cardiomyopathy. Currently, detection of QRS fragmentation in clinical practice is done on a visual basis by inspecting the ECG signal lead-by-lead. Automated detection methods would benefit the clinical usefulness of this parameter. Methods: We propose a fully automatic method that applies Phase-Rectified Signal Averaging (PRSA) to detect fragmented QRS complexes. PRSA consists of 3 steps: First, anchor points on increasing segments of the QRS complex are selected. In a second step, windows surrounding each anchor point are segmented, and finally these windows are aligned and averaged obtaining the PRSA curve. We derive 4 parameters from this curve and its linear approximation. Statistical analysis is done using a two-sample t-test and calculating the effect size using Cohen’s d. Results and conclusion The method has been applied on a fully annotated database from the University Hospitals Leuven consisting of 268 ICD patients. Results show significant differences between fragmented and normal channel for all parameters. Two parameters have a large effect size and one parameter a very large effect size, indicating a very large practical significance. The obtained results prove that the proposed method is a powerful way to detect fQRS and further research will decide whether the parameters can also be used for quantification.

185-125 **Clinical Severity of Noise in ECG**

Estrella Everss Villalba, Francisco Manuel Melgarejo-Meseguer, Francisco Javier Gimeno-Blanes, Salvador Sala-Pla, Manuel Blanco-Velasco, Jose Luis Rojo-Alvarez* and Arcadio García-Alberola

In cardiac signals for rhythm and arrhythmia monitoring, noise is an inherent contaminating component, which is usually measured in terms of quantitative and mathematical magnitudes. However, objective metrics such as the signal to noise ratio and the root mean squared value, are not always related to the actual impact that noise can have on the clinical evaluation. This work is intended to design a database along with a set of criteria to be used as an initial solid gold standard of noise severity within a scale created from the clinical poin of view. Different from previous approaches, we used recordings from cardiac event devices, as far as the morphology and signal characteristics are close enough to usual Holter monitoring, but the recorded events often correspond to noise segments, which makes simpler the retrieval of signal segments with real noise examples. We generated a database recordings from 8 patients (4 female and 4 male with a variety of cardiac pathologies, with age 64.75±25.44 years old). In a first attempt, a set of rules for clinical quality recording are initiall defined by a clinician, so segments with clear clinical description are categorized into free, low, moderate, hard, or other noise. Segments with unclear description are set apart for revision. This process is iterated until convergence of both expert opinion and labels is done. A specific software tool was created and modified for supporting the process for each iteration. The relative duration of the different kinds of noise in both leads according to their clinical severity was: 4h 14m 15s (free, 37.32%), 2h 54m 52s (moderated, 25.67%), 2h 21m 46s (hard, 20.81%), 1h 43m 13s (low, 15.15%) and 07m 07s for other (1.05%). The generated database and criteria represent a valuable gol standard for clinical quality evaluation of noise impact on ECG signals.

186-139 A Correction Formula for the ST Segment of the AC-coupled Electrocardiogram

Ramun Schmid*, Jonas Isaken, Remo Leber and Roger Abächerli

Background: Many ECG devices apply an analog or an equivalent digital first order high-pass filter as part of the ECG acquisition chain. This type of filter is known to not only reduce baseline wandering but also change the ECG signal itself. We present an approach that can estimate the true ST values based on only three standard ECG parameters and the high-pass filter's time constant. Methods: Based on the high-pass filter's time constant T [s], the QRS integral A [Vs], the QRS width W [s] and the RR-interval RR [s], we derived a formula which estimates the high-pass filter induced change in the ST amplitude right after the QRS complex: $\hat{\Delta}$(A,W,RR,T)=A e^(-W/2T)/T(1-e^(-RR/T)) (e^(-(RR-W)/T)-1) A given ST measurement that is based on a high-pass filtered input signal can therefore be corrected by simply subtracting the estimated difference $\hat{\Delta}$. Results: The ECGs used in the experimental setup (1339 different clinical resting ECGs) showed a mean RR interval of 842 ms and a mean QRS width of 95 ms. Furthermore, the effects of the 0.05 Hz high-pass filter showed a linear dependency on the QRS area A. On average, the observed difference in the ST measurement was -0.277 *A which is very close to the difference predicted by the derived formula: Δ (A,W=95 ms,RR=842 ms,T=1⁄((2π0.05 Hz)))=-0.279 *A. Conclusions: The derived formula can be used to correct ST measurements by the use of just a few parameters that are easily obtained by means of automatic measurement. This feature therefore opens up the possibility of reevaluating studies that are based on AC coupled ECGs. Another potential use of this formula is in the diagnoses of patient groups that are known to have large QRS integrals such as patients with a Left Bundle Branch Block (LBBB).

187-488 **QRS Loop Folding Phenomenon in Vectorcardiogram of Healthy Individuals**

Golriz Sedaghat*, Muammar Kabir and Larisa Tereshchenko

Introduction. Recently, we developed a novel approach to study the rap-id and sudden changes in the direction of ventricular activation called fold-ing. In order to better understand this phenomenon, the variation of the ori-entation of QRSi vector for i=1…N and the rotation of its frame of reference were studied using unit quaternions and Euler angles.   Methods. The orthogonal Frank ECG signal was recorded at 1000 Hz us-ing the SpaceLab-Burdick digital Holter recorder in 81 healthy participants from the Intercity Digital Electrocardiogram Alliance study. Respiration was removed using shifting, rotating and rescaling VCG loops. Five clean consecutive sinus beats were selected and their median beat was construct-ed. The spatial QRS vectors, were obtained by joining the QRS loop origin to each sample point of the loop. The rotation unit quaternions which rotate the two consecutive QRS vectors within the shortest arc were calculated. Euler angles were used to compute the angular velocity of the QRS vector across each of the x, y and z axes. Results. We observed that the variance of the elevation of rotation axis (Rax) was significantly higher in men compared to women (1340±421 vs. 1063±381, P=0.003, respectively). Additionally, there was a significant neg-ative correlation between the variance of the azimuth of Rax and height (CC=-0.26, P=0.019) while the elevation of Rax and height was significantly positively correlated (CC=0.24, P=0.034). Moreover, the elevation of Rax had a positive significant correlation with weight and body surface area (CC=0.22, P=0.045 and CC=0.26, P=0.020 respectively). Conclusion. Study of variation of orientation and rotation of QRS vec-tors from sample to sample can add important information to the already existing VCG parameters as well as help us to better characterize the folding phenomenon and its underlying mechanisms. Prospective study is needed to validate the clinical importance of the parameters developed in this paper.

188-202 **Paced ECG Analysis in Mobile Cardiac Monitor**

Alexander Kalinichenko*, Maria Chaykovskaya and Daria Danilova

Aims: Most of the smartphone based ECG recorders do not provide a possibility to analyse pacemaker (PM) rhythm, due to low sampling frequency (100-500 Hz). The objective of our work was to develop the ECG processing method that allows real-time heart rhythm control for the patients with implanted PM. Methods: We used ECG acquisition device based on iPhone series 5 or 5S with sampling frequency 20000 Hz. Frequency range of the ECG is 0.2-5000 Hz. The developed ECG analysis algorithm includes the following stages: noise level analysis, QRS amplitude estimation, PM spike detection with evaluation of its parameters (amplitude and duration), removing of the spike from signal using linear interpolation, compensation of the signal jump caused by polarization using polinomial approximation, low-pass filtering and signal decimation to 1000 Hz. Output signal with removed spikes is transferred to the QRS detection procedure while parameters of the detected spikes are used both for ECG display and for additional ECG analysis. Results: The algorithm was tested with real ECGs set including 83 record-ing, each 300 s long. Following pacing modes underwent analysis: AAA (n=6), VVI (n=11), DDD (n=66), including biventricular pacing (n=17). Total number of the verified PM spikes was 37921. The algorithm correctly detect-ed 37276 spikes (98.3 %) while showed 531 of false positives (1.4 % of the total pulses number). Conclusion: The use of novel smartphone based ECG acquisition device with wide frequency range and high sampling rate allows not only reliable detection of PM spikes but also permits estimation of their parameters. Mo-bile ECG device can be a helpful tool for remote PM patients monitoring.

Tuesday, September 13, 2016 **14:15**

S73 Cardiac Mechanics

Chairs: Johannes Jan Stuijk and Kouhyar Tavakolian

Room: Shaughnessy I

189-258 The Relationship between Mechanical and Electrical Dyssynchrony

Pavel Leinveber*, Josef Halamek, Pavel Jurak, Jaroslav Meluzin, Filip Plesinger, Jolana Lipoldova and Miroslav Novak

Introduction: Patients with true left bundle branch block have a better response to cardiac resynchronization therapy (CRT). Assessment of electrical dyssynchrony based on QRS duration fails to predict CRT response. The time-spatial distribution of high-frequency ECG signals (HFECG) represents an evolution of depolarization that initiates mechanical activity. Methods: Two-dimensional speckle tracking echocardiography (STE) was used to measure mechanical synchrony. For each point corresponding to V1-V6, we measured the first appearance of mechanical activation from STE maps. From electrical maps (QRS amplitude in passband 150-250 Hz) we measured times corresponding to maximal amplitudes in leads (Amax) and 20 % of signal integral (I20 %). At least two measurements were used in each subject and the reproducibility of dyssynchrony shape was tested by correlation. Results: 5 patients proposed for CRT therapy were measured. All results are presented as mean±STD over the subjects. Reproducibility of dyssynchrony shape, defined by correlation: mechanical 0.98±0.02; electrical 0.98±0.04 (Amax), 0.99±0.01 (I20 %). Agreement between mechanical and electrical dyssynchrony shape: 0.80±0.1 (Amax), 0.81±0.23 (I20 %). The level of dyssynchrony was defined as the maximal delay between analyzed leads in each subject. Correlation between the electrical and mechanical dyssynchrony level over subjects was 0.69 (Amax) and 0.85 (I20 %). Discussion: Dyssynchrony analysis based only on QRS duration has many limitations. The time-spatial maps of mechanical and electrical activity have similar shapes and represent detailed information about the time evolution of depolarization. HFECG maps may be used as a simple and cheap diagnostic tool. Limitations: 1) Low number of STE subjects tends to be very artificial, some subjects were immeasurable. 2) Problems with the spatial agreement of mechanical and electrical activity. In three subjects, it seems that electrical lead V1 corresponds to mechanical point V2 (no correction was used).

190-240 **Statistical Left Ventricular Deformation Analysis**

Si Yong Yeo, Xulei Yang, Like Gobeawan, Soo Kng Teo, Liang Zhong, Ru San Tan and Yi Su*

The left ventricular (LV) deformation is associated with LV function, analysis of which gives insight into LV mechanics, increasing the diagnostic value of typical parameters like volume, ejection fraction (EF) and strain. This article describes a statistical technique to characterize the LV deformation. 43 cardiac magnetic resonance imaging (MRI) dataset, consisting of normal and diseased LV, were used in the experiment. The LV endocardial contours were segmented from the MRI slices across the different frames, and reconstructed as spatiotemporal LV meshes. The geometries were aligned and vertex correspondences between the geometries were computed. The deformation of LV geometric vertices were computed at the end-diastolic (ED) and -systolic (ES) frames. The principal component analysis (PCA) was applied to extract the different modes of variation of the LV deformation. This allows the parametric model to describe the complex LV deformation variation. The statistical model can be used to simulate the deformation of the LV geometries. Significant statistical differences were observed between the normal and diseased LV deformation, mostly around the mid and apical regions of the LV. It is shown that 87% of the variation in the LV deformation can be described by the five most significant modes of variation. The PCA transformed data were used as features for training a linear support vector machine (SVM) to classify the normal and diseased LV. The k fold cross-validation technique on the LV dataset yielded a classification accuracy of 92.5%. The SVM model could accurately distinguish the normal LV from the diseased LV with normal EF. This shows that a robust method can be derived from the statistical model of LV deformation to assess the LV function. Such a technique can be used in the analysis of the variation of LV deformation of the different samples.

191-348 **Body Surface Mapping of the Mechanical Cardiac Activity**

Kim Munck*, Bolette Dybkjær Hansen, Nina Jacobsen, Louise Pedersen Pilgaard, Samuel Emil Schmidt, Kasper Sørensen and Johannes Jan Stuijk

Aims: The aim of this study was to evaluate Body Surface Mapping (BSM) of the movement of the chest wall, using a Laser Doppler Vibrometer (LDV), as a method to describe and to investigate mechanical cardiac activity. Methods: The velocity of the chest wall was measured with a LDV in six healthy subjects. The measuring procedure was repeated for 30 points positioned in a grid at the subjects chest. An electrocardiogram (ECG) and respiration were recorded in synchrony with the LDV to support the subsequent processing of the LDV signal to describe the mechanical cardiac activity. Each LDV recording was bandpass filtered at 1-20 Hz, integrated to obtain a displacement signal, and segmented in separate beats using the R-peaks in the ECG. The segments of identical respiration periods were aligned and averaged to obtain the mean systolic interval of the LDV signal. The averaged segments, for each of the grid points, were combined into a series of amplitude maps, revealing the spatial displacement as a function of time. Results: The chest wall displacement maps during systole showed a pattern of initially an outward movement, with the point of maximum deflection moving predominantly laterally during the course of time. The maximum outward displacement occurred 68 ms after the start of the S1 sound (as obtained from the LDV signal in a higher frequency band: 25-80 Hz) at a position of 50 mm left to the sternum and 180 mm inferior to the sternal notch, on average. Subsequently an inward deflection occurred with a maximum at 160 ms after the start of S1 at a position of 64 mm, 135 mm. Conclusion: The LDV is a powerful tool to record low frequency heart sounds and chest wall displacement maps related to the contraction of the heart.

192-208 **Simplified Biomechanical Model of Left Ventricle with Perfusion**

Bruno Burtschell, Radomir Chabiniok*, Magali Bardon, Philippe Moireau and Dominique Chapelle

We propose a simplified biomechanical model of left ventricle accounting for the interaction between myocardium deformations, blood flows inside the cardiac cavity and in the arterial and venous systems, and myocardial perfusion. This model is based on a previously-proposed general poromechanical model formulated to address the specificities of cardiac perfusion, namely, large deformations coupled to rapid fluid flows, and the simplified modeling derivation is performed within a hierarchical approach, whereby the resulting model is directly consistent with a complete family of models of varying complexity. Numerical simulations of our proposed model show that the major features of cardiac physiology are adequately quantitatively represented, both for the cardiac function itself (pressure and flow indicators, ventricle wall thickening, ejection fraction and elastance) and for the perfusion with the so-called flow impediment, in particular. Preliminary simulations of pathological conditions (stenosis of large coronary artery, microvascular disease) as well as of pharmacological impact (vasodilators) are also consistent with clinical observations and data. Furthermore, the complexity of our model is amenable to real time, hence, monitoring applications with diagnostic and therapy planning outcomes can be envisioned as a natural perspective.

193-185 **Measuring Left Ventricular Ejection Time Using Under-the-Mattress Sensor**

Itamar Sela, Zvika Shinar* and Kouhyar Tavakolian

The current experiment aimed to demonstrate the ability to measure the Left Ventricular Ejection Time (LVET) using a piezoelectric sensor placed under the mattress and recording the cardio-ballistic effect (EarlySense (ES) technology). 10 participants were asked to lie supine on a bed with their lower body enclosed in a negative-pressure chamber. Heart system activity was continuously sampled using ES sensors located under the mattress in areas below the sternum. Study's protocol included a baseline phase (a 12 minutes time interval in which the pressure inside the chamber was equal to the pressure outside of the chamber). Then, every 12 minutes the pressure inside the chamber was reduced by a step of 10 mmHg from -20 mmHg to -60 mmHg. The lower body negative-pressure leads to redistribution of the blood due to an increased volume that accumulates in the legs. While increasing the difference between ambient and chamber pressure, and reducing the volume of circulating blood – LVET shortens due to reduced cardiac filling. This is an established model fo controlled hemorrhage in humans. At the end of the protocol the lower body pressure returned to normal for another 12 minutes. A trained echo-cardiographer performed echo measurements throughout the protocol (two measurements per pressure-level) to create an LVET reference dataset. For each subject, and twice per pressure-level, the mean LVET value was calculated at the same time points in which the Echo-cardiograph's LVET was collected. The relationship between the two LVET datasets was analyzed and compared using Pearson correlation and Spearman correlation. Results indicated a correlation of 0.78 ($p<0.001$) and 0.81 ($p<0.001$), for Pearson and Spearman correlation analyses, respectively. The current study's results serve as an evidence for the ability to extract LVET measurements out of an ES's under-the-mattress sensor. One possible use for this technology is early detection of hemorrhage.

194-231 **Detection of Congestive Heart Failure using Renyi Entropy**

David Cornforth and Herbert F Jelinek*

Congestive Heart Failure (CHF) is a disease caused by the inability of the heart to supply the needs of the body in terms of oxygen and perfusion. Detection and diagnosis of CHF is difficult and requires a battery of tests, which include the electrocardiogram (ECG). Automated processing of the ECG signal and in particular heart rate variability (HRV) analysis holds great promise for diagnosis of CHF and more generally in assessing cardiac health, especially for personalized mobile health. However, recording the full 12-lead ECG is a relatively invasive procedure and for that reason it is of interest to determine what can be deduced from the much less intensive measurement of heart rate (RR interval) alone. In addition to calculating SDNN and, RMSSD, which when combined gave an accuracy of 78.8% with the Nearest Neighbour classifier. The best Renyi entropy result was an accuracy of 66.7% using Nearest Neighbour. Combining the best Renyi entropy results with SDNN and RMSSD led to an overall accuracy of 87.9% with sensitivity of 80% and specificity of 94.4%. In this work we have shown that applying Renyi entropy in addition to standard time domain measures identified CHF with higher accuracy than using time domain measures only. In addition, Renyi entropy exponents provide further information about the time signal characteristics that may be important in clinical decision making.

S74 **Atrial Fibrillation-Clinical**

Chairs: Steven Swiryn and Olivier Meste

Room: Shaughnessy II

195-538 **Implantable Device Detected Atrial Tachyarrhythmias: A Few Clinical and Technical Considerations**

Steven Swiryn*

Anticoagulation is known to help prevent stroke in patients with atrial fibrillation (Afib). Early detection of Afib potentially allows early intervention with anticoagulation and prevention of stroke. However, detection of Afib offers a number of difficult technical problems and, even when successful, raises further clinical questions. Can Afib be reliably detected using only RR intervals? What happens to the atrial signal that renders detection difficult? What about short or infrequen Afib episodes compared with longer and more frequent ones? Given Afib, the CHA2DS2-VASc score predicts risk of stroke, but the duration and/or frequency of Afib episodes required to invoke this risk remains uncertain. The temporal relationship between Afib onset and stroke is also uncertain, such that even this basic strategy of early intervention must be questioned. At a more basic level, for those at risk, why does Afib start and stop when it does and what precipitates stroke?

196-370 **Time-Frequency Analysis for Early Classification of Persistent and Long-Standing Persistent Atrial Fibrillation**

Nuria Ortigosa*, Óscar Cano, Antonio Galbis and Carmen Fernández

Aims: This study aimed to assess an early classification of persistent and long-standing persistent atrial fibrillation patients by means of the time-frequency analysis of the surface ECG, which would allow electrophysiologists to choose the most suitable therapeutic approach to treat this arrhythmia. Methods: 140 consecutive unselected patients suffering from atrial fibrillation conformed the study population (84 persistent and 56 long-standing persistent). After ventricular activity cancellation, time-frequency analysis of the atrial activity was performed. Then, the study of phase variations along time for those frequency bands where the average power of atrial activity is concentrated, together with the mean distance between R peaks determined to be significative to allow early classification of these patients. Results: Classification was performed with a Support Vector Machine trained with 20 ECGs (10 corresponding to persistent and 10 to long-standing persistent AF patients). Thus, the test dataset consisted of 74 persistent and 46 long-standing persistent AF signals. Classification results were: Accuracy = 74.16%, Sensitivity = 71.72%, Specificity = 78.26%. Area Under the ROC curve is 0.8189. Conclusion: We propose a non-invasive approach to early classify patients suffering from persistent and long-standing persistent atrial fibrillation. The time-frequency analysis of the surface ECG proposed has obtained promising results, especially taking into account that works aimed to solve this problem are scarce (since most of the state-of-the-art has been working in paroxysmal and persistent atrial fibrillation classification).

197-342 Noninvasive Recurrence Quantification Analysis Predicts Atrial Fibrillation Recurrence in Persistent Patients Undergoing Electrical Cardioversion

Olivier Meste, Stef Zeemering, Joel Karel, Theo Lankveld, Ulrich Schotten, Harry Crijns, Ralf Peeters and Pietro Bonizzi*

Aims: Noninvasive quantification of atrial fibrillation (AF) substrate complexity is increasingly being used to discriminate among AF types and to predict therapy outcome. Parameters that quantify stationary substrate properties appear to be suboptimal in predicting AF recurrence following electrical cardioversion of persistent AF patients. Recurrence plots (RP) and recurrence quantification analysis (RQA) can unveil more subtle information about the oscillatory patterns of a signal, which in turn may result in more accurate prediction. Methods High-density body surface potential maps (BSPMs, 120 anterior, 64 posterior electrodes) were recorded in 63 patients in persistent AF prior to electrical cardioversion (32 recurrences occurred after 4-6 weeks). AF complexity was assessed on extracted atrial activity (AA) by means of several state of the art noninvasive parameters and by novel parameters obtained from non-standard RQA. Novelty resides in the use of a normalized correlation instead of the Euclidian distance to build RP and in transforming RP matrices into signals (by diagonal averaging) containing information about propagation pattern organization. Results: A generalized linear model was individually applied to each complexity parameter. None of those parameters showed to be a significant discriminant of AF recurrence. Novel RQA parameters showed that non-recurrent patients were characterized by temporally more stable propagation patterns than recurrent patients, suggesting more organized AA patterns and a lower complexity of the AF substrate in the former. RP-based parameters gave better performance than state of the art parameters (AUC: 72% vs. 63%, $p<0.05$). Conclusion: Noninvasive assessment of AF substrate complexity in patients characterized by very similar levels of AF disorganization is improved by applying RP and RQA to the extracted AA signals. This analysis and the novel parameters proposed provide a more accurate description of the AA oscillatory patterns and help predicting AF recurrence in persistent patients undergoing electrical cardioversion.

198-350 **Wrist-Located Heart Rate Monitor Device Used for Atrial Fibrillation Screening: A Preliminary Study**

Mathieu Lemay*, Sibylle Fallet, Philippe Renevey, Celestin Leupi, Etienne Pruvot and Jean-Marc Vesin

Introduction: Atrial fibrillation (AF) is increasing with ageing of the population and the epidemic of obesity. Ambulatory electrocardiogram (ECG) monitors have been widely used for the screening of AF. These systems are cumbersome and require time-consuming analysis that limits their use for the screening in large populations. CSEM has recently developed an accurate wearable wrist located heart rate monitoring device using photoplethysmographic (PPG) signals with optimal opto-mechanical design and signal enhancement. This study aims at evaluating the performance of this PPG-based device in terms of AF detection using features based on RR intervals. Methods: The database is made of 11 patients referred for catheter ablation of cardiac arrhythmia in whom episodes of sinus rhythm (SR) and AF coexisted. PPG and 12-lead ECG signals were recorded simultaneously. Segments of SR and AF were identified by experts. On PPG signals, cardiac interbeat intervals (RR intervals) were estimated using first derivative-based approach applied after pre-processing. On ECG signals, RR intervals were provided by electrophysiology system (Siemens Sensis). Resulting PPG- and ECG-based RR interval time series were used to derive 5 features using 10-second windows: mean, standard deviation, minimum, median, and interquartile range values. A support vector machine (linear kernel and margin at 10) was used to classify these two classes of 10-second epochs. Results: A total of 662(580 of AF, 82 of SR) epochs were considered for classification. All feature distributions showed statistical differences between AF and SR (Kolmogorov-Smirnov test with p-values < 0.001). AF and SR classification accuracy of 92.13% and 97.65% were obtained from PPG- and ECG-based features, respectively. Conclusion: These preliminary results confirm that our wrist-located PPG-based monitor with high signal quality might be used for the screening of AF in large population with a reasonable accuracy. Further investigation in specificity improvement is still required to achieve ECG-based diagnostic devices performance.

199-188 **Beat-to-Beat Analysis of P-Waves in Patient with Atrial Fibrillation History**

Valentina Corino, Federica Censi, Marianna Tesoro, Ivan Corazza, Elisa Reggiani, Giuseppe Boriani and Luca Mainardi*

P wave morphology has been shown to be modified in patients with paroxysmal atrial fibrillation and in healthy subjects of different age. These changes are commonly evaluated in the signal averaged ECG, thus in average P waves. Aim of this study is to assess beat-to-beat variations in P wave characteristics. Five-minute 12-lead ECG were recorded (2044 Hz) from 10 healthy subjects (control group), 10/10 patients with/without an AF recurrence (rec/no_rec groups), after electrical cardioversion (EC). The recurrence was defined when an AF episode occurred in the six months following EC. Principal component analysis, implemented through an algorithm based on by Singular Value Decomposition, was performed on a beat-to-beat basis. The dynamic of the first three eigenvalues series (L1, L2, L3) were studied by a linear predictability and a regularity index. In addition, the beat-tc beat variability of the first three principal components (PCs) morphology was analyzed by calculating the Euclidean distance between the average morphology over all the beats acquired and the morphology identified on each beat for the first three PCs (D1, D2, D3). All the indexes were statistically different between the control group and the patients with history of AF, highlighting higher regularit of the eigenvalues series as well as more similar PCs. In addition, the L1 series was significantly less regular in patients with AF recurrence compared to both the other groups (R: 0.12±0.08, 0.02±0.02, 0.06±0.03 control vs. rec vs. no_rec, all $p<0.05$). D1 was also different comparing the rec and no_rec groups (D1: 11±4 , 21±6, 26±5 control vs. rec vs. no_rec, all $p<0.05$). The applied measures were able to discriminate patients with AF history from healthy subject. In addition the preliminary results seem promising to differentiate patients with and without recurrence of AF after EC.

200-310 **Contributing Factors Concerning Inconsistencies in Persistent Atrial Fibrillation Ablation Outcomes**

Tiago Almeida, Gavin Chu, Xin Li, João Salinet, Nawshin Dastagir, Michael Bell, Frederique Vanheusden, Jiun Tuan, Peter Stafford, G. André Ng and Fernando Schlindwein*

Background: We investigated current clinical methods for complex fractionated atrial electrogram (CFAE) classification during persistent atrial fibrillation (persAF). In particular, factors that directly influence the low reproducibility of CFAE-guided ablation outcomes in persAF therapy, such as inconsistencies in automated CFAE classification performed by different systems, the co-existence of different types of atrial electrograms (AEGs), and insufficient AEG duration for CFAE detection. Methods: 797 bipolar AEGs were exported from NavX (St. Jude Medical) from 18 persAF patients undergoing pulmonary vein isolation and roof line ablation (PVI+RL). CFE-Mean, CFE-StdDev and peak-to-peak were exported from NavX, while the interval confidence level, average and shortest complex interval – as defined by CARTO (Biosense Webster) – were calculated offline using a validated MATLAB script. Sample entropy, dominant frequency and organization index were also calculated offline. Results: First, we show that CFAE classification varies for the same individual, depending on the commercial system being used. Revised thresholds were found for the indices calculated by each system to minimize the differences in automated CFAE detection performed independently by them. Second, our results show that some AEGs are affected by PVI+RL in persAF, while others remain unaffected by it. Different types of AEGs might correlate with distinct underlying persAF mechanisms. Multivariate analysis using the multiple descriptors measured from the AEGs effectively discriminated the different types of AEGs. Finally, we show that consecutive AEGs with 2.5 s resulted in different ablation target identification using the CARTO criterion, which would affect the ablation strategy and contribute to conflicting outcomes in AEG-guided ablation in persAF. Our results suggest that CARTO should consider AEGs with longer duration to measure CFAEs. Conclusions: A thorough re-evaluation of the definition of CFAE is necessary in order to refine the identification of critical atrial regions responsible for the perpetuation of the arrhythmia in patients with persAF.

Tuesday, September 13, 2016 **16:00**

S81 ECG Imaging II

Chairs: Henggui Zhang and Willem Dassen

Room: Pinnacle II

201-211 **Performance of Inverse Problem Regularization Methods for Driver Location during Atrial Fibrillation**

Carlos Figuera, Víctor Suárez-Gutiérrez, Óscar Barquero-Pérez, Rebeca Goya-Esteban, Miguel Rodrigo, Ismael Hernández-Romero, Felipe Atienza, Maria de la Salud Guillem Sánchez*, Andreu M Climent and Felipe Alonso-Atienza

Background Regularization methods for the inverse problem of electrocardiography are usually analyzed during stationary rhythms. However, the feasibility of inverse methods to estimate driver locatior under irregular patterns such atrial fibrillation (AF) have not been systematically evaluated. Aim We compare different regularization techniques for driver location in AF conditions by proposing new performance metrics. Methods We use a realistic mathematical model of atria and torso to simulate two complex patterns: AF, with a single reentry; and Complex AF (CAF), with 50% of atria cells under fibrotic conditions. The associated body surface potentials are computed using the model. We tested 14 regularization methods. Bes ones were the Tikhonov (Tik-i0), Greensite (GS) and Bayes. To quantify the feasibility of each method, we estimated the probability of the driver being in a location, (instead of binary detection) and computed the spatial mass function (SMF) of the driver location. We compared estimated and real SMFs (computed from real potentials) using three proposed metrics: weighted under-estimation indicator (WUI), defined as the percentage of the location area (points with SMF>0) that is not detected out of the entire true location area; weighted over-estimation indicator (WOI) defined as the percentage of the misjudged location area out of the estimated area; and correlation coefficient between SMFs (CC). Results Although all three methods identified the main driver, Bayes method presented highest accuracy quantified by WUI and WOI, and CC in both scenarios (AF: WUI = 20.68 %, WOI = 6.53 %, CC=0.78; CAF: WUI = 2.64%, WOI=9.29%). Tik-i0 performance degraded for CAF (CC from 0.52% to 0.24%), while Bayes and GS did not. Conclusion All three regularization methods were able to noninvasively identify AF drivers. Bayes methodology, incorporating prior information, provided highest accuracies. Proposed metrics allowed a systematic comparison.

202-148 **Source Localization Probability Maps for Uncertainty Quantification in Electrocardiographic Imaging**

Jessie France* and Chris Johnson

Aims: This study aimed to quantify the impact of noise amplitude, and it- erative Krylov regularization on source localization for electrocardiographic imaging (ECGI). Using Monte Carlo error propagation, we developed prob- ability maps that illustrate uncertainty in source localization compared to the ground truth source location. Methods: We added artificial Gaussian white noise to the body surface potentials between (0.5% and 7% of their amplitudes) to simulate noisy ob- servations. We solved the inverse problem to recover heart surface potentials using the conjugate gradient least squares (CGLS) and preconditioned CGLS (PCGLS) algorithms with the Laplacian over the heart surface as a right pre- conditioner. We forward propagated these inverse solutions, and performed 200 CGLS and PCGLS Monte Carlo inversions per noise level. For each sample, we recorded the top 1% of lowest potential locations, and normalized across all samples to form empirical probability maps for source localization. Results and Conclusion: Increasing the noise amplitude increased both the uncertainty and inaccuracy for source localization, with PCGLS outperforming CGLS across all noise amplitudes. We conclude that the concept of a source localization probability map may be useful clinically in identifying origins of arrhythmia in cardiac tissue.

203-397 **Reconstruction of Atrial Ectopic Focal and Re-entrant Excitations from Body Surface Potentials: Insights from 3D Virtual Human Atria and Torso**

Erick Andres Perez Alday*, Michael A Colman and Henggui Zhang

Non-invasive electrocardiographic imaging has been seen as a painless and economic method to map the electrical functions of the heart. However, it is still a great challenge to obtain accurate reconstruction of cardiac electrical activity from body surface potentials (BSP) due to the ill-posed behaviour of the cardiac inverse-problem. Though some advances have been made in solving the inverse-problem, few studies have been conducted for the atria, which have dramatic differences to the ventricles in their anatomical structures and electrophysiological properties. It is unclear either how the spatial resolution of electrodes on the BSP and rapid excitation rates of atrial activation during atrial fibrillation affect the accuracy of the inverse-problem. In this study, we used a biophysically detailed model of the human atria and torso to investigate effects of multi-lead ECG on the accuracy of reconstructed atrial excitation pattern on the epicardiac surface during the time courses of atrial fibrillation induced by electrical remodelling. It was shown that the solution of the atrial inverse-problem was dependent on the spatial resolution of electrodes on the body surface. The solution was also influenced by the morphology of the AP, rate and types of atrial excitation as well as the implantation of variant orders of the Tikhonov regularization method.

204-294 **Adaptive placement of the pseudo-boundaries improves the conditioning of the inverse problem**

Judit Chamorro-Servent*, Laura Bear, Josselin Duchateau, Corentin Dallet, Yves Coudière and Remi Dubois

INTRODUCTION: A meshless method based on the method of fundamental solution (MFS) has been adapted to non-invasive electrocardiographic imaging (ECGI). In the MFS, potentials are expressed as summation over a discrete set of virtual point sources placed outside of the domain of interest. It is well-known that optimal placement of these sources can improve the posedness and efficacy o the MFS. Despite this, there have been not attempts to optimize their placement in the ECGI problem. In the standard MFS, the sources are placed in two pseudo-boundaries constructed by inflating and deflating the heart and torso surfaces respect to the isobarycenter of the heart. However, for some heart-torso geometries, it can be a poor reference. METHODS: As the reference to inflate locally the torso surface, we replaced the isobarycenter of the heart by the closest point of the heart for each torso electrode. We used Discrete Picard condition (DPC) and Singular Value Analysis (SVA) as tools to optimize the distance and source distribution and we compared the ill-posedness for different torso-heart geometries. Finally, we compared the dependency of the reconstructed heart signals to different regularization parameters for a patient referred to have scar. RESULTS: The percentage of useful singular values (SVs) provided by DPC is an indication of the conditioning of a problem. For the new distribution of sources we obtained 50% of useful SVs, against 38.30% for the current one. Furthermore, the variability of the minimum activation times for different regularization parameter was also reduced (~16ms for the new distribution against ~22ms for the standard one). CONCLUSION: In this work, we showed that an optima placement of the torso virtual sources improves the conditioning of the MFS problem making the solution less sensitive to the regularization parameter chosen. This improvement is more significan for hearts presenting structural diseases.

205-340 **Assessing Endocardial Activation from Bipolar Intra-Ventricular Electrodes: A Simulation Study**

Peter Johnston* and Gerald Fischer

Aims: Assessment of endocardial activation using filtered catheter recorded electrograms has become a standard clinical technique. This study aims to assess factors affecting the accuracy of this process. Methods: A four-electrode 7F mapping catheter was placed in a half-ellipsoid model of a ventricle filled with blood, with the tip electrode in contact with the ventricular wall. Pacing was introduced into the mid-ventricular wall resulting in a depolarisation wavefront propagating through the myocardium. Electrical potentials were computed on each of the four electrodes on the catheter. The bipolar signals (BP) were produced and 10 to 200 Hz band-pass filtered. Local activation at the catheter location was estimated by automatically determining four signal annotations: onset, first maximum, steepest slope and minimum value. These steps were repeated with the catheter in several locations around the endocardial surface. As a reference timing, the action potential (AP) upstroke at each catheter contact point was determined. Results: The AP reference activation time varied by 56 ms from earliest to latest activation. All four bipolar annotations correctly identified the location of earliest and latest activation. However, in all cases the BP activation interval was prolonged with values ranging from 58 ms (minimum value) to 82 ms (onset). Correlations computed by comparing the BP annotations with the AP reference ranged from 0.82 (onset) to 0.99 (minimum value). Also, for absolute timing, the minimum value annotation produced best results, yielding a mean error of 5.7 ms.   Conclusion: The simulation study confirmed the ability of catheter based signals to assess relative timing (?early vs. late?) of ventricular activation. However, absolute errors were high, amounting to 10% of the activation interval. Computer based investigations provide insight into how relevant parameters (catheter size/angle, filtering) affect accuracy. This may allow for further improvement of catheter based techniques.

206-518 **Electrocardiogram Reconstruction from Optical Mapping Recording of High Spatial-Temporal Resolution of Transmembrane Potentials**

Conner Herndon*, ILIJA Uzelac, James Farmer and flavio fenton

In optical mapping experiments, it is common to record simultaneously electrocardiograms to monitor the overall health condition of heart preparations and to obtain dominant frequencies during arrhythmic and defibrillatory studies. However the ECG reconstructed from optical mapping is seldom used to date and it has not been strictly validated. In this manuscript we present the first detailed validation and comparison of Optical Mapping ECG or OM-ECG with standard ECG recordings by calculating the electrostatic potential in space as a function of series of 2-D images representing transmembrane voltage obtained from heart surface at high frame rates of 500-1000 fps, and describe different approximations used to obtain unipolar or bipolar ECG recordings. We found that in small/medium hearts such as of rabbits and cats, due to symmetries ir the ventricular activations, ECG leads that are aligned apex to base, only require activation recording from one surface (anterior or posterior) for the OM-ECG to match the ECG, while for leads aligned left to right an anterior and posterior optical mapping recordings may be needed. We believe that OM-ECG method has two main direct applications. The first is related to defibrillation studies where ECG information right after the shock may be crucial for development of new defibrillation strategies, as OM-ECG is not dependent on the post shock current artifacts that make impossible to record ECG for some time. We also present examples with stimulated whole rabbit hearts where even just low pacing artifacts are unavoidably captured by the ECG but do not appear in the OM-ECG. The second use of this technique would be for possible reconstructions of intramural dynamics in larger hearts where differences between the ECG and OM ECG obtained from anterior and posterior recordings can be used to derive the intramural activation.

Tuesday, September 13, 2016 **16:00**

S82 **Novel Techniques for Heart Rate Variability**

Chairs: Alejandra Mandujano and Alfredo Hernandez

Room: Shaughnessy I

207-166 **Heart Rate Variability Estimation with Joint Accelerometer and Gyroscope Sensing**

Olli Lahdenoja, Tero Hurnanen, Mojtaba Jafari Tadi*, Mikko Pänkäälä and Tero Koivisto

Aims: Many wearables are equipped with MEMS based 3-axis accelerometer and 3-axis gyroscope. The purpose of this study is to assess the suitability of Heart Rate Variability (HRV) extraction based on joint usage of accelerometer and gyroscope. Methods: The proposed method uses a combination of accelerometer and gyroscope to obtain more robust inter-beat (beat-to-beat interval) estimates. The signals of each axis were first preprocessed with bandpass filtering. Fo each axis the beat-to-beat intervals were extracted by using single-axis autocorrelation (1-AC). The signal was divided into windows of length 2.5s (overlap 1.5s). For each window the period was calculated using autocorrelation. The axes were combined so that one of the six previously calculated beat-to-beat intervals (the closest to the previously calculated interval) was iteratively chosen as the output. This is the 6-AC method. ECG was recorded simultaneously as a reference with the same sampling rate (of 800Hz). Beat-to-beat intervals were estimated also from ECG using the Pan-Tompkins method. This study used 29 healthy male volunteers. The sensor was attached to the chest of the subjects lying in supine position with a double sided tape. The minimum length of the recordings was 1min 44s. The resulting HRV parameters were calculated using the Kubios software. Results: The mean error (1-AC and 6-AC against ECG) of three most important HRV parameters are shown here; HR (Heart rate): (0.216, 0.157) (1/min), STD HR: (0.634, 0.218) (1/min), RMSSD: (11.845, 5.286) (ms). From a total of 17 different HRV parameters, a total of 15 were improved. Conclusions: The results validate that the combination of all 6 axes provides improved HRV estimates.

208-376 **Extraction and Analysis of Short-Time Excursions in RR-interval Time Series**

Jean-Marc Vesin*, Sasan Yazdani, Leila Mirmohamadsadeghi and Nicolas Bourdillon

Purpose: RR-interval time series often present “spikes” corresponding to short-duration increases or decreases in the heart rate, and indicating bursts in autonomic activity. The time-domain heartrate variability index pNN50 is obviously linked to these spikes. As linear filtering is not appropriate for the extraction of these spikes, we developed a nonlinear algorithm for this task. In this study we demonstrate the potential of this approach to assess caffeine-induced changes in the autonomic tone. Methods: Data were recorded from 15 subjects. The ECG and airflow were recorded simultaneously at 1000 Hz. The subjects underwent recording under the influence of caffeine (6 mg/kg). Each recording session consisted of 10 minutes spontaneous breathing (rs), 10 minutes breathing at 9 breaths-per-minute (bpm) and 10 minutes breathing at 12 bpm. Baseline recordings were performed before the subjects ingested the caffeine in all three breathing modes. RR-intervals were extracted from the ECG and regularly resampled at 4 Hz. Then, the spike signals were extracted using our algorithm. Results: For rs, the mean values of the spike signals were smaller in 13/15 subjects after caffeine ingestion, indicating a shift towards downward spikes and thus increased sympathetic activity (Wilcoxon $p<0.01$). The normalized powers in the LF (0.04-0.15 Hz) band increased only in 6/15 subjects ($p = 0.53$). For controlled breathing at 12 bpm (0.2 Hz), the mean values of the spike signals were smaller in 13/15 subjects after caffeine ingestion ($p<0.04$), and the normalized powers in the LF band increased only in 7/15 subjects ($p = 0.51$). Conclusions: Preliminary results show that, although their power is only a small fraction of the total RR-interval power, RR spikes may be useful indicators of autonomic tone.

209-454 **Mental Stress Detection Using Cardiorespiratory Wavelet Cross-Bispectrum**

Spyridon Kontaxis*, Jesus Lazaro, Alberto Hernando, Adriana Arza, Jorge Mario Garzón, Eduardo Gil, Pablo Laguna, Jordi Aguiló and Raquel Bailón

In this work quadratic phase coupling between respiration and heart rate variability (HRV) has been studied during emotional and mental stress using wavelet cross-bispectrum (WCB). A total of 80 healthy volunteers subjected to a standard stress protocol have been analyzed. Some features derived from the WCB, such as the frequencies at which the maximum peak is located, the distribution of the dominant peaks and the phase entropy have shown statistical significant differences between stress and relax stages. A support vector machine classifier based on these features discriminates stress stages from relax ones with an accuracy ranging from 68 to 89%, suggesting that the interactions between respiration and HRV are altered during stress and may be used to assess it.

210-504 **Mobile Based Study Links Insomnia and Sympathovagal Balance**

Shuli Eyal* and Anda Baharav

Aims: Insomnia is a high prevalence sleep disorder. Current theories point towards the role of cognitive and physiological hyperarousal in the pathophysiology of Insomnia. Our aim was to investigate the potential application of autonomic nervous system characteristics for understanding and assessing insomnia. Methods: RR intervals (RRI) were recorded using a mobile app, SleepRate by HypnoCore, and off-the-shelf sport belt (Polar H7 by Polar). App users belonged to one of two groups; those who participated in sleep assessment and therapy program (group A) and those who just monitored their sleep (group B). For sleep assessment, the app requires 6 out of 7 consecutive recording nights. 78 users of group A, were labeled by the app as insomniac. This group had a total of 468 nights (insomnia nights- IN). They were compared to 165 users of group B, with a total of 989 nights (reference group – RG). Heart-rate variability analysis was performed for each night. Nightly autonomic baseline (NAB) for the sympathovagal balance was defined as the minimum mean autonomic balance (averaged over a 10 minutes window), in the first 2 hours of sleep. Values are presented as mean +/-standard error. Results: Mean heart-rate in IN nights (62.5+/-0.46BPM) was similar to that in RG (61.9+/-0.28BPM). NAB value of IN was significantly higher 1.87+/-0.13 compared to 1.59+/-0.06 in RG. The autonomic arousal index, as expressed by a series of decrease in RRI was 12.96+/-0.30 in IN and was not significantly different than in RG, 13.6+/-0.19. Conclusion: Mobile technology enabled very large scale, previously impractical, measurement of physiological signals. The findings show an increased sympathetic predominance in insomniac users. This is consistent with recent theories which have linked physiological hyperarousal and insomnia. The autonomic approach to sleep evaluation may be a useful alternative to the gold standard whole night PSG for poor sleepers.

211-510 **Network Analysis of Heart Beat Intervals Using Horizontal Visibility Graphs**

Tamas Madl*

Heart beat interval time series contain information predictive of heart disease, but most current predictors do not provide sufficient reliability for clinical use. Using several predictors improves prognostic power, but the limit is not yet known, suggesting that not all the information in inter-beat interval series has been captured by previous work. We convert heart beat time series into scale-free networks using horizontal visibility graphs (HVGs), which are well-suited to distinguishing deterministic dynamical systems from stochastic systems, allowing them to model new aspects of autonomic heart rate modulation. Based on the HVG, we introduce and evaluate a general class of predictors, which can be used to augment existing features used in heart rate variability (HRV) analysis, and which exhibit high prognostic power for several types of heart disease. We show the statistical significance of these network predictors, and their competitive performance to popular statistical, geometric and non-linear features, on a subset of the Multi-Parameter Intelligent Monitoring for Intensive Care II dataset, including several heart disease etiologies.

Tuesday, September 13, 2016 **16:00**

S83 Multi-scale Modelling

Chairs: Rob McLeod and Andreu Climent

Room: Pinnacle III

212-425 **Mechanism behind Hyperkalemic Brugada Phenocopy: A Computational Study**

Ismael Hernández-Romero*, Paula Giménez, Allan Rivera, Carlos Figuera, Maria de la Salud Guillem Sánchez, Francisco Fernández-Avilés, Andreu M Climent and Felipe Atienza

Background: Brugada Phenocopy (BrP) describes an ECG pattern that imitates the morphology of a congenital Brugada Syndrome, but is caused by other factors, such as metabolic abnormalities, ischemia, etc. Understanding the underlying mechanisms of BrP can improve the outcome of these patients. This study proposes an explanation to BrP elicited by hyperkalemia. Methods: A 3D wedge model of right ventricle was implemented, along with the three types of cells (endocardial, mid-myocardial and epicardial) described at O'Hara 2011 action potential model. Anisotropic conduction was generated using the fiber directions of the geometrical model, adding a slower zone corresponding to right ventricular outflow tract (RVOT). Computer simulations were performed increasing the amount of extracellular potassium from healthy stage [K+]o = 5.4 to hyperkalemic condition [K+]o = 10 mM. Pseudo-ECGs were calculated at position that V1 occupies of the standard 12 lead ECG. Changes in morphology of ECG waves, isochrones maps over the model and spatial conduction velocity (CV) were quantified. Results: The gradually increment of [K+]o increased the resting potential, (-87.67 mV basal to -71.08 mV), and reduced the conduction velocity, decreasing until the 26,6% of basal CV with [K+]o = 10 mM. This reduction of CV prolonged activation sequence and produced the elevation of the ST segment on the ECG. Moreover, T-wave was decreasing progressively and started to be negative from [K+]o = 7 mM. These two features are typical of Brugada morphology. Attached figure represents ECGs for the different concentrations of potassium. This behavior disappears if the slow zone simulating RVOT is removed, showing the pseudo-ECG a typical hyperkalemic morphology. Conclusions: Heterogeneity of CV is the main reason of Brugada Phenocopy in a hyperkalemic stage. Increasing [K+]o promotes these differences, due to elevation of resting potential and lower availability of sodium channels.

213-160 **Effect of Heart Failure-induced Electrical Remodeling on the Initiation of Atrial Arrhythmias**

Na Zhao*, Qince Li, Kuanquan Wang, Yong Xia, Runnan He, Xiangyun Bai and Henggui Zhang

Heart failure (HF) is a particularly prevalent clinical condition promoting atrial arrhythmias, associated with structural and electrical remodeling in the atrial tissue. However, the underlying mechanism is rarely studied. In this study, using a GPU-based simulation, a biophysically detailed computational model of the three-dimensional (3D) sheep atria is applied to investigate the mechanism by which HF-induced electrical remodeling promoting atrial arrhythmia. The effect of HF-induced changes of L-type calcium channel current (ICaL) (reduction by 36%), the sarcolemma reticulum (SR) calcium release and uptake were mimicked based on experimental data, which were incorporated into the sheep atrial cell model developed by Butters et al. (2013). At the single cell level, effects of such HF-induced electrical remodeling on the action potential (AP) profile and its duration (APD) as well as the intracellular Ca2+ handling were evaluated. Furthermore, the single cell models were incorporated into an anatomically accurate and biophysically detailed 3D model of the sheep atria to quantify the effects of the HF-induced electrical remodeling on the APD dispersion and the vulnerability of the tissue to the initiation of re-entrant excitation that underlies atrial arrhythmias. At the cellular level, simulation results demonstrated that the APD and the amplitude of systolic Ca2+ transient were decreased while the SR Ca2+ content was unaltered in the HF condition, which were consistent with experimental observations. At the 3D whole organ level, simulations results showed that the APD shortening caused by the HF-induced electrical remodeling was non-uniform across the sheep atria, resulting in an increased vulnerability of the tissue for the initiation of the re-entry. This study provided new insights into understanding the mechanism by which HF promotes atrial arrhythmias, demonstrating potential implications for treating and preventing HF-related atrial arrhythmias.

214-280 **Analysis of in-silico Body Surface P-wave Integral Maps show important differences depending on the connections between Coronary Sinus and Left Atrium**

Ana Ferrer-Albero, Eduardo J. Godoy, Rafael Sebastian*, Laura Martínez and Javier Saiz

Motivation: Several studies of the human atria have histologically shown the existence of striated myocardial muscle at discrete locations along the wall of the CS that connects electrically CS and LA myocardium. Existing 3D models of the human atria have tried to model this region, although, there is no consensus on the number and location of these connections, which could affect the atrial activation sequence and the body surface patterns. Aims: This study aims to determine which configuration of CS-LA connection reproduces more accurately a set of clinically observed body surface P-wave integral maps (BSPiM). These maps summarize the P-wave morphology over the torso surface. Methods: A validated multi-scale 3D human atrial-torso model developed by our group was used to perform biophysical simulations of electrical atrial depolarisation and their corresponding BSPiM. Several scenarios were simulated by pacing in distal and proximal LA distinct sites. From the ECG, the integral was calculated and graphically represented by 3D maps on the torso surface. These in silico patterns were then compared with published clinical patterns obtained from patients. Results: The BSPiM produced when the potential wavefront enters through distal muscular CS-LA connections (a), shows that P-wave morphology is positively signed mainly on the right side of the frontal torso surface, i.e., the wavefront depolarizes both the LA and the RA upwards. However, when the wavefront does not find distal muscular CS-LA bridges (b), the LA depolarizes upwards, and the RA activates from the Bachmann bundle and downwards to the ring. This produces a positive P-wave integral pattern on the inferior part of the torso and negative on the superior side. Simulations with proximal CS-LA connections (c) show patterns inverted with respect to those without them (d). The patterns associated to models with proximal and distal CS-LA connections, (a,c) match closely in-vivo clinical BSPiM.

215-477 **Role of Substrate Flexibility on Cardiac Cell Culture Electrophysiological Properties**

Lidia Gomez, Lucia Fuentes, Ismael Hernández-Romero, Maria de la Salud Guillem Sánchez, Felipe Atienza, Francisco Fernández-Avilés and Andreu M Climent*

Background: Engineered cardiac patches are a promising tool to regener-ate damaged cardiac tissue after ischemic and remodeling events. Major con-siderations in the design of engineered cardiac patches are the regenerative and electrophysiological properties of cardiac cells. Purpose: The objective of this study is to compare key cardiomyocyte functional properties for cardiac repair (i.e. proliferation, migration and elec-trophysiological properties) and gene expression depending on the cell cul-ture substrate. Methods: Atrial murine cells (HL-1-myocytes) were cultured in two different substrates: (1) rigid Petri dishes and (2) flexible PDMS (polydimethylsiloxane) wells. The proliferation rate, migration and conduction velocity of the cardiac cells were analyzed and compared in both substrates together with the expression of main genes involved in the action potential generation and propagation (i.e. SCN5A, CACNA1C, KNJ2, GJA5, GJA1, GJA7). Results: Cell cultures grown on flexible membranes showed a significantly higher electrical conduction velocity than on Petri dishes (i.e. 2.4±0.6cm/s vs. 1.5±0.3cm/s, $p<0.01$). This increase in the conduction velocity was associated with an increase in the expression levels of certain genesassociated with action potential generation and propagation (i.e ion channels: sodium, calcium,potassium and connexins). (see Fig.). No significant differences were observed in terms of proliferation and migration rates (i.e. full confluence was achieved within 6 days on both substrates). Conclusion: Flexible PDMS membranes not only maintain cell proliferation and migration rates, they also have shown to play an important role in the electrophysiological maturation of cardiac cells (i.e. characteristic gene expression and functional wavefront propagation). These results may help in the design of novel cardiac tissue engineering regeneration therapies.

S84 **Intrinsic and Electronic Pacing**

Chairs: Larissa Tereshchenko and Steven Niederer

Room: Shaughnessy II

216-415 **Predictive Analysis of Cardiac Resynchronization Therapy Response by means of the ECG**

Nuria Ortigosa*, Joaquín Osca, Carmen Fernández, Antonio Galbis, Rebeca Jiménez and Ydelise Rodríguez

Aims: Cardiac Resynchronization Therapy (CRT) is an effective treatment for heart failure patients with moderate to severe symptoms. Unfortunately, a significant proportion of patients (up to 35%) do not respond to CRT (patients called "non-responders"). This results in a large cost-effectiveness relation for heart failure treatment. This study aims to assess a prediction response to CRT by means of analysing the ECG. Methods: We retrospectively analysed the surface ECG and QRS previous to CRT implantation in 45 consecutive patients with dilated (27) or ischemic (18) cardiomyopathy. We extracted the QRS and then processed a measure of energy of a discrete version of the Stockwell Transform. This feature was used to discern non-responder patients to CRT. Results: 10 out of 45 patients were clinically judged as non-responders to CRT. We observed that, on average, non-responders presented significant lower values for this energy measure than patients who responded favourably to the therapy (with median values 12812 V^2s vs. 5883 V^2s for responders and non-responders, p-value <$ 0.05). Using energy in the spectrum as feature to predict patients' response, as well as mean duration of QRS complexes, our obtained performances for a linear mean-squares classifier were: accuracy (82.2%), sensitivity (85.7%), specificity (70%). Conclusion: The current study presents a novel approach to obtain early predictions of potential candidates to CRT in patients suffering from heart failure by means of calculating the energy of the ECG, which may open a door to reduce and try to minimize the number of CRT treatments with unsuccessful results.

217-407 **Personalised Biophysical Model to Optimise Left Ventricle Pacing Location for Cardiac Resynchronisation Therapy Over Time**

Angela Lee*, Manav Sohal, Jonathan Behar, Simon Claridge, Anoop Shetty, Thomas Jackson, Eoin Hyde, Gernot Plank, Reza Razavi, Pablo Lamata, Christopher Aldo Rinaldi and Steven Niederer

Cardiac Resynchronisation Therapy (CRT) causes changes in cardiac anatomy, electrophysiology and mechanics of the heart after 3-6 months of treatment. Multi-pole pacing (MPP) and multi-vein pacing (MVP) are new technologies that offer the ability to change the location of the pacing site post implant, however, the long term benefits of shifting the left ventricle (LV) pacing site are still uncertain. In three patients, personalised biophysical electromechanical models of the heart were developed from MRI, echocardiogram, ECG and pressure catheter recordings, before and after sustained CRT treatment. Simulations of simultaneous biventricular pacing of the heart were performed for 49 pacing sites across the LV free wall, in models of patients prior to- and after sustained pacing. The optimal region for LV pacing was determined by the acute haemodynamic response (AHR). After sustained CRT treatment the heart remodels and the models predict that the optimal region for pacing the LV would shift after this remodelling. The shift in the optimal LV pacing region predicts that if LV lead location was placed within the optimal region prior to CRT treatment, the probability that this pacing site is still optimal after sustained CRT pacing is 42%, 83% and 91% for the 3 patients. As the heart undergoes physiological changes due to sustained pacing, we predict that the optimal area for pacing the LV relocates. The model predicts that even if the LV lead position is optimised at time of implant there is benefit in optimising pacing location through MVP or MPP over time.

218-375 **Precise pacing artefact detection**

Juraj Jurco*, Filip Plesinger, Josef Halamek, Pavel Jurak, Magdalena Matejkova, Pavel Leinveber and Jolana Lipoldova

Introduction: An analysis of ultra-high-frequencies in ECG (UHF ECG, up to 2kHz) reveals new information about the time spatial distribution of heart depolarization. Such an analysis may be important for diagnosing and treating patients with atrial and ventricular dyssynchrony. The UHF analysis in patients with a pacing device is complicated due to the pacing influence in the ECG. In that case, all pacing artefacts must be eliminated from the measured signal. The first step in removing those artefacts is to precisely detect their temporal position. Although pacing artefacts are usually clearly visible on a measured ECG, capturing the whole pacing artefact may be challenging. Methods: This paper compares different detection approaches and evaluates them on 19 records. Derivatives, a moving statistical window and complex envelope methods were tested followed by descriptive statistics approaches for making a peak detection. We evaluated the variability of the detection position by the distance variability from manual anotations. For each method, sensitivity and positive predictivity were evaluated. Results: The method with the most precise temporal detection was the variance moving window with a standard deviation (SD) of ±0.11ms mark placement. The best detection method was a SD moving window with SE=100 and SP=82.3 and was evaluated as the most appropriate.

219-298 **Dynamic Regulation of Pacemaker Activity by the Na+-K+ Pump**

Stefano Morotti*, Joshua R St. Clair, Catherine Proenza and Eleonora Grandi

The role of Na+ homeostasis in cardiac pacemaking is not well established. Blocking of the Na+-K+ ATPase (NKA) to raise intracellular Na+ concentration ([Na+]i) in ventricular myocytes, thereby reducing Ca2+ removal by the Na+-Ca2+ exchanger, is widely used to improve cardiac inotropy in patients with congestive heart failure. However, NKA-blocking agents have a narrow therapeutic window, and cardiotoxic effects are common, as excessive Ca2+ accumulation is pro-arrhythmic and decreases lusitropy. Here, we updated an existing mathematical model of the mouse sinoatrial node (SAN) cell, based or our consistent dataset of electrophysiological experiments, to determine the effects of increasing [Na+]i on pacemaker cell function, and test whether high [Na+]i levels have disrupting effects similar to those of cardiac glycosides in the ventricle. Model parameter sensitivity analysis revealed that NKA modulation impacts Na+ and Ca2+ homeostasis, as well as several action potential (AP) characteristics. NKA dynamically modulates cell automaticity: upon partial NKA inhibition SAN firing rate instantaneously increases, due tc the direct effect of reducing a repolarizing current to shorten the AP. Over time, reduced Na+ extrusion causes slow [Na+]i accumulation, paralleled by an increase in Ca2+ load, and SAN cell firing rate. When simulating stronger NKA inhibition, the model predicts that excessive [Na+]i and thus Ca2+ overload prevent SAN automaticity, in agreement with what observed in SAN preparations after ouabain administration. Our results show that administration of low dose NKA-blocking agents has a positive chronotropic effect, which can be drastically reversed at higher doses. Our analysis confirms that [Na+]i has a fundamental role in the regulation of pacemaker activity, and that a detailed characterization of Na+ handling properties in isolated SAN myocytes is essential to fully understand cardiac pacemaker function in health and disease.

S85 **Special Session:Recent Advances in Seismocardiography and Ballistocardiography**

Chairs: Marco Di Rienzo and Omer Inan

Room: Dundarave

220-272 **Contact-Free Piezo-Electric Sensor Used for Real-Time Analysis of Inter Beat Interval Series**

Yaniv Katz*, Roman Karasik and Zvika Shinar

Aims: Ballistocardiography (BCG) serves as a convenient way to measure the heart activity, and in particular, inter beat interval (IBI) series. This study was aimed to assess the performance of two novel real-time algorithms. The first measures the IBI series from a signal acquired using a contact-free piezo-electric sensor placed under the mattress (Earlysense). The second is a logistic regression based classification method based on parameters extracted from the BCG signal used to classify measured IBIs according to presumed accuracy. Methods: The algorithms were tested on BCG signals acquired from 25 home sleep recordings of 14 healthy individuals that were measured using a sensor placed below them, in a two people in bed setting. The measurement algorithm produced a continuous IBI set measured while the user was in bed. The classification algorithm was tuned to select a subset with higher estimation accuracy including 70% of the samples from the continuous set. These two sets were compared on a beat by beat (BBB) level to IBI reference data set that consists of almost 500,000 IBIs obtained from ECG signals. Results: The BBB analysis of the continuous IBI set showed an average measurement error of 34.3 milliseconds, where 78% from all IBIs had a measurement error of 21 milliseconds or less and 59% of 8 milliseconds or less. Furthermore, the classification method produced a subset with more accurate results, in which the average measurement error was 13.2 milliseconds, where 90% of the IBIs had a measurement error of 21 milliseconds or less and 70% of 8 milliseconds or less. Conclusions: The results obtained provide evidence that IBI series can be accurately measured in real-time from a contact-free acquired BCG signal. Furthermore, part of the difference between the electrically and mechanically measured IBIs can be explained due to pre-ejection period variability.

221-364 **Direct Pulse Transit Time Measurement from an Electronic Weighing Scale**

Joan Gomez-Clapers, Ramon Casanella* and Ramon Pallas-Areny

Aims: The Pulse Transit Time (PTT) is a recognized marker of arterial stiffness but traditional methods to measure PTT rely on tonometers or other mechanical sensors, or the photoplethysmogram, which require a trained operator. This work presents a novel method to measure PTT from fiducial points of the ballistocardiogram (BCG), the recording of forces in the body as a result of cardiac ejection, which can be obtained in ambulatory scenarios from modified electronic weight scales. Methods: The carotid-femoral PTT and BCG have been simultaneously obtained from 3 healthy subjects while performing a paced respiration maneuver in order to modulate PTT. The interval between the I and J waves of the BCG, which are temporally close to the pressure-pulse arrival to the carotid and femoral arteries respectively, has been compared with the PTT obtained by custom sensors able to measure it in subjects standing on a weight scale. Results: The modulation induced by paced respiration in IJ and PTT is similar in phase and amplitude. The correlation between the IJ interva and this PTT is 0.69 and the difference between measurements is (-5.2±16.4) ms. These results outperform those of some commercial devices that do not rely on carotid-femoral PTT, and are comparable to those of others based on direct PTT measurements, with the extra benefit of only requiring the subject to stand on a modified electronic weight scale and without needing to expose any body part nor the presence of a trained operator. Conclusions: The IJ interval from the BCG enables fast PTT assessment in non-clinical scenarios. The results warrant further investigation including its evaluation for a more numerous and heterogeneous cohort and, combined with the widespread use of electronic weight scales, offer new perspectives for the ambulatory assessment of arterial stiffness.

222-428 **Quantification of Posture Induced Changes in Wearable Seismocardiogram Signals for Heart Failure Patients**

Abdul Qadir Javaid, Sean Dowling, Mozziyar Etemadi, James Alex Heller, Shuvo Roy, Liviu Klein and Omer Inan*

Our goal is to characterize the effects of posture – supine, seated, and standing – on the ballistocardiogram (BCG) signal for heart failure (HF) patients. Posture can both (1) distort the BCG signal, e.g., due to altering the body's mechanical vibration response, and (2) affect a person's cardiovascular physiology, e.g., due to changes in venous return. This work focuses on characterizing the former, such that in future studies we can use the BCG to assess any abnormalities in the latter for HF patients at home. Our team has developed a circular patch (7cm in diameter) which, when placed on the sternum, simultaneously measures the electrocardiogram (ECG) along with BCG signals in the dorso-ventral and head-to-foot directions. We recruited six HF patients thus far for this ongoing study. Each subject was asked to lie down in a supine position on a patient bed for 1 minute followec by 1 minute in each of the sitting and standing postures. The power spectral density (Welch's method) of the BCG signals, normalized by the maximum value in the 0-10 Hz band, was estimated in the three positions. The initial results indicate that the dorso-ventral vibrations in both the supine and seated positions are accompanied with an increase in energy in the high frequency band (greater than 10Hz). The head-to-foot vibrations show increased energy in the 5-10Hz band for the supine position only. These results are consistent with our previous findings with healthy subjects that the changes in BCG morphology – specifically, increased higher frequency vibration modes in addition to the primary mode in the 1-5 Hz range – are more associated with body mechanics rather than physiologic changes. Our future work will focus on correcting for these changes and analyzing the postural effects on the physiology of HF patients at home using wearable BCG.

223-115 **A New Technological Platform for the Multisite Assessment of 3D Seismocardiogram and Pulse Transit Time in Cardiac Patients**

Marco Di Rienzo*, Prospero Lombardi, Diana Scurati and Emanuele Vaini

We recently developed a hardware architecture for the multisite measure of seismocardiogram (SCG) , photoplethysmogram (PPG) and pulse transit time (PTT). The system is composed of several multisensor nodes (motes) and a small electronic module (hub). Each mote has the size of a coin and includes an accelerometer for the SCG assessment and a photopletysmograph for the PPG measure. The motes may be positioned in different parts of the body by adhesive tape, elastic bands or clips to obtain a multisite assessment of the signals. The hub allows one-lead ECG assessment and the node data collection. PTT is computed as the time delay between the SCG fiducia point associated with the opening of the aortic valve and the foot of the pulse wave detected by the PPG at a distal artery. The device may be configured to simultaneously detect the SCG from different precordial positions and/or provide a multisite assessment of PPG and PTT from diverse vascular sites. We exploited this system to investigate if the accelerometer placement on different zones of the sternum may influence the SCG waveform. In 8 supine patients suffering from cardiac heart failure we simultaneously recorded three SCG tracings by positioning the sensor nodes on the upper (SCGu), mic (SCGm) and the traditional lower (SCGl) part of the sternum. Differences in the ensemble SCG profiles were quantified by the maximal cross-correlation coefficient (MCCC), with a value < 0.8 taken as indicative of marked shape differences. The group average MCCC between SCGu and SCGl was <0.6 and no subject reached the 0.8 value. SCGm provided intermediate waveforms. In most patient we also observed that SCGu was closer to the canonical SCG profile than SCGl. These preliminary results foster further investigations on the most appropriate location of the SCG sensor on the patient's chest in clinical protocols.

Wednesday, September 14, 2016 **8:30**

S91 **ECG Signal Processing II**

Chairs: Pablo Laguna and Roger Abaecherli

Room: Pinnacle II

224-413 **Sparse Coding of Cardiac Signals for Automated Component Selection after Blind Source Separation**

Daniel Wedekind*, Denis Kleyko, Evgeny Osipov, Hagen Malberg, Sebastian Zaunseder and Urban Wiklund

The integration of sensors into clothing provides novel wearable solutions for ambulatory electrocardiography. However, textile electrodes most often go along with low signal quality. Blind Source Separation (BSS) provides an effective tool for extracting cardiac signals like the Electrocardiogram (ECG) out of heavily distorted multi-channel measurements. To practically use BSS, the component representing the ECG has to be automatically selected among the unordered BSS outputs, which typically also contain a large amount of undesired components (e.g. distortions separated from the ECG). We propose a solution to this problem, known as permutation indeterminacy, which exploits the sparsity of the ECG modeled as a spike train of successive heartbeats. We analyzed recordings from ten healthy subjects wearing a garment with textile electrodes while performing common motions (standing up, sitting down, walking, flexing chest muscles). Seven non-standard ECG leads obtained from the garment were processed in subsequent 10s segments with spatio-temporal BSS. For selection of the (best) ECG component, the BSS output is handled by an automated single-channel output selection. Our proposed component selection (RCODE) generates a sparse binary code of each component by utilizing a two-item dictionary {peak, no peak} and physiological a-priori temporal information as minimum heart rates and the cardiac refractory period. Peak detection was performed with an algorithm satisfying the needs of sensitive separation between channels of different quality. One component is further selected by assessing a modified Hamming Distance comparing the obtained binary code with an expected code behavior. The performance of RCODE was evaluated by the heart beat detection accuracy (ACC) calculated with the aid of a simultaneously recorded standard ECG. RCODE achieved 98.1% ACC on average. In comparison, selecting manually the component with highest ACC resulted in 99.5% while traditional component selection based on skewness yielded 67.6% ACC.

225-367 **ECG analysis based on Lempel-Ziv Complexity algorithm as a detection tool of Sleep-Related Breathing Disorders**

Agnieszka Pregowska, Klaudia Proniewska* and Janusz Szepanski

Process of sleeping plays an important role in physiology of Human and all living being. In recent years, many people have been suffering from sleep disorder caused by work-related stress, irregular lifestyle o mental health problems. To properly understand the influence of slee quality and quantity on human health and well-being, it is important to find a correlation between two particular physiological signals i.e., vital functions like acoustic signal of breathing and ECG-signal represented by heart activity parameters acquired at the same period of breathing during sleep. These may lead to specify system scoring of sleep-related breathing disorders (SRBD). The aim of this study is to elaborate methods for automatic detection of SRBD patients suffering from such ailments like snoring and wheezing using bio-signals. Specifically, our methods are applied to patients ECG-signals acquired during sleeping. We also conduct a hypothesis that sleep related combining of ECG analysis with breathing biomarkers leads to effective predictors of cardiovascular disorders. The Holter ECG method, most common for monitoring long-term heart activity, was used to acquire ECG signal during the night. Lempel-Ziv Complexity (LZC) algorithm as SRBD detection tool via ECG is applied. LZC measures the rate of generation of patterns along the signal and the range of its values is between zero and one. Two encoding methods to digitalize the ECG signals were proposed. Both encoding procedures have physiologically well posed interpretation. The approach considered was successfully used for quantifying the dynamical changes of ECGs, this way to classify cardiovascular states of the patients with SRBD. Our main quantitative results show that LZC were significantly lower, i.e. even 0.3 for patients with SRBD what indicates that surprisingly the ECG-signal for sick people is more regular while for healthy patient the LZC is equal to 0.7 and the variability of

226-121 **A Model for Estimation of Noise Tolerance in ECG Parameters**

Reza Firoozabadi*, Richard Gregg and Saeed Babaeizadeh

Background: Parameters extracted from noise-corrupted ECG signals have different noise tolerance levels. Some parameters may be slightly affected by noise, while the others could be inaccurate. Choosing a single noise threshold for all parameters may lead to adoption of invalid results or discarding valid parameters. In this study we derive a noise model and compare the noise-tolerance of several ECG parameters. Method: The study population (n = 103) comprises 5-minute pre-PTCA 12-lead ECG segments from STAFF-III database, added to the physical noise recordings from MIT-BIH database split into 5-min segments containing electrode motion, muscle artifact and baseline wander. Lead QRS peak to peak (signal) and noise RMS amplitudes were measured and the desired signal-to-noise ratio (SNR) was achieved by scaling the additive noise properly. We generated 3193 noise-added 12-lead ECG signals with SNR from -6 to 24 dB. For each 10-sec segment, the noise measure (NM) was computed by our Signal Quality Indicator algorithm (SQI), and the ECG parameters were measured by the Philips DXL algorithm. Results: By running the SQI algorithm on our noise-controlled database, an exponential regression model was derived between the SQI noise measure and the SNR of the noise-added data. The threshold for noise tolerance of each parameter was defined at the point where adding more noise caused considerable deviation of the parameter from its actual value. Conclusions: We created a controlled noise-added database and derived a model between our noise measure and the SNR. Various noise-tolerance thresholds were observed for a number of ECG parameters. As expected, heart rate was the most noise-tolerant parameter and P-wave amplitude was less tolerant to the noise. Differing thresholds suggest using a specific threshold for each parameter to avoid affecting the accuracy.

227-184 **Multi-classification of Cardiac Diseases Utilizing Wavelet Thresholding and Support Vector Machine**

Qin Qin*, Jianqing Li, Wei Li and Yinggao Yue

Automatic classification of electrocardiogram (ECG) is an importance issue in heart disease diagnosis. Support vector machine (SVM) has drawn more and more attention on pattern recognition, including ECG feature extraction and cardiac disease detection. The most prominent advantage of SVM can be represent as its excellent performance on simplification of inner product operation from high dimensional space to low dimensional space, skillfully avoiding the calculation in high dimension space. In this study, a multi-classification method is proposed utilizing wavelet shrinking threshold (WST) and SVM. WST is applied to eliminate interference with frequency beyond the typical frequency interval of ECG signals (0.05~100Hz). Meanwhile, WST provides detail coefficients and approximation coefficients of different decomposition levels, which are the input features fed into SVM for classification. After that, SVM is employed to recognize 6 types of cardiac beats from MIT-BIH arrhythmia database. Besides, to achieve better recognition accuracy, different parameters C and γ are discussed and tested. Experimental results indicate that the classification performance gets better as C increases and γ decreases. When C and γ are set to be 1000 and 0.1 respectively, an overall classification accuracy, sensitivity and positive predictivity of 95.23%, 97.42% and 97.71% respectively are achieved utilizing the proposed algorithm over ECG signals from MIT-BIH arrhythmia database.

228-113 **Motion Artifact Suppression in Ambulatory ECG with Feed Forward Combine Adaptive Filter**

huanqian zhang*, Shulin Zhang, Qinghui Jin, Xuehua Liu, Qing Li, Jian Yang and Jianlong Zhao

Aim: Ambulatory electrocardiogram (AECG) is widely used for heart disease diagnosis and treatment after surgery, but the quality of AECG signal will be negatively affected by the motion artifact (MA) coupling in the AECG signal. Adaptive filter (AF) has been used to suppress MA from AECG. Unfortunately, because of the non-stationary property of AECG and MA, the distortion and the artifact suppression performanc of the AF cannot be satisfied simultaneously, resulting in a poor diagnosis, such as: low QRS beat detection accuracy. Methods: This paper proposes a new kind of AF: Feed Forward Combine AF (FFC-AF). It is composed by two separate AFs (one fast convergence speed AF 'FCS-AF' and one high convergence accuracy AF 'HCA-AF') and one combination parameter which varies with the evaluation of signal stationary. Results: Twenty minutes measured data from ten experiments in five healthy volunteers, totaling in 1143 cardiac cycles, were evaluated. The distortion of AF was estimated by correlation anc the artifact suppression performance of the AF was evaluated by signal artifact ratio (SAR). QRS beat detection accuracy was assessed by sensitivity (Se) and positive predictivity (+P). The experiment result showed that, compared with the separated fast convergence speed AI (FCS-AF) and high convergence accuracy AF (HCA-AF), the FFC-AF proposed in this paper had the lowest output distortion, moderate artifact suppression performance and the highest QRS beat detection accuracy. Conclusion: This new kind of FFC-AF can suppress MA in AECG and maintain low output distortion. FFC-AF can be used to study other characteristics of AECG signal, such as P and T waves or QRS morphology.

229-377 **Assessment of the Dynamic Response of Cardiac Depolarization During Stress Test Recovery Evaluated in Patients with Brugada Syndrome**

DANIEL ROMERO*, Nathalie Behar, Virginie Le Rolle, Philippe Mabo and Alfredo Hernandez

Background: Brugada syndrome (BrS) is a genetic disease that may cause sudden cardiac death, mainly due to cardiac arrhythmia occurring at rest or during sleep. This study aims to assess the dynamic response of cardiac depolarization features extracted from the ECG during exercise, and to evaluate if these dynamics may help to distinguish between symptomatic and asymptomatic BrS patients. Methods: A study population that comprises 23 patients suffering from BrS was analyzed. Eleven patients presented clinical symptoms, including ventricular fibrillation or syncope (symptomatic group) while 12 patients did not present any of the BrS-related clinical symptoms (asymptomatic group). A 12-lead ECG recording during standardized treadmill exercise test was acquired for each patient. Patients were analyzed by evaluating a set of depolarization-related electrophysiological features during the whole ECG recording. Non-linear approaches, based on three-constant S-shaped curves, were applied to assess the dynamics of each electrophysiological feature, by modeling their response during exercise recovery. The dynamics of the heart rate, mainly modulated by the parasympathetic tone during this period, was also assessed. Results: The non-linear approach that best fits the dynamic response of the depolarization, account for parameters describing the amount of change Δ, the lag τ and the change rate θ of the dynamic curve shape. Asymptomatic BrS patients presented significant higher amounts of change and faster change rates than symptomatic BrS patients in several of the evaluated features (R downslope ($p=0.01$) and R angle ($p<0.01$) for Δ; S upslope ($p=0.03$) and S angle ($p<0.02$) for θ), especially in left precordial leads V4-V6. Symptomatic patients presented instead longer lag values (τ: S upslope ($p=0.02$) and R angle ($p<0.01$)) in their dynamics as compared with asymptomatic ones. Conclusion: Dynamics of depolarization features, assessed during periods of increased parasympathetic tone, seems to be linked with the presence of symptoms in BrS patients.

Wednesday, September 14, 2016 **8:30**

S92 **Physionet Challenge II**

Chairs: Gari Clifford and Roger Mark

Room: Pinnacle III

230-536 **Classification of Normal/Abnormal Heart Sound Recordings: the PhysioNet/Computing in Cardiology Challenge 2016**

Gari Clifford*, Chengyu Liu, David Springer, Benjamin Moody, Qiao Li, Ricardo Abad, Jose Millet, Ikaro Silva, Alistair Johnson and Roger Mark

In the past few decades heart sound signals (i.e., the phonocardiogram or PCG) have been widely studied. Automated heart sound segmentation and classification techniques have potential to detect pathology accurately in a variety of clinical applications. However, comparative analyses of algorithms in the literature have been hindered by the lack of a large and open database of heart sound recordings. The PhysioNet/Computing in Cardiology (CinC) Challenge 2016 addresses this issue by assembling the largest public heart sound database, aggregated from six sources obtained by multiple research groups around the world. The database includes 2,051 heart sound recordings in total collected from 906 healthy subjects and patients with a variety of conditions such as heart valve disease and coronary artery disease. These recordings were collected using heterogeneous equipment in both clinical and nonclinical (such as in-home visits). The length of recording varied from several seconds to several minutes. Additional data are provided including subject demographics (age and gender), recording information (number per patient, body location, and length of recording), synchronously recorded signals, sampling frequency and sensor type used. Participants were asked to classify recordings as normal, abnormal, or not possible to evaluate. The overall score for an entry was based modified sensitivity and specificity scores with respect to manual expert annotations. A brief summary of the commonly used heart sound segmentation and classification methods is provided, including a description of open source code, which has been provided in association with the Challenge. The open source code provided a score of t score of 0.75 (0.7 Sensitivity, 0.8 Specificity). During the unofficial phase of the competition, a total of 64 teams participated, with a highest score of 0.88 (0.75 Sensitivity, 1.0 Specificity). We conclude with a discussion of several potential benefits from this newly released public heart sound database.

231-260 **Discrimination of Normal and Abnormal Heart Sounds Using Probability Assessment**

Filip Plesinger*, Juraj Jurco, Josef Halamek and Pavel Jurak

Aims: According to the “2016 Physionet/CinC Challenge”, we propose an automated method identifying normal or abnormal phonocardiogram recordings. Method: Invalid data segments are detected (saturation, blank and noise tests) and excluded from further processing. The record is transformed into amplitude envelopes in five frequency bands. Systole duration and RR estimations are computed; 15-90 Hz amplitude envelope and systole/RR estimations are used for detection of the first and second heart sound (S1 and S2). Features from accumulated areas surrounding S1 and S2 as well as features from the whole recordings were extracted and used for training. During the training process, we collected probability and weight values of each feature in multiple ranges. For feature selection and optimization tasks, we developed C# application PROBAfind, able to generate the resultant Matlab code. Results: The method was trained with 3153 Physionet Challenge recordings (length 8-60 seconds; 6 databases). The results of the training set show the sensitivity, specificity and score of 0.93, 0.97 and 0.95, respectively. The method was evaluated on a hidden Challenge dataset with sensitivity and specificity of 0.87 and 0.83, respectively. These results led to an overall score of 0.85.

232-191 **Heart Sound Classification via Sparse Coding**

Bradley Whitaker* and David Anderson

Introduction: The aim of the Physionet/CinC Challenge 2016 is to automatically classify heart sound recordings as normal or abnormal. The Challenge provided 3,125 labeled audio recordings taken from a single precordial location, as well as Springer's state-of-the-art beat segmentation algorithm. Algorithm: Using Springer's segmentation algorithm, we divide each audio segment into an array of sub-second audio files corresponding to the four phases of the cardiac cycle. We take an N-point FFT of each audio segment and create five different data matrices: one for each sub-cycle (S1, Systole, S2, and Diastole), and one for a complete cardiac cycle. A column of the data matrix corresponds to the N-point FFT of one audio segment. Using sparse coding, we decompose the data matrix into an overcomplete basis matrix and a sparse coefficient matrix. The basis matrix represents statistically important spectral features of the audio segments. The sparse coefficient matrix is a mapping that represents which features are used by each segment. Working in the sparse domain, we train support vector machines (SVMs) for each sub-cycle and for the complete cycle. We train a sixth SVM to combine the results from the preliminary SVMs into a single binary label for the entire sound recording. Results: When presented with the unknown challenge test data, our algorithm achieved a sensitivity of 0.79 and a specificity of 0.91, resulting in an overall challenge score of 0.85. Conclusions: We developed an algorithm to classify heart sound recordings as normal or pathological. Our results show that sparse coding is an effective way to define spectral features of the cardiac cycle and its sub-cycles for the purpose of classification. Further work will attempt to increase the sensitivity and specificity of the algorithm by exploring other classifiers while still working in the sparse domain.

233-109 **Nonnegative Matrix Factorization and Random Forest for Classification of Heart Sound Recordings in the Spectral Domain**

Christoph Hoog Antink*, Julian Becker, Steffen Leonhardt and Marian Walter

This year's PhysioNet/CinC challenge aims to stimulate the development of robust algorithms to accurately classify heart sound recordings automatically. The approach presented in this paper is based on time and frequency domain analysis. In the first step, the recording is processed using an open-source logistic regression-HSMM based heart sound segmentation algorithm. With it, the recording is segmented into the four states S1, systole, S2, and diastole. The features used for classification are obtained in the frequency domain. First, the phonocardiogram (PCG) is downsampled to 1 kHz. Next, the absolute spectrogram of the PCG is calculated using a moving Hann-window of 50 milliseconds length and a hop-size of 13 samples. To extract the dominant spectral components of the four states, nonnegative matrix factorization (NMF) is used. With this method, the spectrogram is decomposed into four vectors representing the temporal excitation and four vectors representing the respective spectral pattern. The initialization of the excitation vectors is derived from the time-domain segmentation. After NMF, the four resulting spectral patterns are used as features. Finally, the residuum of the NMF is used as an additional feature. A Random Forest classificator with 3000 trees is trained using a total of 105 features, classifying into `normal', `unsure' and `abnormal'. To optimize the parameters of the approach, the Out-of-Bag-Error is minimized. The biased distribution of the training data is compensated for by manually adjusting the expected distribution of classes. The algorithm is implemented in MATLAB and is executed with an average and maximum running time of 12% and 24% of the quota, respectively. Using the proposed approach, the top score achieved on a random subset of the hidden test set in phase II was a sensitivity of 0.797 at a specificity of 0.831, resulting in an overall score of 0.814.

234-175 **Classifying Heart Sound Recordings using Deep Convolutional Neural Networks and Mel-Frequency Cepstral Coefficients**

Jonathan Rubin*, Rui Abreu, Anurag Ganguli, Saigopal Nelaturi, Ion Matei and Kumar Sricharan

Aim: The goal of the 2016 PhysioNet Computing in Cardiology Challenge was to accurately classify normal and abnormal heart sounds from phonocardiogram waveforms. A particular aim was to identify from a single short recording whether a subject should be referred on for expert diagnosis. Accurate and robust algorithms were required that could deal with heart sounds that exhibit very poor signal quality. Dataset: The challenge training set consisted of 3,126 heart sound recordings, lasting from 5 seconds to just over 120 seconds. Recordings were collected from nine different locations on the body (including aortic area, pulmonic area, tricuspid area and mitral area, among others). Recordings from healthy subjects were labeled as normal. Recordings from subjects with a confirmed cardiac diagnosis were labeled as abnormal. Abnormal recordings were collected from patients who suffered from a variety of illnesses, including heart valve defects (mitral valve prolapse, mitral regurgitation, aortic stenosis, valvular surgery) and coronary artery disease. Methods: We present an algorithm that computes heat maps of the time-frequency distribution of signal energy (spectrograms) and uses a deep convolutional neural network to automatically classify normal versus abnormal heart sound recordings Logistic regression hidden semi-Markov model-based heart sound segmentation was first performed. Spectrograms consisting of 13 cepstral coefficients that capture Mel-frequencies varying over time were derived for overlapping sliding windows, beginning at the first heart sound, S1. A deep convolutional neural network was trained to perform automatic feature extraction to distinguish between normal and abnormal spectrograms. Results: The top model submitted to Phase I of the challenge achieved a sensitivity and specificity of 75% and 100%, respectively for an overall score of 88%. These results suggest that convolutional neural networks are able to automatically extract useful features from Mel-frequency cepstral coefficient heat maps to distinguish between normal and abnormal heart sounds from noisy data.

235-325 **Automatic Heart Sound Recording Classification using a Nested Set of Ensemble Algorithms**

Masun Nabhan Homsi, Natasha Medina, Miguel Hernandez, Natacha Quintero, Gilberto Perpiñan, Andrea Quintana and Philip Warrick*

Abstract: Automated phonocardiogram (PCG) analysis may provide better clinical information to physicians for analyzing and diagnosing different heart abnormalities. However, despite recent advances in PCG analysis methods, it is still a challenging task to extract accurate and useful information from contaminated heart sound recordings. Aims: The first objective was to introduce a new approach for classification of normal and abnormal heart sound recordings using LogitBoost, based on the Random Forest algorithm. The second objective was to measure the effectiveness of the feature selection method on the overall performance of the PCG signal classification. Methods: The approach consisted of three stages: preprocessing, classification and evaluation. In the preprocessing stage, PCG signals were first downsampled to 1 kHz using a polyphase antialiasing filter. Next, each heart sound was segmented using Springer's improved version of Schmidt's method to identify four states; S1, S2, systole and diastole. Thereafter, 35 features in time, frequency and statistical domains were extracted from the timings of the states. Additional features were calculated over the entire recording, including the entropy of five levels of wavelet packet decomposition and on the approximation of the last level. Finally, class imbalance was dealt with using the SMOTE algorithm. In the classification stage, the Random-Forest-based LogitBoost algorithm was cross-validated on the entire training dataset provided by Physionet Challenge 2016. In the evaluation stage, the sensitivity and specificity of the trained algorithm was tested with unseen signals selected randomly by the Challenge testing environment. Results: Experimental results showed that the proposed approach achieved an overall score of 82%. Conclusion: The use of LogitBoost with a set of combined features extracted from different domains has helped in reducing overfitting and improving classification performance.

Wednesday, September 14, 2016 **8:30**

S93 **Modelling Ion Channels and Drug Effects**

Chairs: Eleonora Grandi and Javier Saiz

Room: Shaughnessy II

236-173 **Sub-Cellular Network Analysis of Ryanodine Receptor Positioning in Control and Phosphorylated States**

Ismail M. Khater*, David R.L. Scriven, Edwin D.W. Moore and Ghassan Hamarneh

Type 2 ryanodine receptors (RyR2) are large (mass=2.2 MegaDalton) proteins expressed in heart cells that mediate the release of calcium ions (Ca2+) that, in turn, modulate contraction of the heart. In this work, we analyze the sub-cellular spatial distribution of RyR2 using data from superresolution microscopy, an imaging technique that allows highly accurate positioning (<10 nm in x and y; <40 nm in z) of the RyR2 within the heart muscle cell. In particular, we present the first work to examine network measures of extracted RyR2 locations to examine the clustering behaviour of these channels. We collected images from two groups of healthy cardiac cells; the control consisted of 8 cells, while the second group of 8 cells were treated with a chemical cocktail to phosphorylate the RyR2 and to inhibit dephosphorylation. We examined the classification accuracy (using random forest classifier) and the group differences (using Mann-Whitney statistical test and Bonferroni multiple comparison correction) based on several network measures, at multiple proximity thresholds. Several network measures we examined revealed features (e.g. network clustering) that enabled us to differentiate between these two populations (p<0.00045) with high classification accuracy (>95% at proximity thresholds 200 and 250 nm). Our findings may help in better understanding Ca2+ signaling during contraction and give insight into the changes that underlie its regulation.

237-489 **The Effect of Bioenergetic Impairment of Cytosolic Processes in Spatio-Temporal Ca2+ Dynamics in a Three-Dimensional Cardiomyocyte Model**

Gareth Jones*, Henggui Zhang and Michael A Colman

Introduction: The heart consumes large amounts of energy with each beat. Mitochondria are the source of over 95% of this energy in the form of ATP, and rely on increased Ca2+ uptake to stimulate production in times of increased work. Ca2+ uptake into the mitochondria primarily occurs within microdomains formed between the junctional sarcoplasmic reticulum and the mitochondria. Structura remodeling associated with heart failure, such as detubulation and mitochondrial clustering, disrupt these microdomains and mitochondrial Ca2+ uptake, which may contribute to energetic impairment and arrythmogenesis. Methods: To investigate the effect of structural changes on single cell behavior, a model describing mitochondrial dynamics and energetics production was modified and incorporated into a recently developed three-dimensional model of spatio-temporal Ca2+ handling, which preserves microdomain structure and incorporates stochastic processes in Ca2+ handling protein kinetics. Modifications to the mitochondria model included a reformulation of mitochondrial Ca2+ uniporter uptake (MCU) making it suitable for concentrations in microdomains, where concentrations can be an order of magnitude greater than that of the bulk cytosol. Fo simulation of structural remodeling observed with disease, modifications were made to mitochondrial Ca2+ uptake and cellular Ca2+ handling proteins. Results: A reduction in mitochondrial Ca2+ uptake leads to energetic impairment due to a reduction of ATP production. This results in impairment of intracellular processes such as the sarcoplasmic reticulum Ca2+-ATPase (SERCA). Spatially heterogeneous sarcoplasmic reticulum uptake and loading is observed and Ca2+ alternans produced at faster pacing rates. Conclusion: With this model we demonstrate the importance of an ordered structure within the cell for normal function. Structural changes can lead to cellular energetic impairment and altered Ca2+ dynamics. Understanding the effect of these changes may give insight into the underlying causes of arrhythmogenesis observed in heart failure and other conditions.

238-360 **Modelling the Effects of Nifedipine on Ventricular and Myometrial Cells of Pregnant Rats**

Craig P Testrow*, Dominic G Whittaker, Arun Holden and Henggui Zhang

Aims: In this study we have used mathematical models to investigate the effects of nifedipine on two different cell types; the rat ventricular cell and the rat myometrial cell. Nifedipine is a calcium-channel blocker commonly used by health services around the world to treat both cardiovascular conditions (such as high blood pressure) and as a tocolytic to treat pre-term birth. The latter usage is prohibited in pregnant patients with pre-existing heart conditions. Methods: By applying discrete blocks to the L-Type calcium channels in both cell models we were able to simulate the presence of nifedipine at varying concentrations. Using the electrical and ionic responses to blocking these channels as indicators, we have been able to quantify and describe the effects of nifedipine in each cell type and compare them qualitatively. Results: Although any level of block will reduce the maximum level of intracellular calcium in the myometrial cell, a 60% block is required to produce a change in the morphology of the calcium transient. This level of block could result in a patient with a pre-existing heart condition experiencing hypotension or other pathological cardiac conditions during labor. Conclusions: If nifedipine were to be used as a tocolytic on a patient with a pre-existing heart condition such as hypotension, then they are likely to experience hear trouble before the dosage of nifedipine applied can reach sufficient levels to effectively halt uterine contraction. If nifedipine were to be used as a means of treating high blood pressure in a pregnant patient then it could potentially have the additional effect of extending labor, if taken at sufficiently high doses. It may be worth considering reducing or halting this treatment during the later stages of pregnancy, in order to avoid unnecessarily complicating the birth.

239-414 **Rapid Characterisation of hERG Channel Kinetics using Sinusoidal Voltage Protocols**

Kylie Beattie*, Remi Bardenet, James Louttit, David Gavaghan, Teur de Boer and Gary Mirams

The KCNH2 gene (known as hERG in humans) encodes the primary subunit of the rapid delayed rectifier potassium current (IKr) which plays an important role in repolarisation of the cardiac action potential. Action potential morphology depends on hERG expression, and mathematical action potential simulations depend on the choice of hERG channel model. It is therefore important that hERG channel kinetics are accurately represented within cardiac electrophysiology models. Many different mathematical models have been proposed to represent hERG channel kinetics. We have explored the behavior of these models when simulating a range of standard voltage-step and action potential protocols and find great variability in their behavior. We question whether all observed behaviours are expected experimentally, and if so, which model should we choose to represent hERG within an action potential model? We have designed novel sinusoidal voltage protocols to rapidly explore hERG channel kinetics. We used a Bayesian inference approach to assess the suitability of the protocols for parameterising hERG channel models. We performed the protocols in patch clamp experiments using hERG-transfected HEK-29 cells. Using experimental current recordings from the sinusoidal protocols we calibrated a selection of candidate model structures to describe hERG channel kinetics. We then validated each model by assessing its ability to predict currents recorded in response to voltage step protocols performed on the same cell. We also compared our models to published models. We found the models providing the best fit to experimental data were not necessarily the most predictive, with simpler model structures often demonstrating similar or enhanced predictive ability than more complex models, including the best performing literature models. This study demonstrates the necessity of careful consideration of experimental design, model parameterisation and model selection when constructing ion channel kinetic models. Such considerations may be a prerequisite for more predictive cardiac electrophysiology models.

240-212 **In Quest of a Sinoatrial Cell Model to Assess the Functional Effects of Mutations in the HCN4 Funny Current Gene**

Ronald Wilders* and Arie Verkerk

--Background: Since 2003, several loss-of-function mutations in the HCN4 gene, which encodes the HCN4 protein, have been associated with human sinus bradycardia. Tetramers of HCN4 subunits constitute the ion channels that conduct the hyperpolarization-activated ‘funny current’ (If), which plays an important role in sinoatrial node (SAN) pacemaker activity. Voltage-clamp experiments on HCN4 channels expressed in cell lines have revealed changes in the expression and kinetics of mutant channels, but the functional effects of these changes on SAN pacemaker activity remain unresolved. --Aim: We attempted to assess the effects of HCN4 mutations on SAN pacemaker activity through computer simulations, using the most recent comprehensive mathematical models of single SAN cells. --Methods: We incorporated the experimentally identified changes in expression and kinetics of If in the Severi-DiFrancesco and Maltsev-Lakatta models of a single rabbit SAN cell. --Results: In the Severi-DiFrancesco model, 5 out of 11 mutations tested lead to cessation of pacemaker activity rather than bradycardia, emphasizing the critical role of If in this model. In contrast, the decrease in pacing rate amounts to a maximum of only 5.2% for the most severe mutation in the Maltsev-Lakatta model. These results become even more distinct upon replacement of the If equations of either model by the ones that we recently derived from our experimental data on rabbit SAN cells. With these alternative If equations, pacemaker activity of the Severi-DiFrancesco model already ceases under control conditions, whereas the maximum decrease in pacing rate is reduced to an almost negligible 3.3% in the Maltsev-Lakatta model. --Conclusion: We conclude that the most recent comprehensive mathematical models of single SAN cells do not allow adequate investigations of the functional effects of mutations in the HCN4 funny current gene.

241-411 Synergistic Anti-arrhythmic Effects of Combining Blockade of Ultra-rapid Delayed Rectifier Potassium and Sodium Channels in the Human Atria

Haibo Ni, Dominic G Whittaker*, Wei Wang and Henggui Zhang

Background: Atrial fibrillation (AF) is the commonest cardiac arrhythmia. Developing effective and safe anti-arrhythmic drugs remains challenging and fraught with potential complications including promoting ventricular ar-rhythmias by prolonging action potential durations (APD). Acacetin, a block-er for the atrial-specific ultra-rapid delayed rectifier potassium current (IKur) isolated from a traditional Chinese medicine, was reported to be effective and safe in the treatment of AF. Blocking multiple channels is conceived to have advantages over blockade of a single ion channel in anti-arrhythmogenesis. We used computational models of the human atria to test the efficacy of combining acacetin and a sodium current (INa) blocker in anti-AF treatment. Methods and Results: A mathematical model of IKur channel block was de-veloped to describe the frequency- and use-dependent blockade of IKur with acacetin. INa blockade was simulated using the guarded-receptor model as developed in previous studies. These drug actions on their targeted ion chan-nels were incorporated into the Colman et al. model of human atrial myo-cytes. For IKur blockade, 3.2 µM acacetin was applied to achieve 50% block-ade at 1 Hz. The results show that both blockers exhibited anti-arrhythmic effects. Applying acacetin rendered significant APD prolongation (by 30 ms at 1 Hz). The INa blocker significantly reduced peak INa (by 32.8% at 4Hz) and thus the conduction velocity in tissue at fast pacing rates, whereas it ren-dered no effect at 1 Hz. Combined action of these two drugs further de-creased peak INa (by 41.8% at 4Hz) and prolonged APD at fast pacing rates, increasing effective refractory period and mediating enhanced anti-arrhythmic effects. These effects were also demonstrated in two-dimensional simulations, where combined blockers showed enhanced efficacy in terminat-ing re-entrant excitation waves.   Conclusion: Combining INa blockade with IKur blockade produced synergistic anti-arrhythmic effects in the human atria, which provides a potentially valu-able strategy for the treatment of AF.

Wednesday, September 14, 2016 **8:30**

S94 **Respiration, Heart Rate and Sleep Disorders**

Chairs: Carolina Varon and Jean-Marc Vessin

Room: Shaughnessy I

242-357 **Closed-loop Kinesthetic Stimulation for the Treatment of Sleep Apnea Syndromes**

Diego Perez*, Gustavo Guerrero, Delphine Feuerstein, Laurence Graindorge, Amel Amblard, Lotfi Senhadji and Alfredo Hernandez

Background: Sleep apnea syndrome (SAS) is a disease characterized by repeated episodes of breathing pauses (apneas) or reduction in respiratory amplitude (hypopneas) during patient's sleep. These episodes provoke significant cardio-respiratory modifications and fragmentation in patient's sleep that may have long-term cardiovascular consequences. In previous works, we developed and evaluated a therapy for SAS treatment, based on real-time "on-off" control of kinesthetic stimulations, triggered by respiratory event detections. This paper proposes a new control algorithm for adaptive stimulation, as a function of the patient's physiological response. Methods: The proposed closed-loop proportional-integral-derivative (PID) controller adapts the stimulation amplitude using as control variables the instantaneous heart rate, oxygen saturation and the duration of the current respiratory event. The controller was tested on one SAS patient for two nights. During the first night (reference), the stimulator was deactivated, while the controller was activated during the second night (therapy). ECG, nasal pressure and the result of the real-time respiratory event detector were acquired for further analysis. Episode durations and apnea-hypopnea index (AHI) for each night were determined from the acquired data. Markers obtained from the reference night were compared to those obtained from the therapy night through a Wilcoxon test. Results: Results reveal that respiratory episode duration (seconds) for the reference night was 11.55 +/- 9.99, while in the therapy night was 8.05 +/- 8.35. These results show a significant reduction of 30.3% ($p < 0.05$). The AHI (episodes/hour) of the first night was 39.56 +/- 25.02, and for the second night 23.40 +/- 17.17, meaning a reduction of 40.8%. Conclusion: This paper shows the feasibility of the proposed closed-loop therapy, integrating a PID controller for adaptive optimization of the kinesthetic stimulation amplitude. A pilot multicenter, randomized and prospective clinical protocol has been initiated to validate the proposed system on 40 severe SAS patients.

243-293 **Information Transfer Between Respiration and Heart Rate During Sleep Apnea**

Carolina Varon*, Luca Faes, Dries Testelmans, Bertien Buyse and Sabine Van Huffel

Aims: It is well-known that sleep apnea affects the respiration and the heart rate (HR), and studies have shown that the cardiorespiratory coupling is also compromised during obstructive sleep apnea (OSA). Furthermore, the classification of hypopneas is challenging, in particular when only ECG-derived features are used. In this context, this study investigates how differ-ent ECG-derived respiratory (EDR) signals resemble the respiratory effort during different types of sleep apnea, and how the amount of information transferred from respiration to HR varies according to the respiratory signal used, namely, real or ECG-derived. Methods: ECG and respiratory signals recorded from apnea patients of the sleep laboratory of the University Hospitals Leuven were analyzed. All signals were segmented into epochs containing normal activity and different types of respiratory events, namely, obstructive, central or mixed apneas, and obstructive or non-obstructive hypopneas. From the ECG, the tacho-gram and three different EDR signals were computed. These EDRs were compared against the respiratory effort measured on the thorax and abdo-men, using correlation and coherence. Furthermore, the transfer entropy was computed between the respiratory signals and the tachogram using infor-mation dynamics. Results: A multicomparison test shows that the values of coherence and correlation between the EDRs and the respiratory effort are significantly higher ($p<<0.05$) for normal events than for apnea episodes. Moreover, the information transfer measured from the respiratory effort to HR is signifi-cantly larger ($p<<0.05$) during normal activity than during all apneas. How-ever, the difference between normal and non-obstructive hypopneas disap-pear ($p>0.05$) when the EDRs are used. Conclusions: These findings show that the cardiorespiratory interactions are affected during all apneas. In addition, they suggest that the use of the EDR might reduce the performance of sleep apnea detectors, in particular, in the detection of hypopneas.

244-183 **Sleep Apnea Screening with a Contact-Free Under-the-Mattress Sensor**

Maayan Lia Yizraeli Davidovich, Roman Karasik, Asher Tal and Zvika Shinar*

Background: Sleep apnea is a highly prevalent yet under-diagnosed condition. In the hospital, severe sleep apnea is associated with anesthesia-related complications, and at home years of sleep apnea are linked to low quality of life and long term cardiovascular consequences. Aim: This study tested the sleep apnea screening capabilities of a contact-free system based on a piezo-electric sensor (EarlySense) for easy home or hospital use. Methods: The study population included 76 subjects who were referred to a sleep study and signed a consent form. They all underwent full polysomnography (PSG) in a sleep lab. 12 participants were diagnosed with severe sleep apnea, 10 with moderate, 24 with mild and 30 with no sleep apnea. Subjects were simultaneously measured with the contact-free system, utilizing a piezo-electric sensor placed under the mattress, for measuring parameters, including respiration effort, heart rate and movement. The system's algorithm identified periodic patterns of respiration effort associated with apnea to classify the subjects into two groups: one above and one below an Apnea-Hypopnea Index (AHI) of 15. This threshold is considered the cut-off for treating moderate (15<AHI<30) and severe (AHI>30) apnea. The classification was compared to PSG-based classification of a blinded sleep expert. Results: The system had a sensitivity of 86% in detecting AHI of 15 and above. It detected 100% of severe sleep apnea, and 70% of moderate sleep apnea. Additionally, it had a positive predictive value (PPV) of 83%, with false positives related to subjects with AHI larger than 10. A PPV of 100% may be achieved with stricter algorithm conditions. However, the cost is reducing the sensitivity to 64%. Conclusions: The tested contact-free system showed high sensitivity and PPV in detecting moderate and severe sleep apnea. It can be unobtrusively used at home for screening, and at the hospital to reduce risk of anesthesia-related complications.

245-496 **Cerebral Oximetry Versus Pulse Photoplethysmography to Monitor Respiration Rate**

Iraia Isasi, Unai Irusta*, Elisabete Aramendi, Goiuri Peralta and Erik Alonso

The pulse photoplethysmosgram (PPG) it is known to be modulated by res- piratory activity in amplitude and/or rate. The cerebral oximetry signal (OXY) monitors the oxygen saturation and fluctuates with every cardiac beat. The hy- pothesis of this study is that the pulse rate variability measured in the OXY is as accurate as the PPG to monitor the respiration rate. Aim: To test the accuracy of the PPG, measured in the finger, and the OXY, measured by infrared spectroscopy in the forehead, to monitor respiration rate. A method based on spectral analysis was developed and tested with different respiration rates. Materials: Signals were recorded simultaneously from 29 healthy volun- teers during 10 min for three respiration rates: 9/12/18 min-1 . The PPG from the index finger and the thoracic impedance (TI) were recorded at a sampling rate of 250 Hz with the Biopac OXY100C and EBI100C modules respectively. The OXY was recorded with a sampling rate of 50 Hz with a wireless labora- tory oximeter by Artinis. Methods: The PPG and the OXY signals were band-pass filtered and pulse- beats were automatically detected. The pulse-duration signal in 1-min was spectrally analyzed using the lomb-scargle periodogram. The respiration rate was identified as the most prominent peak (with corrections) in the 6-24 min-1 range. Rates were compared to those observed in the TI-signal. Fig. 1. Bland-Altman plots for rates derived from the PPG. Results: The mean(SD) absolute error was 0.3(1.2)min-1 for the PPG, 0.2(0.9)/0.3(1.2)/0.5(1.5)min-1 for the 9/12/18 rates. The error was 0.4(1.3) min -1 , 0.2(1.1)/0.4(1.2)/0.5(1.6)min-1 for the three rates in the OXY. The Bland-Altman plots showed a 95% level of agreement of -1.0–1.4min-1 for PPG (Fig. 1) and -2.4–2.0min-1 for OXY. Conclusion: Both the OXY and the PPG are accurate to monitor respiration rate. Relative errors increase with respiration rate

246-112 **Beat-To-Beat Autonomic Cardiovascular Response to Short-Term 100%O2 Breathing: a Time-Frequency Analysis Approach**

Salvador Carrasco-Sosa and Alejandra Guillén-Mandujano*

Very few studies have examined the effects of hyperoxia on HRV. Moreover, the reported effects are contradictory, so it is unclear which mechanisms of cardiovascular and respiratory neural control are affected and how. To clarify this issue, using a time-frequency distribution we assessed the instantaneous time course of the effects of short-term 100%O2 breathing on: sympathetic and vagal activities, baroreflex sensitivity (BRS), R-R intervals (RR), arterial pressure (AP) and pulmonary ventilation. Sixteen healthy volunteers underwent 1-min control (air breathing), 2-min maneuver (100%O2 breathing) and 1.5-min recovery stages. From ECG, AP, respiratory volume, arterial oxygen saturation (SaO2) and expired CO2 concentration recordings, time series of RR, systolic pressure (SP), diastolic pressure (DP), end tidal CO2 pressure (PETCO2), tidal volume (TV) and respiratory frequency (RF) were computed. Series were separated into level and variability by low-pass filtering. Time-frequency spectra of RR and SP variability series were estimated to obtain their low-frequency powers (LFRR, LFSP), high-frequency power of RR (HFRR) and the LFRR/HFRR ratio. Instantaneous BRS was obtained by alpha index in the low-frequency band. Compared to control, during maneuver SaO2 raised to a plateau ($p<0.001$) that remained elevated throughout the recovery stage. While HFRR, BRS, RR, SP and DP showed instantaneous response patterns of progressive increment, LFRR, LFSP and LFRR/HFRR ratio presented decreasing patterned responses. The pooled means of the above variables corresponding to the final 45s were different from control ($p<0.01$). RF, TV and PETCO2 were not different from control. During hyperoxemia, the instantaneous time courses of autonomic cardiovascular variables are fluctuating, with subtle yet significant changes. Hyperoxemia initially causes RR lengthening through a direct vagal activity increase followed by a vasomotor-effect-dependent AP increment, which, via baroreflex mechanisms (whose sensitivity is augmented), intensifies vagal outflow and reduces sympathetic activity, but it does not modify chemoreflex mechanisms nor respiratory sinus arrhythmia.

247-283 **Real-Time Respiratory Rate Estimation using Imaging Photoplethysmography Inter-Beat Intervals**

Leila Mirmohamadsadeghi*, Sibylle Fallet, Virginie Moser, Fabian Braun and Jean-Marc Vesin

Aim: Imaging photoplethysmography (iPPG) has emerged as a contact-less heart-rate monitoring tool. We investigate the accuracy of iPPG in conveying the inter-beat variation due to the respiratory modulation of the heart rate. The instantaneous respiratory rate was estimated in real-time from the iPPG inter-beat variations. Methods: The heartbeats were detected from the iPPG red, green and blue channels (obtained by pixel averaging from the forehead region) by maxima detection, with the detection window determined from the fundamental period of the signals. The fundamental period was computed using a notch filter bank (NFB) real-time instantaneous frequency estimation method. The respiratory rate was estimated using the NFB algorithm from the high-pass filtered iPPG inter-beat intervals, and compared to an estimate from the ECG inter-beat intervals and one from the reference respiration, recorded simultaneously (12 subjects, 92 minutes of data). A quality index based on the amplitude of the iPPG signals was developed to detect large variations in the signals such that respiration rates were only estimated for sufficiently good-quality data. Results: The green channel yielded the inter-beat intervals most similar to the ECG ones with an average correlation of 0.75±0.23 (all per-record correlations were significant with $p<0.001$). The mean absolute error between the iPPG-green respiratory rate estimate and the reference was 3.53±2.03 breaths-per-minute (bpm) while the error between the iPPG-green and the ECG estimates was 3.16±1.82 bpm, and the error between the ECG estimate and the reference was 2.94±3.67 bpm. The results were obtained on 89% of the iPPG data selected as having a sufficient quality index. Conclusions: In this study, errors are comparable to commonly reported errors for respiratory rate estimation from the ECG. Moreover, the data were recorded with varying respiration rates, which is challenging. These findings are encouraging in the use of iPPG for real-time contactless respiration rate monitoring.

Wednesday, September 14, 2016 **10:30**

SA1 Special Session: QT, Drugs and Computing

Chairs: Blanca Rodriguez and Jean-Philippe Couderc

Room: Pinacle II

248-441 **Evaluating the Effect of a Novel Cardiac Late Sodium Current Inhibitor (Eleclazine) on the QT, QTpeak and TpTe Intervals in LQT3 Patients Using the QT Clock Concept**

Alex Page*, Jennifer Hellawell, Patrick Yue, Luiz Belardinelli, Wojciech Zareba, Tolga Soyata and Jean-Philippe Couderc

Background: Mutations in the SCN5A gene in LQT3 patients are associated with an increased cardiac late sodium current (INaL), prolongation of the QTc interval, and higher propensity to cardiac events that usually occur at night and during bradycardia. Eleclazine is a novel selective inhibitor of INaL being investigated as a new medication to shorten ventricular repolarization. We applied the "QT clock" concept to the QTc, QTpc (QT peak corrected), and TpTe intervals to describe the circadian patterns of eleclazine's effect on ventricular repolarization. Methods: Beat-to-beat QT, QTp, and TpTe intervals were measured automatically from 24-hour Holters from five LQT3 patients with baseline QTc>480 ms. Patients received 50mg of eleclazine on Day 1, 10mg on Days 2-3, and 20mg on Days 4-7. One patient was excluded from our analysis due to unreliable T wave annotations. The "QT clock" method was used to evaluate the drug's effect on QT and its sub-intervals for days 2-7. The QT clock displays the median and interquartile range of these intervals across 24 hours, delivering a simple and comprehensive assessment of circadian changes of the drug's effect on ventricular repolarization. Results: We observed a clear shortening effect by eleclazine of the QTc interval in LQT3 patients which ranged from 20ms to 40ms during the day and night, respectively. The contribution of the TpTe intervals to this shortening was constant across 24 hours and averaged <10ms (~10% shortening of the baseline TpTe interval). Hence, changes in QTpc interval account for most of the reduction in QTc induced by Electazine. Conclusion: QT clocks reveal that treatment with eleclazine is associated with significant shortening of the QTc interval in LQT3 patients, including both QTpc and TpTe interval shortening. The TpTe shortening might be a reflection of reduced dispersion of ventricular repolarization, whereas QTpc reflects reduction in repolarization duration.

249-247 **In Silico Drug Trials Predict Safety and Efficacy of 10 Anti-Arrhythmic Compounds and Identify Sub-Populations at Higher Risk**

Elisa Passini*, Oliver Britton, Alfonso Bueno-Orovio and Blanca Rodriguez

Introduction and Aim: Safety and efficacy of anti-arrhythmic drugs remain a big challenge in cardiology. Inter-subject variability determines different responses to therapies, and arrhythmias occur only in certain patients and/or conditions. In silico drug trials can investigate changes in cellular electrophysiology and key ionic mechanisms responsible for arrhythmias. The aim of this study is the assessment of 10 well-known anti-arrhythmic compounds in populations of human ventricular models, to identify sub-groups of patients at higher risk. Results are compared with QT measurements and arrhythmic risk in vivo. Methods: Two populations of action potential models including inter-subject variability were constructed, based on the O'Hara-Rudy model and human experimental data: a normal/control population (n=986) with ionic conductances varying [50-150]% of their original values; a population (n=1213) with larger variability ([0-200]%), thus including abnormal current profiles representing e.g. specific mutations/diseases. Multichannel blocking action of anti-arrhythmic drugs (classes I, III and IV) was simulated using simple pore-block models and IC50 values. Drug-induced changes in action potential duration and upstroke velocity were analysed, together with repolarisation and depolarisation abnormalities. Results: In silico predictions are in agreement with clinical data showing prolonged repolarisation and increased dispersion for class III drugs and slow depolarisation for class I drugs. Safe compounds do not show abnormalities, even at high doses. Compounds with a clinical history of arrhythmias provoke dose-dependent occurrence of repolarisation/depolarisation abnormalities (more likely in the population with wider ionic profiles). Repolarisation abnormalities occur in human models with a compromised repolarisation reserve due to: reduced Na+/K+-pump and IKr; increased Na+/Ca2+-exchanger and ICaL. These changes recur in many cardiac pro-arrhythmic disorders, suggesting that modelling diseased populations may be crucial for drug safety evaluation. Conclusions: In silico drug trials predict safety and efficacy of 10 anti-arrhythmic compounds, highlighting inter-subject variability and

diseased modelling as key factors for an accurate risk assessment.

250-509 **Cell-to-ECG Modeling and Clinical Trial ECG Evaluation of ECG J-to-Tpeak Interval**

Joel Xue*

Drug induced prolong QT can cause Torsade-de-Point (TdP), therefore has been under a thorough investigation by FDA for last 10 years. The main focus has been on the potassium channel (Ikr) effects on the ECG QT interval. Lately, multi-Ion channel effects like late-sodium and calcium currents have also been investigated, and the new ECG parameter like Tpeak-to-Tend (TpTe) and J-to-Tpeak (JTp) have been shown to correlate with multiple ion-channel changes. This study used a newly modified Cell-to-ECG whole heart model to simulate multi-Ion channel effect on QT, TpTe and JTp intervals. The heart model combined the modified ion-channel with added Late Sodium channel and a human ventricle heart geometry. The simulation induced the blockage of Ikr, InaL, Ica separately, and with some combinations. The clinical data is from a FDA sponsored clinical trial with 22 healthy subjects received a single dose of a pure hECG blocker (dofetilide) and 3 drugs that also block calcium or sodium (quinidine, ranolazine, and verapamil) as part of a 5-period, placebo-controlled cross-over trial. The modeling results showed the Ikr block can cause QT, TpTe and JTp prolongations. The InaL block caused more QT and TpTe prolongation, but much less prolongation, or even shortening of JTp interval, depending on the transmural dispersion introduced. When combined block of Ikr and InaL, QT and TpTe were prolonged, but JTp's change was depend on the balance of the Ikr and InaL. The clinical trial data verified that for hECG blocker dominant drugs like dofetilide and quinidine, QT, TpTe and JTp were all prolonged when drug concentration increased; For late-sodium blocker drug ranolazine , JTp was shortened with the increase of the concentration. The modeling simulation predicted the trend of clinical results. Late-sodium ion channel block can shorten the JTp, while dominant Ikr block can cause QT, TpTe, JTp prolongation.

251-483 **Optimization of an In Silico Cardiac Cell Model for Proarrhythmia Risk Assessment**

Sara Dutta*, David Strauss, Thomas Colatsky and Zhihua Li

Introduction: The Comprehensive In vitro Proarrhythmia Assay (CiPA) is a new regulatory paradigm proposed to replace the ICH S7B and E14 guidelines for assessing drug-induced proarrhythmia. CiPA proposes to measure drug effects on multiple cardiac ion channels in vitro and to integrate these data into an in silico model of the adult human ventricular cell, based on the O'Hara-Rudy(ORd) model. Block of the late sodium current (INaL) can mitigate repolarization effects, but this activity is not accurately reproduced in the published ORd model. The present study aims at assessing and improving the simulation of INaL block in ORd. Methods and Results: Using the original ORd model to reproduce INaL blocking data from in vitro and clinical studies, we found that changes in action potential duration (APD) were consistently underestimated when INaL blockers were simulated. In our initial attempts to adjust INaL representation in the ORd model, we found that a two-fold increase in INaL conductance improves the prediction of both in vitro and clinical data (APD shortening of 9ms for 20% INaL block and 21ms for 54% INaL block compared to 4 and 11ms with the original ORd model). Currently we are systematically adjusting INaL and other channel equations in the model, to fit not only individual level channel blocking data but also the system level output of the cardiomyocyte. Conclusion: By adjusting the ORd model it is possible to better predict in vitro and clinical data of INaL block. The modified model can better reflect known clinical pharmacology and improve the quantitative prediction of drug effects and proarrhythmia risk in the context of the CiPA initiative.

Wednesday, September 14, 2016 **10:30**

SA2 Ultrasound Imaging

Chairs: Enrico Caiani and Alan Murray

Room: Shaughnessy I

252-490 **Automatic Dynamic Quantification of Oesophagus Position from Intra-cardiac Echocardiography During Atrial Fibrillation Ablation**

Federica Lauretti*, Rachele Angeletti, Alessandro Dal Monte, Corrado Tomasi and Cristiana Corsi

Introduction: Left atrium posterior wall (LAPW) is an essential target for transcatheter radiofrequency ablation (RFA) of atrial fibrillation (AF), but poses problems due to retro-atrial structures potentially damaged by RF. Apart from the dreaded atrio-oesophageal fistula, which is rare, oesophageal and mucosal lesions have been described ir up to 20% of cases; no preventative method has gained wide acceptance yet. Intracardiac echocardiography (ICE) can be integrated with the 3D electro-anatomical map and provide unique real-time anatomical information about all closely-located peri-cardiac structures. The present study aimed to automatically detect dynamic oesophagus position and its spatial relationship from the LAPW by ICE during RFA. Methods: A fast algorithm based on the evaluation of gray level intensity distribution in the image was developed to detect candidate pixels belonging to the oesophagus wall. Fitting of candidate pixels resulted in distal and proximal oesophagus boundaries. The algorithm was tested in 15 ICE acquisitions. The detected oesophagus boundaries and those manually traced (MT) by an experienced cardiologist in one image for each ICE sequence were compared by linear regression, Bland-Altman analysis and similarity indices. In 5 ICE sequences, dynamic tracking of proximal oesophagus boundary was performed and its distance from the LAPW was evaluated throughout the sequence. Results: Mean analysis time was 4.5 sec/frame. Detected oesophagus positions were in good agreement with MT (mean difference in distal/proximal wall: 2±1.4mm/2.6±2mm). Mean oesophagus thickness was 6.4±2.8 mm (range: 2.8-13.9mm). In 5 ICE sequences mean minimum dynamic distance between LAPW and oesophagus proximal wall was 0.3±0.2mm (range: 0.0-0.6mm; mean maximum distance: 5.8±1.5mm (range: 4.3-8.3mm); mean average distance: 1.7±0.5mm (range: 1.0-2.4mm)). Conclusion: This technique allows automated and accurate dynamic detection of LAPW and oesophagus position in ICE sequences. It represents a first step for real-time tracking of LAPW and oesophagus placement monitoring during AF RFA to prevent oesophagus injuries.

253-417 **Design of a Multiplexing Scheme for a Matrix Array for 3D Cardiac Imaging**

Carolina Vallecilla* and Jan D'hooge

Volumetric cardiac ultrasound imaging requires 2D array transducers with thousands of elements to allow beam steering and focusing. Controlling elements independently is favorable but expensive and impractical, especially for research purposes. Multiplexing could offer a solution by grouping various elements per electronic channel, keeping the array density. However, multiplexed elements intrinsically share phase and amplitude when transmit-ting thereby impacting beam forming. Which transducer elements to be grouped is thus not obvious. We propose two methods to design a multiplexed probe suitable for 3D cardiac ultrasound system of 1024 elements and 256 channels. The matching algorithm: commonly applied to allocate doctors to hospitals. We created a co-occurrence matrix in which elements with a phase mismatch (<10% of the wave period) at the focal position were paired for a series of 2500 transmit events in the 3D image sequence. Elements then were "allocated" in channels based on their joint "co-occurrence" value. The virtual array: elements were grouped geometrically creating a "virtual array" with bigger elements (4X height). The four multiplexed elements were active on transmit but only one element was active on receive. Then the two-way beam profiles were simulated as well as for a fully-wired array. The side-lobe to-main-lobe energy ratio (SMER) was computed for a beam focused along the diagonal in the 3D image sequence (focus 60 mm, opening angle of 37.5 degrees). The mean SMER was -33 ± 2 dB for the fully-wired array, -28 ± 5 dB for virtual array and -23 ± 3 dB for the matching algorithm array. Although the virtual array showed the best SMER, receiving with ¼ of the array could affect image quality. The matched array uses most of the elements (i.e. the energy in acquisition), giving flexibility to the system. The proposed multiplexed probes are suitable solutions for experimental 3D cardiac ultra-sound transducers.

254-480 **Multicenter Validation of Three-Dimensional Echocardiographic Quantification of the Left Heart Chambers using Automated Adaptive Analytics**

Diego Medvedofsky, Roberto Lang, Mihaela Amzulescu, Covadonga Fernández-Golfín, Rocio Hinojar, Mark Monaghan, Joseph Reiken, Masaaki Takeuchi, Wendy Tsang, Jean-Louis Vanoverschelde, Indrajith Vath, Lynn Weinert, Jose Luis Zamorano and Victor Mor-Avi*

Background. Although recommended by the current guidelines, three-dimensional echocardiographic (3DE) quantification of the cardiac chambers in clinical practice has been lagging, because it relies on time-consuming analysis. We recently tested the feasibility of an automated algorithm that measures left atrial (LA) and left ventricular (LV) volumes and ejection fraction (EF). This study aimed to determine the accuracy and reproducibility of these measurements in a multicenter setting. Methods. 180 patients underwent 3DE imaging (Philips) at 6 sites. Images were analyzed using the automated HeartModel (HM) software with endocardial border correction when necessary, and also by conventional manual tracing. Measurements were performed independently by each site and by the Core Laboratory (CL), whose measurements were used as the reference for comparisons. Inter-technique comparisons included HM measurements by the sites with and without corrections against manual tracing by CL. Intra-technique comparisons included HM measurements by the sites against those by CL (with and without corrections, correspondingly). Reproducibility was expressed as percentage of absolute differences in repeated measurements. Results. Without contour corrections, inter-technique comparison showed strong correlations (r-values: LVEDV:0.97, LVESV:0.97, LVEF:0.88, LAV:0.96), with the automated technique slightly underestimating LV volumes (biases: LVEDV:-14±20ml, LVESV:-6±20ml), LVEF (-2±7%) and LAV (-9±10ml). Corrections were either unnecessary or minimal in most patients, and improved the measurements only modestly. Intra-technique comparison without corrections showed perfect agreement for all parameters. With corrections, intra-technique correlations were better (r-values LVEDV:0.99, LVESV:0.99, LVEF:0.94, LAV:0.99) and biases (LVEDV:-8±12ml, LVESV:-6±12ml, LVEF:1±5%, LAV:-10±6ml) smaller than in the inter-technique comparison. All automated measurements with

corrections were more reproducible than manual measurements. Conclusions. Automated volumetric analysis of left-heart chambers is an accurate alternative to conventional manual methodology, which yields almost the same values across laboratories and is more reproducible. This technique may contribute towards full integration of 3DE quantification into clinical routine.

255-427 Feature Tracking Algorithm for Circumferential Strain using High Frame Rate Echocardiography

Martin Vandborg Andersen*, Cooper Moore, Samuel Schmidt, Peter Søgaard, Johannes Struijk, Joseph Kisslo and Olaf von Ramm

Aim: This study aims to describe a feature tracking algorithm tailored to estimate circumferential strain on high frame rate ultrasound (HFR-US) images. Methods: The algorithm used the Hungarian assignment algorithm for tracking a basic feature descriptor. A second order Kalman model was used to recursively describe regional myocardial displacement along the myocardial contour, and the strain was calculated using these displacements. Results: HFR-US images at 360 fps were acquired from a patient with left bundle branch block (LBBB) in the parasternal short axis view with a biventricular (BiV) pacer turned off and on. There was a large variation in the onset and end of mechanical contraction for each individual myocardial region when the BiV pacer was turned off. The variation reduced immediately wher the BiV pacer was turned on. Conclusion: The presented algorithm can estimate circumferential strain using high frame rate ultrasound images. The circumferential strain does suffer from high intra- and inter-operator variance due to the lack of landmarks making it difficult to reproduce results. However, as circumferential and longitudinal strain offer two different, but somehow interrelated, descriptors of complex mechanical movement of the heart. The observed variance reduction may be indicative for a positive BiV response in LBBB patients.

256-250 **A Combined Multi-scale Deep Learning and Random Forests Approach for Direct Estimation of The Left Ventricular Volume from 3D Echocardiography**

Suyu Dong*, Gongning Luo, Guanxiong Sun, Kuanquan Wang and Henggui Zhang

Background: Estimation of left ventricular (LV) volumes from 3D echocardiography (3DE) is a popular clinical approach in accurate assessment of left ventricular function for the diagnosis of cardiac disease. The segmentation of 3DE volumes is a crucial step in traditional methods. Nevertheless, segmentation itself is an extremely challenging problem due to the presence of speckle noise and discontinuous edges. Therefore, direct left ventricular volumes estimation methods without the segmentation become attractive in cardiac function analysis. So this paper presents a fully learning framework to estimate the left ventricular volumes in 3DE. Methods: The proposed method combines unsupervised multi-scale convolutional deep network and random forests. The multi-scale convolution deep network adopts multi-scale convolutional filters and restricted Boltzmann machine (RBM) to represent features of unlabeled end-diastolic and end-systolic 3DE volumes (EDV and ESV). And then we formulate left ventricular volumes estimation as a regression problem and use random forests for efficient volumes estimation. The proposed method can associate the features with the left ventricular cavity in 3DE. 60 unlabeled volumes from 30 patients are used for unsupervised feature learning, 120 labeled volumes from 60 patients for the training of random forests and 120 labeled volumes from another 60 patients for the validation of left volumes estimation. We compared the estimated volumes with the labeled results from cardiologist in terms of correlation coefficients (R) and mean errors (ME) on EDV, ESV, and ejection fraction (EF). Results: Clinical indexes derived from the estimated volumes are in good agreement with the golden standard from manual evolution (EDV: R=0.850, ME=10.9±5.7ml; ESV: R=0.871, ME=15.5±7.5ml; EF: R=0.863, ME=7±2.3%). Conclusions: The direct estimation of LV volumes using a fully learning method is feasible. Besides, this method can accurately evaluate the LV volumes, even in case of irregular geometry.

SA3 Fetal, antenatal and neonatal Cardiovascular Control

Chairs: Laura Burattini and Guy Carrault

Room: Pinnacle III

257-501 **Antenatal Fetal Heart Rate Acceleration Detection**

Philip Warrick* and Emily Hamilton

Objectives: Fetal heart rate (FHR) accelerations (ACC) are transient tachycardia having a minimum amplitude 15 beats per minute, lasting 15 s to several minutes. They are viewed by clinicians as a positive indicator of fetal health. During the antenatal period non-stress test, FHR is routinely measured noninvasively by cardiotocography. While we have developed an FDA-approved detector of FHR events for term labour (PeriCALM PatternsTM), we have not applied it in the smaller amplitude, lower SNR antenatal context. The purpose of this study wa to measure the performance of ACC detection for gestational age (GA) 28-40 wks, comparing our existing detector to one based on a hidden semi-Markov model (HSMM). Methods: From a dataset of 72 antenatal CTG recordings with durations ranging from 20 min to several hours, an expert obstetrician manually annotated the ACCs. Each antenatal GA group included at least 5 recordings. Features were derived from a median-detrended signal decomposed by the discrete cosine transform. We used an HSMM (adapted from the Physionet Logistic Regression HSMM [Springer2016]) because it accounts for the state durations of the ACCs. We allowed two states (ACC and non-ACC and used a fixed Gaussian durational model with forced transitions only after the ACC state. We then applied the two detectors to the recordings and compared their performance to the expert markings. Results: Sensitivity (Sens) and positive predictive value (PPV) appear in the figure. The reference detector was consistently superior PPV while HSMM sensitivity was more stable across the GA groups with higher Sens at low GA. Conclusions: Both detectors degrade in the lower SNR conditions of earlier GA. In the next phase of this study, an improved HSMM model accounting for GA based on a larger dataset should improve PPV.

258-352 Relationship between Deceleration Areas in the Second Stage of Labor and Neonatal Acidemia

Angela Agostinelli*, Flavio Palmieri, Alessandra Biagini, Agnese Sbrollini, Luca Burattini, Francesco Di Nardo, Sandro Fioretti and Laura Burattini

Understanding the Fetal Heart Rate (FHR) in the second stage of labor is of great importance to understand some critical clinical outcomes observed in deliveries. During the second stage of labor, fetuses are subject to head compressions that can activate baroreceptor reflexes which cause FHR decelerations. Early decelerations (i.e. synchronous to uterine contractions) are generally considered as benign and physiological; however, large deceleration areas (DA: measured as duration by depth), have been found to be associated with critical fetal outcomes. In 2013, a preliminary study on 33 pregnant women attempted to quantify this phenomenon, previously only qualitatively described, and reported a significant inverse correlation between DA in the last 60 minutes before delivery and umbilical pH at birth (the latter being a measure of fetal distress when ≤ 7.1). The aim of the present study was to further characterize the relationship between DA in the last 60 minutes before delivery and pH at birth on a larger population. To this aim, 433 FHR recordings from the CTU-UHB Intrapartum Cardiotocography Database of Physionet was used. Tracings were classified as Controls, when neonatal pH > 7.1, and Cases, when neonatal pH ≤ 7.1. Results confirmed that Cases have significantly higher DA than Controls (median values: 5.32 cm2 vs 1.44 cm2; P < 0.05). However, the inverse correlation between DA in the last 60 minutes before delivery and neonatal pH, although significant (P < 10-6), was weak (r = -0.23).The area under the receiver operating characteristic was 0.61. Thus, our results confirm that critical fetal outcomes increase with increasing acidemia (decreasing pH); however, such relationship may not be strictly linear. Future investigation are needed to identify criteria for discrimination of cases of fetal distress using DA.

259-494 **Heart Rate Variability Analysis of Normal and Intrauterine Growth Restricted Children using Sample Entropy**

Taher Biala*, Fernando S. Schlindwein, J. Alexandre Lôbo Marques and Michael Wailoo

It is well documented in literature that Heart Rate Variability (HRV) entropies for healthy subjects may present higher values of Sample Entropy (SampEn), a measure of system complexity, when compared with subjects with specific pathological conditions. Nevertheless, for new groups and conditions, nonlinear measures must be considered and discussed. This work proposes the use of SampEn to analyze 2 different groups of children during 24-hour ECG/HRV monitoring. The considered database consists of 20 children (age 9.18 ± 0.68), divided in two groups: 10 Normal children (5 female) and 10 children (5 female) with medical history of intra-uterine growth restricted (IUGR). Four different entropy calculations were considered: the complete 24 hours trace; before sleep time; during sleep and after sleep time. Statistic t-test was considered for intra and intergroup comparison. The results showed significant difference ($P < 0.0349$) during sleep time interval between normal group (SampEn=1.2325 ± 0.094) and IUGR group (SampEn=1.3517 ± 0.122). This result may indicate that IUGR children may develop higher levels of complexity during sleep time. The other intervals presented no significant difference in intergroup comparison. An intragroup analysis was also considered and both groups showed significant difference between before sleep and during sleep intervals. For the normal group ($P<0.001$), before sleep (Sampen=1.0237 ± 0.103) and during sleep (SampEn=1.2325 ± 0.094). For the IUGR group ($P<0.013$), before sleep (Sampen=1.1173 ± 0.223) and during sleep (SampEn=1.3517 ± 0.122). The results indicate that SampEn may be considered as a measure of HRV complexity to monitor normal and children with medical history of IUGR. Further studies with other nonlinear measures and with an expanded database are going to be considered.

260-390 **Regularity of Fetal HRV Changes in an In-vivo Sheep Model of Labor**

Massimo W Rivolta, Md Aktaruzzaman, Tamara Stampalija, Daniela Casati, Martin G Frasch, Enrico Ferrazzi and Roberto Sassi*

Aims. Labor exposes the fetus to repetitive transient hypoxic stress that manifests with changes in heart rate variability. In this study, we assessed whether such repetitive events alter the regularity of the fetal inter-beat interval series (fRR), using an in-vivo near-term sheep model, by means of entropy measures. Dataset. Umbilical cord occlusions (UCO), from partial to complete (MILD, MODERATE and SEVERE), were applied to 7 near-term pregnant sheep. During the entire protocol, fetal blood samples were collected at intervals of 20 minutes, to quantify three biomarkers: pH, lactate and base deficit. An electrocardiographical (ECG) recording was obtained using electrodes implanted into the fetus, and then used to automatically derive the fRR series. Methods. For each 2.5 minutes-long cycle of occlusion and successive recovery, sample entropy (SampEn), permutation entropy (PE), and differential PE (dPE) were estimated for patterns of various lengths (m=1 to 3 for SampEn and m=2 to 6 for PE), obtained from the RR series. First, we tested, for statistical significance using the Spearman's rank-order correlation, if the entropy values evolved in time during the course of the experiment. Then, we further verified the direct correlation between the values of the biomarkers and those of the entropies obtained from the three occlusion-recovery periods, time-aligned with each blood sample (from 1 cycle before to 1 after). Results. All the values of entropy decreased during the experimental protocol (rs=-0.28 for PE at m=5 and dPE at m=4; rs=-0.62 for SampEn at m=1; $p<0.05$). There was also a strong correlation between the values of the biomarkers and SampEn ($0.52<|rs|<0.63$; $p<0.05$), while only a weak correlation with PE values ($0.36<|rs|<0.43$; $p<0.05$). Conclusions. Repetitive umbilical cord occlusions led to a progressive change of regularity of the fetal HRV, suggesting a more pronounced FHR modulation as first line adaptive response.

261-169 **Effects of Postnatal Environmental Tobacco Smoke on Cardiorespiratory Control in Newborn Lambs**

Sally Al Omar*, Virginie Le Rolle, Nathalie Samson, Jean-Paul Praud and Guy Carrault

Aims: While prenatal environmental tobacco smoke (ETS) exposure is established as an important risk factor for sudden infant death syndrome, the effects of postnatal ETS exposure are unclear. We assessed the effects of 15-days postnatal exposure to 20 cigarettes/day on heart rate variability (HRV), respiratory variability (RV) and cardiorespiratory coupling in newborn lambs. Methods: On postnatal day 16, six-hours polysomnographic recording was obtained from six control lambs exposed to room air (group C0) and six lambs exposed to 20 cigarettes/day (group C20) for the first 15 days of life. ECG and respiratory movements (RSP) were continuously monitored. We extracted RR intervals from the ECG and the durations of inspiration (Ti), expiration (Te,) and total breathing cycle (Ttot) from the RSP signals. Linear (time and frequency domains) and nonlinear (SD1, SD2 from Poinca-ré plots and sample entropy) analyses were performed on RR intervals and Ti, Te, Tot time series. Cardiorespiratory coupling was assessed from RR and RSP signals by: linear correlation (r^2), bidirectional nonlinear regression (i.e. h^2RR,respi and h^2Respi,RR), phase synchronization and counting the number of heartbeats in each inspiration and expiration. The Mann-Whitney U test was used for statistical analyses and the presence of a significant trend is decided for $p < 0.06$, due to the small number of lambs. Results: Only main results are here reported and presented as mean±SD. For HRV, only skewness showed a difference between the two groups (C0: 0.5±1.4, C20: -0.01±0.6). For RV, the standard deviation of Te (C0: 0.1±0.04, C20: 0.2±0.1) showed a significant increase in the C20 group while SDNN (C0: 0.1±0.05, C20: 0.2±0.1) of Ttot and h^2Respi,RR (C0: 0.12±0.08, C20: 0.16±0.09) tended also to differentiate between the two groups. Conclusion: Our results suggest ETS exposure for the first 15 postnatal days leads to slight alterations of cardiorespiratory control, which predominate on respiration.

Wednesday, September 14, 2016 **10:30**

SA4 **Monitoring**

Chairs: Daniel Guldenring and Rich Gregg

Room: Shaughnessy II

262-161 A Multicentric Study of Long-term Rhythm Patterns in Heart Rate

Rebeca Goya-Esteban*, Ó Barquero-Pérez, J Alzueta, X Viñolas, N Basterra, E García, J Villacastín, I Fernández-Lozano, J Brugada, JB Martínez-Ferrer, JL Rojo Álvarez, F Zumalde, M Martín-Méndez, F Chavarría-Asso and A Garcia Alberola

Introduction. Heart rate (HR) is known to have oscillations with different periods, as a result of the sympatho-vagal balance. The most studied ones are short-period variations (seconds, minutes) and the circadian pattern. However, the existence of rhythms of longer periods has not been systematically studied. Aim. To study long-period rhythms in HR and their possible relationship with the patient clinical data. Methods. A multicentric database including 336 patients in sinusal rhythm, with implanted cardioverter defibrillator, was assembled from SCOOP database. Daily and nightly mean HR were extracted from each patient for its analysis (monitoring period between 382 and 2348 days). We used a rhythmometric procedure based on a multicomponent COSINOR approach and a non-parametric statistic test to automatically select the statistically significant rhythms present in the HR signal. Furthermore, we used the LASSO path approach to analyze the order of activation of the rhythms, representing the importance of each rhythm. Results. Most of the population showed a significant annual rhythm (78% day/80% night). Weekly and trimestral rhythms were also present (weekly 26% /26% ; trimestral 22%/21%). Monthly rhythm was rarely present. Most present rhythm combinations were annual plus weekly (21%/21%) and annual plus trimestral (19%/18%). The order of activation given by the LASSO path was in agreement with the multicomponent rhythmometric model in the 86%/85% of the cases. Conclusion. The long monitoring period, and the high number of patients in the database, represent an ideal scenario to robustly assess the existence of long-term rhythms. Two technical approaches were in agreement in most of the cases, being the LASSO path used for the first time in rhythmometric analysis. The annual rhythm is by far the most significant one. Further studies will be devoted to assess the relation of the rhythm presence and the patient clinical data.

263-207 **Evaluation of the Accuracy and Noise Response of an Open-source Pulse Onset Detection Algorithm on Pulsatile Waveform Databases**

Chengyu Liu*, Qiao Li and Gari Clifford

The open-source algorithm ‘wabp.c’ (Zong et al. 2003) has been widely used for onset detection of arterial blood pressure waveforms. This code was subsequently modified by Li et al. (2011) for onset detection for photople-thysmogram (PPG) pulsatile signals. However, its performance was not sys-tematically validated, especially on a noisy pulse database. This study aimed to evaluate its detection accuracy on both clean and noisy pulsatile signals. Two multi-parameter databases (set-p and set-p2, both including ECG and PPG recordings) from the PhysioNet/Computing in Cardiology Challenge 2014 were used (http://physionet.org/challenge/2014/). Signal quality in set-p is relatively high, while relatively poor in set-p2. Each database includes 100 10-minute recordings. The ECG ‘R’ peak annotations were provided from the ECG signal and served as the benchmark for pulse onset detection. True positive (TP), false positive (FP) and false negative (FN) beats were identified for each recording. Detection accuracy was calculated as TP/(TP+FP+FN)×100%. For the relatively ‘clean’ database set-p, there were a total of 72454 pulse beats. The detected TP, FP and FN beats were 72132, 141 and 181 respec-tively, resulting in a final accuracy of 99.56%. For noisy database set-p2, there were totally 62954 pulse beats. The detected TP beats totaled 49483, accompanied by large numbers of FP and FN beats (7532 and 5939 respec-tively), resulting in a relative low accuracy of 79.60%. In summary, open-source pulse onset detection code was found to achieve high detection accuracy in a low noise pulsatile waveform database while relative low detection accuracy was observed when using a relatively noisy pulsatile waveform database. Combining the code with a signal quality assessment procedure is therefore recommended to improve the reliability.

264-145 **Computational Efficiency and Accuracy for QRS Detection Algorithms on Clinical Long Term Multilead Monitoring**

Francisco-Manuel Melgarejo-Meseguer*, Estrella Everss-Villalba, Jan Široký, Francisco-Javier Gimeno-Blanes, Jose-Antonio Flores-Yepes, Manuel Blanco-Velasco, Jose Luis Rojo-Alvarez and Arcadi Garcia-Alberola

The availability of new technology for long term ECG monitoring may enhance clinical diagnosis capabilities thanks to the increase of available information. But this will only happen if processing-technology evolves synchronic with data volume increase. An important number of relevant clinical measurements are derived from QRS detection, and so the fast and accurate calculation becomes a key factor to meet this target, especially when the huge amount of beats recorded in long term monitoring (from 7 days to 21 days) leaves very little room for clinical effective supervision. In this paper, we analyze both, the accuracy and the computational cost, for most relevant and published QRS detection algorithms, as well as for several additional ones developed in this project (9 different methods total). A gold-standard was developed by expert clinicians who evaluated manually every single visible beat inside 48h multilead holter signals. We selected the 17 more challenging cases in terms of noise, from a database of 120 recordings from Hospital Virgen de la Arrixaca of Murcia (Spain). Relevant published digital filtering and wave-form methods were implemented following careful instructions from authors. To maximize the accuracy, we tacked the free parameters tuning with a standard training process. As a result, computational efficiency required optimal segment lengths from 5 minutes to 7 hours, depending on the selected method. Fortunately, the computational cost showed no correlation with the accuracy, and optimal simple digital filtering method outperformed other complex mathematical calculations, leading to a positive trade-off between computational cost and accuracy. The adjusted Pan-Tompkins method, as defined in this work, that included the Or function application through with all the available the leads while using the 5-minutes length segment, provided the best results (sensitivity 99.23%, specificity 95.63%, accuracy 97.06%), and almost the minimum processing time of 77 seconds for 48h multilead signals.

265-273 **Assessing Effect of Beat Detector on Detection Dependent Signal Quality Indices**

Chathuri Daluwatte*, Lars Johannesen, Loriano Galeotti, Jose Vicente, David Strauss and Christopher Scully

Patient monitoring algorithms which use multimodal physiological waveforms are needed to reduce alarm fatigue by alarming only for physiologic events and not signal artifacts. When combining information from multiple ECG signals, computational approaches tha automatically identify artifacts in ECG signals play an important role. Signal quality indices (SQIs) have been derived which can differentiate between ECG signal artifacts and normal QRS morphology. Some of these SQIs are derived using beat detections and might be affected by the beat detector used. Using ECG signals from the asystole, bradycardia and tachycardia alarms of the PhysioNet/Computing in Cardiology Challenge 2015 training set, we studied the effect of beat detector on previously reported ECG SQIs derived using beat detections. Human annotators labelled R peaks in 10 s epochs durin and immediately before the alarm in each ECG signal to create reference annotations. Twelve SQIs were calculated for each epoch using five previously reported beat detectors and reference annotations. SQI distributions from five beat detectors were compared to those calculated from reference annotations using Dunn's test with Bonferroni correction. For each ECG epoch and beat detector, detection performance was defined as F1=2*TP/(2*TP+FP+FN) (True Positive, False Positive, and False Negative beat detections). The ability of SQIs to discriminate beat detector performance was assessed by area under the receiver operating characteristic curve (AUC) to separate records with F1 ≤ 90% (considered poor detector performance) and F1 > 90% (considered acceptable detector performance). We found that, while being affected by the beat detector, some of these SQIs can predict beat detector failure. SQI average template matching correlation coefficient identified poor beat detector performance for four of the five detectors. Using beat detector specific SQIs can improve the designs of robust monitoring algorithms.

PB1 **Ventricular Arrhythmias**

Room: Pinnacle I

266-275 **Modeling and Simulation Study of the T618I Mutation in Human Ventricular Cell and Tissue**

Weigang Lu*, JiaZhi Du, Fei Yang, Jie Li, Kuanquan Wang and Junyu Dong

Short QT syndrome (SQTS) is a relatively new cardiac disease which is first recognized in 2000. It is associated with ion channel gene defects and a risk of sudden cardiac death. To date, there are six identified SQTS: SQTS1 to SQTS6. For SQTS1, recently a mutation in KCNH2 gene – T618I is discovered, which causes an amino-acid substitution at the position 618 of hERG. As a novel mutation, the effects of T618I-induced electrophysiological properties' changes of cardiac cells on electrical wave conduction and arrhythmia genesis have not been understood yet. In this study, to explore the functional impacts of the mutation, we develop a human ventricular cell and tissue models, in which the rapid delayed rectifier potassium channel current (IKr) is adapted with experimental data. Based on the above models, we simulate the action potentials of endocardial, midmyocardial and epicardial cells, measure respective action potential duration (APD90) and action potential duration restitution curves under WT and the T618I mutation condition. Then the effective refractory period (ERP) is computed. The vulnerable window and the perpetuation of re-entry are also considered. The simulation results show that compared with WT, the T618I mutation reduces APD90, flattens the APD restitution curves, and causes a leftward shift of the APD restitution curves in all three cell types. The ERP is abbreviated distinctly and the cellular membrane excitability is increased. Furthermore, the T618I mutation increases the width of vulnerable window at some localized region, which is easier to produce the unidirectional conduction. And it also decreases the minimal stimulation size that maintains re-entry. Our findings provide an explanation that the T618I mutation has greater probability to induce arrhythmia.

267-519 **A Novel Method for Automated Fractionation Detection in Ventricular Tachycardia**

Divyanshu Gupta, Damian Redfearn*, Javad Hashemi and Selim Akl

Introduction: Catheter ablation therapy has become a key interventior in treatment of recurrent Ventricular Tachycardias (VT). However, current fractionation mapping methods used to isolate the ablation targets in VT patients are done manually, and are therefore time consuming. They also have limited success rates (50% recurrence rate within 2 years). We propose an automated fractionation detection method for VT patients which can potentially increase the accuracy and success rate of the ablation therapy. Performance is evaluated by comparing the results with a control cohort (absence of VT). Methods: Latency, normalized delay between pace and start of activation; electrogram (EGM) duration, duration of the activation; and deflections, number of peaks in activation, were used to define fractionation. Data was processed with Teager-Kasers Energy Operato (TKEO) for peak detection. Features were extracted, using surface EGM and pacing catheter as reference points. Results: Intracardiac recordings were taken from the left ventricle (LV) in 10 patients (5 tests, and 5 control); for a total of 1350 segments of approximately 30 seconds. For every site, 18 paced beats, originating from a catheter located at the RV apex, were recorded. These consisted of three trains with extrastimuli timings close to Ventricular Effective Refectory Period (VERP): 600/(VERP+150), 600/(VERP+100) and 600/(VERP+50) in miliseconds (first/second beat in train). Test patients showed a larger mean and standard deviation for all three extrastimuli. All patients showed an overall increase in ΔCT and EGM duration as pacing approached VERP. Highly fractionated regions, and potential ablation sites, were obtained by filtering test data with 'normal' values obtained from control patients (mean +2*standard deviation). Conclusion: We showed that this process can be automated, and that the data obtained is correlative with arrhythmia. Furthermore, we showed that this data might be useful in isolating arrhythmogenic tissue for better targeted ablation.

268-392 **Modulation of Effective Refractory Period at the Infarct Border-Zone Provides a Mechanism for Focal Arrhythmogenesis**

Adam Connolly, Pawel Gawenda, Gernot Plank and Martin Bishop*

Infarct Border-Zone (BZ) tissue is known to correlate strongly with the formation of focal arrhythmias post infarction. However, the origin of focal arrhythmogenesis from the BZ remains unknown. Using computational monodomain modelling, we have discovered that significant gradients in Action Potential Duration (APD) and Effective Refractory Period (ERP) occur at the transition zone between healthy myocardium and BZ tissue, because of ionic remodelling. Specifically, the ERP was modulated by the magnitude of the fast sodium-channel conductance alone, while APD was relatively unaffected. Including the effects of the BZ modified repolarization currents modulated the APD (as observed experimentally), and further increased gradients in ERP. Gradients in APD and ERP of sufficient magnitude are known to facilitate the formation of re-entrant arrhythmias by providing a mechanism for uni-directional propagation. Using the monodomain model, we observed uni-directional propagation upon weak focal stimulation at the transition region between healthy myocardium and BZ tissue. This leads us to conclude that the interfacial region between BZ tissue and healthy myocardium may be an important site for arrhythmogenesis - future experimental validation is required.

269-177 **Functional Effects of Island-distribution of Mid-cardiomyocytes on Re-entrant Excitation Waves in the KCNQ1-linked Short QT Syndrome**

Cunjin Luo*, Kuanquan Wang and Henggui Zhang

Introduction:It is recognized that specific mutations in ion channels responsible for cellular repolarization underlie various idiopathic forms of short QT syndrome(SQTS).However,the functional effects of spatial heterogeneities in cardiac electrophysiology,such as island-distribution of mid-cardiomycytes(M island) in cardiac tissue on the electrical instability of excitation waves in SQTS are poorly understood.The aim of this study was to investigate such possible effects. Methods and Results:The role of M island in ventricular transmural wall in the generation and maintenance of re-entrant excitation waves was investigated by using a 2D model of human ventricular tissue incorporating ten Tusscher et al.model for cellular action potentials.The single cell model was modified to simulate changes to IKs based on experimental data of a gain-of-function mutation in KCNQ1 gene identified in SQT2.A 2D tissue model,representing a transmural slice,comprised of 100×400cells(15mm×60mm),among which 35%were mid-cardiomyocytes,either distributed in island form(M island) or continuous band form(M band),25%were endocardial and the rest were epicardial cells.In the tissue model,S1-S2 protocol was used to evoke excitation waves with the second premature stimulus(S2) produced a unidirectional conduction leading to genesis of re-entry if it fell in the vulnerable window.In WT condition,the initiated spiral wave spontaneously terminated for M island model,but sustained for M band model.However,in SQT2 condition,the spiral wave sustained for M island model,as well as for M band model,demonstrating an increased susceptibility of the tissue to sustain arrhythmias.Shortening of APD due to SQT2 mutation decreased the wavelength of the ventricular excitation wave,thus reduced markedly the minimal length of S2 necessary for initiation of re-entry,demonstrating the increased susceptibility of the tissue to initiate arrhythmias. Conclusion:It was shown that in SQT2 re-entry was more easily initiated and sustained in M island model than in M band model.It illustrated the important role of spatial electrical heterogeneities of cardiac tissue in the increased incidence of ventricular fibrillation associated with SQTS.

270-289 **Computational Investigation of Pro-arrhythmogenesis of Heart Failure Induced Electrical Remodelling in Ventricles**

Kun Jian, Chen Li, Gareth Jones* and Henggui Zhang

Introduction: Heart failure (HF) is one the most common cardiac diseases that are associated with increased susceptibility of ventricular arrhythmia causing morbidity and mortality. Previous studies have found that HF causes a series of electrical and structural remodelling in the heart, which may be responsible for arrhythmogenesis. However, it is still unclear how these remodelling facilitate and sustain ventricular arrhythmias. The aim of this study was to determine the predominant factor of HF-induced remodelling responsible for ventricular arrhythmias. Methods: We developed a new family of cellular electrical models of canine ventricular and Purkinje fibre (PF) myocytes in control and HF condition based on experimental data. These models were validated by reproducing experimentally observed AP prolongation in HF condition. Single cell models were then incorporated into a 3D anatomical model with detailed electrical heterogeneity and structural anisotropy, as well as PF network. Re-entrant excitation waves were initiated using the phase distribution method. Role of each individual HF-induced electrical and structural remodelling on lifespan of re-entry was investigated. Results: The initiated re-entry lasted for 620ms in control condition and 1500ms in HF condition. When the HF-reduced conductivity alone was considered, the re-entry lasted for the whole period of simulation of 5000ms, whilst either ion channel or anatomical remodelling did not alter the sustainability of re-entry compared to control condition. In the absence of intercellular conductivity or geometry remodelling, the re-entry broke and only lasted for around 500ms in HF condition. However, in absence of ion channel remodelling, the re-entry sustained for more than 5000ms. Conclusion: HF increased susceptibility of sustainment of re-entry. Among HF-induced remodelling, the reduction of intercellular conductivity plays an important role in sustaining ventricular arrhythmia. The ion channel remodelling though prolongs APD leading to increased vulnerability, it however reduces sustainability of re-entry.

271-416 **Nonuniform Interpolation of Cardiac Navigation Maps Using Support Vector Machines**

Beatriz Castro-García, Margarita Sanromán-Junquera, Alicia Guerrero-Curieses, Beatriz Trenor-Gomis, Arcadi García-Alberola and Jose Luis Rojo-Alvarez*

Cardiac navigation systems are currently used for building electroanatomical maps from sequentially measured bioelectrical characteristics, such as activation time, voltage amplitude, potentials, or organization. The nonuniform interpolation problem in these maps should be based on the estimated surface of the cardiac chamber under study. In this work, we proposed and benchmarked a new method for nonuniform interpolation of electroanatomical cardiac maps. We adapted the equations of support vector machines (SVM) for estimation problems in terms of the two angular dimensions azimuth and elevation and used an autocorrelation kernel. The training dataset, composed of measured values in a map and their spatial coordinates, was used to estimate the two-dimensional (angular) autocorrelation function by reinterpolating them to a uniform grid. Following a machine learning approach for interpolation, then an independent test dataset was used to evaluate this method. We used several basic simulation scenarios, namely: (a) a prolate semi ellipsoid, yielding a geometry similar to the ventricular chamber, with different width pulse and Gaussian activation in the two-dimensional coordinates; (b) a detailed simulated model of cardiac activity in the atrium. The suitability of the free parameters search procedure was first benchmarked showing that a simple search strategy can be followed for this purpose. For the wide-Gaussian activation, the largest decrease in mean absolute error (MAE) for the test set was achieved by using 150 spatial locations for training (MAE = 0.015), and similar behavior was observed for a narrow-Gaussian activation (MAE = 0.007). For a pulse-like activation with strong boundaries, this approximation decreased its quality (MAE = 0.115 for 150 spatial locations). In the detailed simulation model, the error stabilized at 500 spatial locations (MAE = 0.004). Results generally improved the traditional interpolation method, such as nearest neighbors, or linear interpolation. The proposed method can provide with improved quality for electroanatomical maps.

272-246 **Calcium Calmodulin Dependent Protein Kinase II (CaMKII) Contribute to Arrhythmias after Acidosis:A Simulation Study**

Huanling Liu, Kuanquan Wang, Jieyun Bai, Suyu Dong* and Henggui Zhang

Aim: It is well known that post acidosis arrhythmias are associated with increased sarcoplasmic reticulum (SR) Ca2+ load. However, the underlying mechanisms of arrhythmias are incompletely understood yet. This study aims to investigate mechanisms responsible for the genesis of post acidosis arrhythmias. Methods: The ten Tusscher and Panfilov (TP06) model was modified by incorporating hydrogen ion concentration (PH) and calcium calmodulin dependent kinase II (CaMKII) regulation. Acidotic condition was simulated by changing PH from 7.15 (Normal) to 6.7(Acidosis). To investigate mechanisms of arrhythmias, dynamic changes of cellular electrical activity and the propagation of reentry excitation waves under condition of post acidosis in 2D human ventricular tissue were simulated. Results: During the acidotic period, with elevated intracellular calcium and sodium concentration, CaMKII was highly activated. Due to effects of CaMKII on L-type Ca2+ channel (ICaL) and sarcoplasmic reticulum (SR) Ca2+-ATPase (SERCA2a), sarcoplasmic reticulum Ca2+ concentration ([Ca2+]SR) continuously accumulated and reached a high level (~4.9 mM) at the end of acidosis. When PH returned to normal (PH=7.15) after acidosis, delayed afterdepolarizations (DADs) was observed due to increased Na+-Ca2+ exchange current (INCX) in response to SR Ca2+ overload. In addition, along with the increase of acidotic size in 2D tissue, triggered activities induced in the cellular membrane potential caused premature beats, resulting in the generation of reentry waves. Compared with normal condition, the conduction velocity of the reentry wave was slower and the depolarization was advanced in the region of post acidosis. However, the ectopic beats did not happen when the effects of CaMKII on all ion currents were removed. Conclusion: The results of this study suggest that CaMKII plays an important role in the generation of post acidosis arrhythmias.

273-126 **A Quantitative Analysis on the Intracardiac Electrogram Contact During Ventricular Tachycardia Ablation**

David Rivas-Lalaleo, Mónica Huerta, Margarita Sanromán-Junquera, Juan José Sánchez-Muñoz, Arcadi García-Alberola and Jose Luis Rojo-Alvarez*

Cardiac arrhythmias are currently treated with ablation procedures, which are guided by X-ray and intracardiac electrograms (EGM) recordings. Recently, the use of catheters with force sensors have been proposed for improving the contact of the catheter over the heart wall, aiming to guarantee the reliability of the electrical measurement. The manufacturers of the equipment used for this type of studies have suggested that the catheter has to take a reading above or equal to 5g. We aimed to determine wether the waveform of the EGM can provide us with some information about the good contact conditions of the catheter on the endocardium, by using the recorded force as a gold standard. We first performed a correlation analysis of EGM morphology in terms of the force threshold, and then we made a multivariable analysis based on the Fisher discriminan. A database of 1161 EGM from 11 patients (8 males, average age 64.9 years) was analyzed. The EGM set corresponded to the voltage maps of the left ventricle during sinus rhythm. During the electrophysiological study, the force information was registered by the system at each point. Correlation coefficient between consecutive EGM beats larger and lower than 0.8 in EGM morphology showed similar ratios of averaged force in those beats larger (49% vs 44% force >5g, 29% vs 28% force <5g). Fisher discriminant analysis yielded error probability larger than 0.3 for the best discrimination case. These previous results show that the EGM morphology has limited information about the catheter contact when scrutinized with simple processing methods.

274-124 **In Silico Investigation of Spontaneous Calcium Release on Premature Ventricular Contractions in Human Ventricles**

Jieyun Bai, Kuanquan Wang*, Gongning Luo and Henggui Zhang

Aim: Sarcoplasmic reticulum (SR) calcium overload increases spontaneous calcium release, causing delayed afterdepolarizations (DADs) that promote premature ventricular contractions (PVCs). In this study, we modified a detailed human ventricular model to investigate quantitatively how SR calcium features at the subcellular scale influence cellular DADs, facilitating the onset of PVCs at the tissue level. Methods: Based on the 4-state Shannon model, calcium-induced-calcium release flow into the dyadic cleft via the SR ryanodine receptor (RyR2) in Ten Tusscher and Panfilov (TP06) model was modified. SR calcium release was varied by changing SR calcium content for simulating beta-adrenergic stimulation. The cellular DAD amplitude required to depolarize the cell to threshold and trigger an action potential (AP) was quantified. A one-dimensional cable model, which contained a central area of contiguous myocytes susceptible to DADs, was constructed to investigate requirements for DADs to overcome the source-sink mismatch and trigger PVCs. Results and Conclusion: Depending on the content of SR calcium, SR calcium release in cardiac cell resulted in DADs. When the amplitude of a DAD is above a certain threshold (20.7 mV, from -86.2 mV to -65.5 mV), a suprathreshold DAD in single cell can trigger an AP, which can cause a PVC in cardiac tissue. However, the subthreshold DADs didn’t produce APs but formed a conduction block region. The number of contiguous susceptible myocytes required for a suprathreshold DAD to trigger a propagating AP is 76 in a cardiac cable with 100 cells, corresponding to 11.4 mm. The number was significantly decreased by increased SR calcium load, reduced gap junction and fibrosis. In conclusion, SR calcium overload caused by electrical remodeling in combination with slow conduction induced by structural remodeling decreased the number significantly but still require synchronization mechanisms for DADs to overcome the source-sink mismatch to trigger PVCs.

275-220 Relationship between EtCO2 and Quality-Parameters during Cardiopulmonary Resuscitation

Jesús Ruiz Ojeda, Sofía Ruiz de Gauna*, Digna M González-Otero, Mohamud Daya, James K Russell, José Julio Gutiérrez and Mikel Leturiondo

Introduction: During cardiac arrest, quality of cardiopulmonary resuscitation (CPR) is a key determinant of outcomes. Resuscitation guidelines provide target values for ventilation rate and for chest compression rate and depth. Monitoring end-tidal carbon dioxide (EtCO2) has been recently suggested as a potential guide to CPR quality since it reflects blood-flow to the lungs. However, the relationship between EtCO2 and CPR quality parameters is poorly understood. Aim: To analyze the linear relation between EtCO2 and CPR quality parameters. Materials and Methods: Six episodes (one per patient) were extracted from an out-of hospital cardiac arrest database collected in Oregon (USA) between 2006 and 2010. From each episode intervals with a stable EtCO2 value were selected, and the EtCO2 value, the frequency of the ventilations (fv), and the frequency and depth of the chest compressions (fc and dc) were annotated.A median of eleven intervals were selected per episode. A multivariate linear regression was used to model the variation in EtCO2 between consecutive intervals based on the variation of the quality parameters. Goodness of fit was evaluated using the coefficient of determination R^2. This analysis was performed both per patient and for all the patients jointly. Results: R^2 had a median (P_25,P_75$) of 0.86(0.78,0.89) in the analysis per patient, but decreased to 0.64 when all values were considered jointly. The main explanatory variable was fv; an increase of one ventilation per minute caused a decrease of 1.1mmHg in the EtCO2. For dc, an increase of 1mm caused an increase of 0.26mmHg. The fc was least important, and excluding it from the model did not significantly alter the global R^2. Conclusions: EtCO2 reflected CPR quality during resuscitation attempts, although its relationship with CPR quality parameters varied between patients. The frequency of the ventilations and the depth of the chest compressions were the main explanatory variables.

276-141 **Attraction of Arrhythmia Sources by Fibrotic Scars via Dynamical Restructuring of the Activation Pattern**

Nele Vandersickel*, Ivan V Kazbanov, Massaya Watanabe, Qian Tao, Jan Fostier and Alexander V. Panfilov

One of the most dangerous cardiac arrhythmia is VT. It is widely believed that VT is driven by a spiral wave, and that the core of a spira wave can be a potential target for ablation. It is therefore paramount importance to know whether the final position of the core is affected by the specific local properties of the cardiac tissue. One of such local properties is the presence of scar tissue which is widely observed with patients who suffer from VT. A scar is characterized by excessive amount of fibroblasts and connective tissue: fibrosis. There is a lot of evidence that the scar can serve as an anchoring region for the spiral waves. However, the processes leading to this anchoring are not identified, which is the topic is this study. We used a generic model as well as a patient specific model of left ventricle of the human heart. We found that a scar not only anchors spirals but it also attracts it. However, attraction does not occur as a drift, as was always observed before. We found that the waves generated by a distant spiral started to break up at the scar region. These wave breakups resulted in appearance of secondary sources, which propagated towards the initial spiral core. This led to appearance of a fibrillatory-like pattern in between the initial spiral and the scar. When one of the secondary sources reached the tip of the initial spiral, the source and the spiral annihilate, which resulted in deceleration of the activation pattern and promoted a chain reaction of merging all the secondary sources together. As a result we obtained a spiral wave anchored to the scar. We also compared the ECG of the process with clinical ECGs for the same type of patient and found good similarity.

277-251 **Combined Signal Averaging and Electrocardiographic Imaging Method to Non-Invasively Identify Atrial and Ventricular Tachycardia Mechanisms**

Corentin Dallet*, Josselin Duchateau, Mélèze Hocini, Laura Bear, Marianna Meo, Frédéric Sacher, Michel Haissaguerre and Remi Dubois

Introduction: Electrocardiographic imaging (ECGi) is clinically used for electro-anatomic mapping of arrhythmias. Current practice is to reconstruct epicardial signals using a single selected beat, based on the assumption of a stationary underlying mechanism. However, the ill-posed nature of the inverse problem makes it susceptible to even minor sources of error that can be present on a beat-to-beat basis. This can complicate arrhythmia mechanism identification and thus the diagnosis. Aim: In this study, we show the contribution of signal averaging (SA) to ECGi on atrial (AT) and ventricular (VT) tachycardia diagnosis compared to a beat-to-beat approach. Methods: For VT mapping, a multi-lead SA algorithm was applied to QRS-complexes to obtain a robust template. For AT mapping, first a QRS removal algorithm was used to extract atrial activity, and then a multi-lead SA algorithm designed for P-waves was applied. Datasets came from patients with NaVX/CARTO system confirmed diagnosis acquired at Hôpital Haut-Lévèque, including: 3 monomorphic VTs (n=1 with cardiomyopathy); and 9 post AF ablation ATs in 7 patients (n=2 ICT-dependent flutters, n=2 peri-mitral flutters, n=4 roof-dependent macro-reentries and n=1 roof foci). Results: For AT patients, all automatic diagnosis from P-wave SA were correct versus 45.7% for single P-wave analysis. The results showed an average cycle length error of 35.56ms±24.21ms with SA versus 48.7ms±21.11ms. The reconstructed coronary sinus propagation was identical for both approaches: correct for 6 ATs, and difficult to assess for 3 due to activation time marker misplacement. For VTs, the mechanisms were correctly identified with SA, compared to 75.9% in non-averaged approach. Conclusion: SA improves the quality of non-invasive diagnosis for tachycardia. Nevertheless, the contribution differs between mechanisms: lower for macro-reentries and monomorphic VTs; higher for flutters and focal. These preliminary findings will be confirmed on a larger dataset from the clinic and on ex-vivo torso-tank data.

PB2 **Atrial Fibrillation**

Room: Pinnacle I

278-153 **An Automatic Framework for the Non-rigid Alignment of Electro-anatomical Maps and Pre-operative Anatomical Scans in Atrial Fibrillation.**

Martino Alessandrini*, Maddalena Valinoti, Roberto Mantovan, Antonio Pasini, Stefano Severi and Cristiana Corsi

Introduction: In atrial fibrillation (AF), electro-anatomical maps (EAMs) are used for ablation guidance. Yet, the reconstructed anatomy is prone to substantial localization errors, so that catheter navigation remains heavily dependent on the operator's expertise. To ease navigation, existing systems allow co-registering EAMs with pre-operative MR scans by rigidly matching a set of manual landmarks. Nevertheless, the deformation between the two datasets is highly nor rigid due to i) differences in time-triggering, ii) the aforementioned localization errors. Moreover, 3D land-marking is a cumbersome task. The aim of this work was therefore to develop a framework for the non-rigid alignment of EAMs and anatomical scans to improve ablatior guidance. Methods: EAMs and MRI scans of 3 AF patients were used for testing. The left atrium (LA) was segmented from the MRI scans using a previously presented technique. Our framework aligns the EAM on the segmented LA. First, the 2 geometries were pre-aligned b matching pulmonary veins and LA center of mass, all automatically detected. The registration was finalized on the full surfaces. Hereto, 4 surface-matching techniques were contrasted: Iterative Closest Point (ICP, rigid); affine registration; Coherent Point Drift (CPD, non-rigid) and Gaussian Mixture Model (GMM, non-rigid). We sought to balance the goodness of match against the amount of distortion introduced. Hereto, we measured the mean distance between segmented LA and registered EAM (MD1) as well as the distance between the EAMs before and after registration (MD2). Results: The obtained values (MD1, MD2), in mm, were: ICP (4.37, 0); affine (4.06, 6.21); GMM (1.8 6.7); CPD (1.9, 6.3). Against rigid and affine registration, GMM and CPD improved matching accuracy while limiting distortion, as confirmed by eyeballing. We have shown non-rigid surface registratior is viable for a more accurate alignment of EAMs and pre-operative anatomical scans. This can lead to better ablation guidance.

279-158 **Enabling Atrial Fibrillation Detection Using a Weight Scale**

Brian Ayers, Connor Beshaw, Ernesto Serrano-Finetti, Oscar Casas, Ramon Pallas-Areny and Jean-Pilippe Couderc*

Aims: In this proof-of-concept study we evaluate the ability of a weight scale with embedded limb-lead ECG recording capability to detect the presence of atrial fibrillation (AF) in a clinical setting. Methods: ECGs were recorded using the prototype of a weight scale embedded with hand and feet sensors to acquire body-surface ECGs. We evaluated this prototype for AF detection in cardiac patients going through an in-patient clinic (University of Rochester Medical Center, Rochester, NY). Two trained ECG experts annotated the ECGs as either AF or normal sinus rhythm. The ECGs were randomly separated into two datasets: learning and validation. We modified the RdR map method for AF detection using the ECGs recorded with the scale device. This method plots RR intervals versus change in RR intervals to distinguish irregularly irregular heartbeats. The learning set was used to adjust the method parameters (cell size and classification threshold to maximize classification accuracy. In addition, we investigated the relationship between the length of the ECG and accuracy of AF detection.   Results: We enrolled 60 patients (62 ± 12 yrs, 68% male) and recorded 153 ECGs using the scale device; 25 ECGs were in AF, the remaining in sinus rhythm. After optimizing the algorithm on the learning set (N=77 ECGs), the AF detection method delivered 83% accuracy (sensitivity and specificity = 83%, N=76) using the validation dataset. Applying a constraint that each ECG recording contains a minimum of 7 beats in order to be eligible for classification, accuracy improved to 89% (sensitivity = 83%, specificity = 90%, N = 70). Conclusion: We present an innovative device for AF detection that can be seamlessly integrated into physicians' current workflow without any significant changes to current medical routines.

280-343 **Prediction of Atrial Fibrillation Termination by Catheter Ablation Using Adaptive Frequency Tracking of Atrial ECG Signals**

Adrian Luca*, Andrea Buttu, Jean-Marc Vesin, Patrizio Pascale, Laurent Roten, Christian Sticherling and Etienne Pruvot

Aims. Termination of persistent atrial fibrillation (pAF) by stepwise catheter ablation (step-CA) within the left atrium (LA) is associated with improved maintenance of sinus rhythm on the long term. We hypothesized that new ECG organization indices based on the harmonic components of AF activity may track step-CA efficiency and predict pAF termination. Methods. In 34 consecutive patients (61±7 y, pAF duration 19±11 m), pulmonary vein isolation (PVI) and LA ablation were performed until AF termination. 2-min ECG time series devoid of QRST were recorded at baseline (BL), after PVI and at the end of LA ablation (end_ABL). Using adaptive harmonic frequency tracking schemes, two organisation indices were computed on the atrial ECG as measures of AF regularity: the variance of the phase difference (aPD) between the AF dominant frequency and its first harmonic and the adaptive organization index (AOI) defined as the ratio between the power of the extracted components and the total power of the signal. AOI and aPD were estimated on leads V1 to V5 and V6b (placed on the patients back). Results. pAF was terminated within the LA in 68% (LT - left terminated) of the patients, while in 32% (NLT - not left terminated) it did not. LT patients displayed significantly higher AOI and lower aPD values at BL indicative of greater pre-ablation atrial ECG organization that further increased significantly ($p<0.05$ for V1 and V6b) at the end of LA ablation as opposed to NLT patients. However, no significant changes in AOI and aPD were noticed at the end of PVI (compared to BL) in both groups. Conclusion. Organisation indices derived from the adaptive frequency tracking of atrial ECG signals appear as promising metrics for tracking changes of AF dynamics induced by catheter ablation and for the prediction of the procedural outcome.

281-355 ECG-Derived Markers to Identify Patients Prone to Atrial Fibrillation

Adrian Luca*, Sasan Yazdani, Alain Viso, Jean-Marc Vesin, Giulio Conte and Angelo Auricchio

Aims. Reliable methods for indicating risk for atrial fibrillation (AF) are lacking and careful analysis of the ECG may help to minimize potential health risks. This study presents different markers based on single leac ECG analysis in order to identify patients prone to AF. Methods. The database consisted of 76 consecutive patients divided into two groups: the study group including 36 patients (mean age of 59 ± 9 years; 23 male) with a history of AF and the control group including 40 patients (mean age of 54 ± 10 years; 29 male) without any history of AF. After the pre-processing, several features based on the P-waves and RR-intervals were extracted from the lead II of a 5-minutes ECG recorded during sinus rhythm. Among extracted features, the most discriminative ones to identify the AF susceptibility were the mean P-wave duration, the standard deviation of the beat-to-beat Euclidean distance between P-waves (an indicator of P-wave morphological variability over time) and the approximate entropy (ApEn) of the RR-intervals. A multivariate analysis based on decision tree classification was performed in order to evaluate the discriminative performance of the aforementioned features. Results. The statistical analysis revealed that the study group presented significantly longer P-wave duration ($p<0.001$) and higher variability of P-wave morphology over time ($p<0.01$) than the control group. The multivariate discriminant analysis led to a global accuracy of 86.8% with sensitivity, specificity and positive predictive value of 80.8%, 92.5% and 90.6% respectively. Conclusion. The results show that the combination of P-wave duration, beat-to-beat Euclidean distance between P-waves and ApEn could efficiently separate the two populations and therefore be used as effective detection tool of patients at risk to develop atrial fibrillation.

282-471 **Latent Variable Analysis of Causal Interactions in Atrial Fibrillation Electrograms**

David Luengo* and Victor Elvira

Multi-channel intracardiac electrocardiograms (electrograms, EGMs) are sequentially acquired during heart surgery performed on patients with sustained atrial fibrillation (AF), and used by cardiologists to determine candidate areas for ablation (e.g., areas corresponding to high dominant frequencies or fractionated electrograms). An analysis of the causal interactions among the different channels in AF EGMs, based on Granger causality, has been recently performed by the authors (D. Luengo, G. Rios-Muñoz, V. Elvira, “Causality Analysis of Atrial Fibrillation Electrograms”, CinC 2015). However, the approach followed in this paper is based on a direct analysis of the signals recorded by the different EGMs, without taking into account that an exogenous source is actually responsible for all the signals observed. In this paper, we propose introducing a well-known latent variable model from the machine learning literature (the Gaussian process latent force model (GP-LFM) described in [Alvarez, Luengo and Lawrence, AISTATS 2010] and [Alvarez, Luengo and Lawrence, IEEE Trans. on Pattern Analysis and Machine Intelligence, 2013]) to learn the relationship between the observed signals and the unknown (latent or exogenous) source causing them. The output of the GP-LFM model can then be used to perform a causal analysis of the whole dataset, resulting in a discrimination between normal and unnormal (e.g., rotors) propagation patterns and ultimately serving to guide cardiologists towards problematic areas that may require catheter ablation. Results on synthetic signals and several real data (both for sinus rhythm and atrial fibrillation) acquired during ablation therapy are used to validate the proposed approach.

283-253 **Regional Conduction Velocity Calculation based on Local Activation Times: A Simulation Study on Clinical Geometries**

Bhawna Verma*, Axel Loewe, Armin Luik, Claus Schmitt and Olaf Doessel

Abstract: Atrial arrhythmias are the most common cardiac arrhythmias. Regional conduction velocity (CV) calculation is a challenging task for the clinical cases, because of the presence of heterogeneity and unknown artifacts in the atrium. This work is regarding the CV calculation using the simulated local activation times (LAT) on the clinical geometries. Methods: The study has been performed on four clinical cases. The recordings of the clinical cases were carried out at Städtisches Klinikum Karlsruhe with a written informed consent. EnSite Velocity mapping system was used for the 3D electroanatomical mapping of the left atrium. The LAT were simulated for the homogeneous as well as heterogeneous propagatior over the atrium using fast marching method. The trigger point and the regions with heterogeneous propagation were manually selected. The CV was calculated for all the cases. The regional CV magnitudes and propagation directions were visualised on the geometries for regional-specific analysis. The trigger point, spread of depolarisation wavefront and the collision of the propagating depolarisation wavefronts in different regions has been marked on the atrium. Result: The regional CV gives an insight into the atrial substrate. The magnitude and direction of the CV were calculated from the simulated LAT at all the nodes on the triangular mesh of all clinical geometries. The propagation of depolarisation wavefront at different time stamps was visualised to represent the regions of wavefront collisions. For all cases, CV magnitudes exceeded the expected values by less than 5%. These were the regions where collision of depolarisation wavefront was taking place. The percentage error in the magnitude of CV for the non-collision wavefront area was from 1.9 to 6.5%. Conclusion: This work could be seen as a step towards the regional CV calculation for the clinical cases with respect to the wavefront propagation over the atrium for different scenarios.

284-359 **Dominant Atrial Fibrillatory Frequency Estimation using an Extended Kalman Filter**

Ebadollah Kheirati Roonizi and Roberto Sassi*

Background: In patients with atrial fibrillation (AF), the dominant repetition rate of the atrial fibrillatory waves (f-waves), or fibrillatory frequency (FF), (usually in the range 3-12 Hz) plays an important role for non-invasive assessment of atrial electrical remodeling. It can be assessed from the electrocardiogram (ECG) by signal processing tools such as power spectral analysis and short-time Fourier transform (STFT), after ventricular activity (VA) cancellation. Aims: Our objective was to explore if it is possible to estimate the FF accurately, while ignoring the step of VA cancellation. Methods based on singular or independent component analysis of ECG signals were previously proposed for this task, but: (i) they requires multi-lead recordings (not available in mobile single-lead ECG devices); and (ii) the fibrillatory activity is inherently spread into multiple components. Method: We propose an adaptive model-based extended Kalman filter (EKF) for concurrent atrial and ventricular activity detection. VA is represented by a sum of Gaussian kernels, while a sinusoidal model is employed fo atrial activity (AA). This new model is able to track AA, VA and fibrillatory frequency simultaneously, in short recordings (where the FF can be assumed to be constant). Results: The strategy was validated using 290 synthetic signals obtained from ECGs in sinus rhythm (Physionet PTBDB), where P-waves were replaced by artificial waves, at different signal-to-noise (SNR) ratios. At a SNR of 0, 20 and 40 dB, the average root mean square errors were 0.35, 0.32 and 0.31 Hz respectively. Conclusion: The results showed that an accurate FF estimation is possible using EKF, while avoiding a preliminar step for VA cancellation. The technique effectively estimated also the AA itself. We can foresee two future extensions for the methodology: (i) an adaptation to situations in which the FF changes in time; and (ii) a test on real ECGs of AF patients.

Wednesday, September 14, 2016 **12:15**

PB3 **Heartrate Variability**

Room: Pinnacle I

285-404 **Nonlinear Dynamics of Heart Rate Variability after Superoxide Dismutase Inhibition in Rats**

Stanislaw Zajaczkowski* and Tomasz Wierzba

Introduction: Reactive oxygen species, including superoxide anion, have been suggested to play a role in cardiovascular regulation as chemoreflex triggers. Aim: The study aimed to test the effect of oxidative challenge induced by inhibition of superoxide dismutase (SOD) on heart rate variability (HRV) in rats. Methods: Diethylthiocarbamate (DETC; 250mg/kg i.p), a nonspecific SOD inhibitor, was used as an oxidant. ECG was continuously recorded at sampling rate 4 kHz (PowerLab, AdInstruments, Australia) from previously instrumented unrestrained male Wistar rats (N=7). HRV was analyzed (Kubios HRV Pro software; Kuopio, Finland) in time- and frequency domains (FFT method) from time series of 1024-RR-intervals (RRi). Frequency ranges: 0,27 to 0,75 Hz (LF) and O,75 to 2,5 Hz (HF) were selected for spectral powers. Non-linear dynamics of HRV was analyzed through recurrence plots, sample and approximate entropy (SampEn, ApEn) and detrended fluctuation analysis (DFA). Results: DETC evoked a significant decrease in RRi (from 190±21 to 141±15ms; p=0,003), SDNN (from 3,70±0,98 to 1,50±1,08ms; p=0,002), LF (from 2,3±1,2 to 0,13±0,08ms2; p=0,001) but not rMSSD (from 3,1±0,97 to 1,7±0,95ms; p=0,08) and HF (from 2,6±1,3 to 1,3±1,1ms2; p=0,17). In contrast to unchanged SampEn and ApEn, DETC resulted in a significant reduction of the following nonlinear parameters: recurrency (%REC; from 46±4,4 to 33±10; p=0,02), determinism (%DET from 99,4±0,27 to 97,9±1,3; p=0,04), DFA $\alpha1$ (from 1,08±0,15 to 0,53±0,17; p=0,001) and DFA and $\alpha2$ (from 1,25±0,12 to 1,01±0,27; p=0,03). Summary: Oxidative challenge induced by SOD inhibition resulted in suppression of autonomic control upon the heart with an increased sympathetic drive. Decrease in %DET and %REC suggests lower predictability of the regulatory control and potential higher risk of unexpected severe events. Changes in HRV evoked by DETC reconfirm hypothesis that exogenous modulators of superoxide generation play a role in cardiovascular regulation. The study was supported by National Science Center (DEC-2011/01/N/NZ4/01132) and 01-0245/08/261

286-438 **Physical Conditioning Status Stratification Based on Heart Rate Variability: Principal Component Analysis of Power Spectrum Density Function**

Olivassé Nasario-Junior, Paulo Roberto Benchimol-Barbosa* and Jurandir Nadal

Introduction: The physiological adaptations resulting from physical training cause changes in cardiac autonomic modulation, usually assessed by heart rate variability (HRV) at rest. The standard analysis of HRV in the frequency domain for short duration signals takes into account the lower (LF; 0.05-0.15 Hz) and high frequency bands (HF, 0.15-0.4 Hz) of the power spectral density function (PSD). On the othe hand, principal components analysis (PCA) allows assessment of variations over the whole PSD (0-0.5 Hz) and their morphological characteristics. The purpose of the study was to investigate the application of PCA on PSD of normal consecutive RR intervals (iRR) aiming at distinguishing physical conditioning status. Methods: In a case-control study, 10 healthy sedentary volunteers and 10 matched professional long distance runners were enrolled. The subjects had their maximal metabolic equivalents (MET) estimated (controls 8±2 vs athletes 19±2 METs; $p<0.05$), and 20 min resting ECG recorded. In iRR series, a 5 min segment with less variance was selected. iRR sequence was interpolated at 1 Hz (cubic spline) to estimate the PSD by fast Fourier transform. The PSD were used for cross correlation functions computation and PCA, in which the first three principal components were retained (representing 90% of the total variability). A logistic regression model based on Mahalanobis distance determined the optimal separation threshold. The area under the ROC curve (AUC) of the proposed method was compared to LF and HF parameters ($\alpha=0.05$). Results: The proposed method allows to correctly separate all subjects (AUC=1.0), according to the prior classification based on MET, while the HRV parameters in the frequency domain LF and HF provided AUC equal to 0.8 and 0.9 ($p>0.05$), respectively. Conclusion: The PCA applied to PSD of iRR series properly classified the physical conditioning of controls and athletes with superior performance to standard HRV.

287-243 **Analysis of Heart Rate Variability Indices with Slowly Changing Heart Rate**

Masaki Hoshiyama* and Alan Murray

Cardiac autonomic function is often assessed by a variety of cardiac ECG indices. The ECG is usually assessed from recordings during stable ECG conditions with subjects in comfortable lying or sitting positions. However, it is accepted that heart rate may change during the recording, usually by becoming slower as the subject relaxes. Such changes are usually small, and therefore normally neglected. We were interested in assessing the effect of very small changes. ECGs were recorded in sequential one-minute samples, during sitting as this induces smaller changes than would be the case if subjects were asked to lie down. Recordings were made with electrodes positioned to give a stable positive QRS complex, and the RR was measured between consecutive complexes. All RR intervals were converted to instantaneous beat-to-beat heart rate. Indices were calculated from these data, and averaged over 1 min periods. Heart rate over one min periods changed from 75.9 ± 1.1 to 68.8 ± 1.7 (mean ± SD) beats/min ($p<0.001$), with a 1 min average change over the 30 min period of -0.25 ± 1.11 beats/min. The figures respectively for successive beat differences were -0.024 ± 0.383 to -0.025 ± 0.519 ($p=\text{NS}$) and 0.000 ± 0.037 beats/min, and for successive RMS beat differences were 0.27 ± 0.27 to 0.37 ± 0.37 ($p=\text{NS}$) and 0.0034 ± 0.088 beats/min. In spite of very significant changes in rate, the indices calculated from successive differences were less prone to the rate changes.

288-119 **Looking for Changes in the Heart Rate of Patients with Neurocardiogenic Syncope**

Fatima Maria Helena Simoes Pereira da Silva*, Mariana Adami Leite, Julio Cesar Crescencio, Antonio Carlos Silva Filho and Lourenço Gallo Junior

Neurocardiogenic Syncope (NCS) is a temporary loss of consciousness due to a global cerebral hypoperfusion caused by bradycardia and/or significant hypotension; these mediated by the autonomic nervous system. We analyzed the heart rate variability (HRV) of three groups during the Tilt-test, a challenge test, in the supine and standing position, before hypotension, and at end of test (45min). The groups are: 1) 17 healthy individuals who had no complaint of NCS (12 women and 5 men), 2) 18 patients with complaint of NCS, but a negative Tilt-test (11 women and 7 men) and 3) 16 patients with complaint of NCS and a positive Tilt-test (15 women and 1 man). There is no statistically significant difference for age and anthropometric characteristics among groups (at level of 5%). We did multifractal analysis by the MFDFA technique. We estimated, also, the Largest Lyapunov Exponent (LLE), using the Rosenstein algorithm developed for a small data set, which is our case (on average, 1211 points in the supine position and 1432 points in standing position). The loss of multifractality, as well as a decrease in the LLE, imply less complex system. The multifractal analysis showed no significant difference among groups, in both the supine and in the standing position (5%). However, compared to LLE, there are significant differences among groups, in the standing position, but not significant in the supine. Now there is significant difference between the supine and standing position for all groups. Still, in the standing position, we conclude that, on average, the LLE for groups 2 and 3 are lower than the LLE for the group 1. Furthermore, groups 2 and 3 are statistically equal. We concluded that in the standing position, there is a reduction of complexity of HRV for patients with complaint of NCS, during that period before fainting (5%).

289-299 **Personalized Sedation Level Monitoring in ICU Patients Using Heart Rate Variability**

SUNIL BELUR NAGARAJ*, Siddharth Biswal, Valdery Moura Junior, Patrick Purdon and Brandon Westover

Aim: To develop an automated system to monitor sedation levels in intensive care unit (ICU) patients using heart rate variability (HRV). Methods: We developed an automatic sedation level prediction system using HRV as input to a support vector machine learning algorithm. Our data consisted of electrocardiogram (ECG) recordings from a heterogeneous group of 50 mechanically ventilated adults receiving sedatives in an ICU setting. The target variable was the Richmond agitation-sedation scale (RASS) scores, grouped into four levels: “comatose” (-5), “deeply sedated” (-4 to -3), “lightly sedated” (-2 to 0), and “agitated” (+1 to +4). As input we used 10 features derived from the normalized-RR (NN) interval. We used leave-one-subject-out cross-validated accuracy to measure system performance. Results: A patient-independent version of the proposed system discriminated between the 4 sedation levels with an overall accuracy of 52%. A patient-specific version, where the training data was supplemented with the patient’s labeled HRV epochs from the preceding 24 hours, improved classification accuracy to 60%. Conclusions: Our preliminary results suggest that the HRV varies systematically with sedation levels and has a potential to supplement current clinical sedation level assessment methods. With additional variables such as disease pathology, and pharmacological data, the proposed system could lead to a fully automated system for depth of sedation monitoring.

Wednesday, September 14, 2016 **12:15**

PB4 **Cardiorespiratory Characterization and Analysis**

Room: Pinnacle I

290-217 **Phase Difference between Respiration Signal and Respiratory Modulation Signal from Oscillometric Cuff Pressure Pulses during Blood Pressure Measurement**

Diliang Chen, Fei Chen, Alan Murray and Dingchang Zheng*

Respiration influences the oscillometric cuff pressure waveform from which blood pressure (BP) is estimated. However, there is little information available on the phase shift between reference respiration signal and respiratory modulation signal from oscillometric cuff pressure pulses during BP measurement. This study aimed to provide this information and investigate the effect of breathing pattern on the phase difference. Twenty healthy subjects (10 male and 10 female; age from 23 to 65 years) participated in this study. For each subject, two manual BP measurements were performed under both normal and deep breathing conditions. During the measurement, oscillometric cuff pressure pulses (OscP, from an electronic pressure sensor) and the respiration signal (Resp, from a chest magnetometer) were digitally recorded with a sample rate of 2000 Hz during linear cuff deflation. Pulse interval of OscP was calculated as the time interval between the maximum slope point of each OscP pulse. Respiratory modulation signal from OscP was then extracted from the pulse interval series through cubic spline interpolation. After filtering the Resp and respiratory modulation signals with a bandpass filter (center frequency: respiratory frequency, bandwidth: 0.06 Hz), phase shift was calculated by cross spectral analysis and then compared between the two conditions. Experimental results showed that there was phase shift between Resp and the respiratory modulation signal from OscP under both normal (phase difference 0.20±0.09 rad) and regular deep breathing (phase difference 0.64±0.19 rad) conditions. Statistical analysis showed that deep breathing significantly ($p<0.05$) increased phase shift in comparison with normal breathing. In conclusion, this study demonstrated that the presence of phase shift between respiration signal and respiratory modulation signal from OscP during blood pressure measurement, and that the phase shift is associated with the breathing pattern.

291-285 **Cardio-Respiratory Characterization of the Autonomic Balance**

Leila Mirmohamadsadeghi*, Nicolas Bourdillon, Grégoire P. Millet and Jean-Marc Vesin

Aim: The autonomic balance is often measured using the low frequency (LF) power (sympathetic activation) and high frequency (HF) power (para-sympathetic activation) of the heart beat-to-beat intervals. However, these indices do not adequately integrate the influence of the respiration and have been widely criticized. We investigated the autonomic balance with measures from the heart beat-to-beat intervals taking into account the respiratory activity. Methods: The ECG and respiration from 21 healthy subjects were record-ed in supine (parasympathetic dominance) and orthostatic (sympathetic dominance) positions. By least-squares system identification, the respiratory component of the beat-to-beat intervals, referred to as the respiratory sinus arrhythmia (RSA) was extracted. The variability and the coherence of the relative phase difference of the RSA and the respiration were analyzed. For comparison, the powers in the classic LF and HF bands of the beat-to-beat intervals were also computed. Results: Despite 7 subjects having respiratory rates lower than the classic LF upper boundary (0.15 Hz), the HF power was lower in the orthostatic position in 20 subjects, meaning that the non-respiratory HF content was also affected by the autonomic particularities of the position change. The LF power was higher in the orthostatic position for only 9 subjects. On the other hand, the normalized RSA power was significantly lower in the orthostatic position (0.67±0.17 vs. 0.79±0.12). The variability of the relative phase difference of the RSA and the respiration was significantly higher (0.21±0.24 vs. 0.07±0.06 rad) and the coherence significantly lower (0.93 vs. 0.99) in the orthostatic position. Conclusions: The LF and HF power indices do not account for respiratory characteristics. The respiratory influence on the beat-to-beat intervals is less prominent and less stable in the orthostatic position (sympathetic activation), which could be a physiologically meaningful indicator of autonomic activity.

292-147 **Sleep/Wake Classification Using Cardiorespiratory Features Extracted from Photoplethysmogram**

Parastoo Dehkordi*, Ainara Garde, Guy A. Dumont and J Mark Ansermino

Aim- The purpose of this study was to implement a model to classify the 30-second epochs of an overnight sleep data into wakefulness and sleep using features extracted from photoplethysmogram (PPG). The features provided information about cardiorespiratory activity, vascular tone and body movement. PPG was recorded using the Phone OximeterTM, a mobile device that integrates a pulse oximeter with a smartphone. Database- The database contains the overnight recordings of polysomnography (PSG) from 146 children. In addition, PPG recorded simultaneously with the Phone OximeterTM. Methods- All PPG signals were divided into 30-second epochs. Each epoch was scored as wakefulness or sleep based on the PSG report. For each epoch, 30 features of cardiorespiratory activity, morphology of each pulse and signal quality were extracted from PPG. The dataset was divided into the training and test datasets. All epochs in the training dataset were used to train the sleep/wake model using the Least Absolute Shrinkage and Selection Operator (LASSO) classifier. Validation was performed, epoch-by-epoch, for each subject in the test dataset and results were represented as accuracy, sensitivity, and specificity. The general performance of the model was assessed using the distribution of the accuracy, sensitivity and specificity for all subjects in the test dataset. Results- Among the 30 features, 17 features were selected as relevant features by the LASSO classifier. The median values for the individual epoch-by-epoch accuracy, sensitivity and specificity results, for subjects in the test dataset, were 77%, 80% and 64%, respectively. Conclusion- This study shows a model trained with features extracted from PPG, can classify 30-s epochs of an overnight sleep into wakefulness and sleep. This model could enable at-home sleep monitoring based on the PPG and provide detailed epoch-by-epoch analysis, similar to the one provided by PSG.

293-322 **Effect of Chest Compression Leaning on Accelerometry Waveforms**

James Russell*, Dana Zive and Mohamud Daya

Cardiopulmonary resuscitation (CPR) monitors provide feedback on rate, depth and release force (RF) of chest compressions. Excessive RF ("leaning") may impede venous return, reducing blood flow. Available monitors detect leaning with a force sensor, an expensive component. Since rate and depth feedback can be provided by just an accelerometer, our objective was to determine if leaning could be detected through the accelerometry signal independent of a force sensor. Methods Brief intervals (0.32 s) of accelerometry signals (100 sps) centered on force minima were extracted from 476649 compressions detected in a randomly selected subset (n=289) of recordings from Philips MRx defibrillators equipped with CPR monitors used out-of-hospital in the Portland metropolitan region from 2009 – 2015. Leaning was defined as present (RF >= 2000 g), absent (< 500 g) or intermediate. Evidence for effects of leaning on the accelerometry waveform was sought with various neural networks using the Matlab ® Neural Networks Toolbox. Intermediate compressions were excluded during training. Testing was done with 249045 additional waveforms (47296 leaning, 105305 non-leaning, 96444 intermediate) extracted from 147 additional cases. Results A moderate sized cascade forward network with 2 hidden layers of 32 and 4 nodes using Bayesian regularization backpropagation outperformed simpler alternatives during training. Testing yielded 73.1% correct classifications (Sensitivity 64.3%, Specificity 75.1%) with leaning defined as > 2 kg RF. Cases with zero RF were identified correctly as non-leaning in 92.2% of 62817 cases. Discussion The accelerometry signal in the vicinity of the release point provides considerable information about the force at release. Although the described neural nets are not sufficient for clinical use, further studies exploring alternative measures and classification algorithms based on this signal are warranted.

294-336 **Comparing ECG Derived Respiratory Signals and Chest Respiratory Signal for the Detection of Obstructive Sleep Apnoea**

Nadi Sadr* and Philip de Chazal

In this paper, three approaches for estimating ECG derived respiratory signal (EDR) were utilized for apnoea detection and the results were com-pared with apnoea detection by chest respiratory signals. Two methods are presented for computing the EDR signal by principal component analysis (PCA) applied to entire overnight ECG signals. The proposed approaches simplified the PCA computation and resulted in fast algorithms with low memory requirements. The third method used the QRS area method of EDR estimation. In the first phase, the 8 recordings available in the MIT PhysioNet Apnea-ECG database which contained simultaneously recorded respiratory signals were utilized and the chest respiratory signals were employed for OSA detec-tion and the results were compared to OSA detection by EDR signals. In the second phase, the EDR signals of the 35 available ECG recordings from the same database were used for apnoea detection. The results of both phases for the EDR and respiratory signals were classified by three different machine learning techniques including the extreme learning machine, linear discriminant analysis and support vector machine. It was revealed that QRS area method with LDA classifier results in the highest performance. However, the results of first phase indicate that respira-tory signal leads to better apnoea detection compared with EDR signals.

295-381 **Apnoea-Hypopnoea Index Estimation using Craniofacial Photographic Measurements**

Hadis Nosrati, Nadi Sadr* and Philip de Chazal

This paper presents a novel way of estimating the apnoea-hypopnoea index (AHI) using craniofacial photographs. We compared the correlation and classification performance of the photograph-determined AHI against expert-determined AHI for a number of selected measurement sets. Our best performing system used five craniofacial measurements selected from 71 manual craniofacial phenotype features, which had been determined from frontal and profile photographs of a patient's head and neck. The measurements were processed with a Support Vector Machine Regression algorithm to estimate AHI. The best features included face width, mandibular length, binocular width, cranial base area, and criocomental space distance. A database of 114 subjects with OSA (AHI >=10/h) and 66 controls (AHI <10/h) was used for algorithm development and testing. Leave-one-record-out cross-validation was used to estimate performance. The Pearson correlation was 0.52 for the AHI estimation. Classification performed using an AHI threshold of 10 events per hour, resulted in an estimated accuracy of the algorithm of 73.3% with an area under the ROC of 0.78.

296-508 **Quality Estimation of Electromechanical Derived Respiration Signals: A Machine Learning Approach**

Nasim Alamdari, Kouhyar Tavakolian*, Vahid Zakeri, Reza Fazel-Rezai and Alireza Akhbardeh

Quality Estimation of Electromechanical Derived Respiration Signals: A Machine Learning Approach Nasim Alamdari, Kouhyar Tavakolian, Vahid Zakeri, Reza Fazel-Rezai, Alireza Akhbardeh To detect respiratory phases of heart cycles, electrocardiogram (ECG) and seismocardiogram (SCG) have been used in our previous studies to derive respiratory signal, and then identify the respiratory phases of heart cycles. In this morphological-based application, the quality of estimated respiratory signals can be deteriorated due to body movements and other artifacts; therefore, the derived respiration signals from 3D accelerometer and ECG sensors can vary from subject to subject. There is no single feature as a quality metric that can choose the best-estimated respiration signal in each segment of the recorded data. Therefore, a properly trained classification method is proposed to classify the quality of estimated respiratory signals in each segment based on extraction of some specific features. Forty recording from twenty subjects were used for this study. In each recording, the reference respiratory belt signal, 3D accelerometer, and electrocardiogram signals were recorded in ten minutes. We used reference respiratory signal to assign SCG and ECG signals to inhale and exhale phases. From each recording, twenty-nine electromechanical-derived respiratory signals were extracted such as electrocardiogram-derived respiration (EDR) using linear principle component analysis (PCA). Several physiological-related features in both time and frequency domains including respiration rate (RR), and total harmonic distortion were extracted from each signal. Then, support vector machine (SVM) has been used as a multilevel signal quality classification algorithm to distinguish these signals. The result shows that among twenty-nine estimated respiratory signals, the four dominant signals are ADR in z and in y-direction using lower or upper envelope. In addition, this framework reduced the error of heart cycle identification from 21.0% to 10.9%, presenting a potential method to improve the performance of phase detection of heart cycles.

Wednesday, September 14, 2016 **12:15**

PB5 **ECG**

Room: Pinnacle I

297-222 **Irregular Heartbeats Detection Using Tensors and Support Vector Machines**

Alexander Suarez* and Griet Goovaerts

Aim: The study evaluates the performance of a method to detect irregular heartbeats in ECG signals using a combination of a tensor decomposition method and Support Vector Machines (SVM). Methods: First, the signal is band-pass filtered in order to reduce noise and baseline drift. Then, for each record a third order tensor is constructed. The tensorization process consists of arranging each windowed multichannel heartbeat one after other. A windowed heartbeat starts at R - 195 ms and extents 506 ms length, where R is the R-peak location of current heartbeat. Here, the R-peaks locations are previously known (annotated signals were used). This assures that the results depend on the classification method rather than on the R-peak detection approach. Next, a rank-3 Canonical Polyadic Decomposition (CPD) is applied over the constructed tensor. CPD yields three loading matrices corresponding to time course, space (channel) and heartbeat dimensions respectively. The third loading matrix, i.e. the heartbeat dimension, is taken as input of a linear SVM classifier. The SVM is trained to classify between irregular and normal sinus rhythm heartbeats. The training set is randomly selected using 2% of the available patterns in each record, 98% was used as testing set. Results: The method was applied to the St. Petersburg Institute of Cardiological Technics 12-lead Arrhythmia Database. Both, sensitivity and specificity were above 90% over the test dataset.

298-302 **Changes in Non-Invasive Wave Intensity Parameters with Variations of Savitzky-Golay Filter Settings**

Nicola Pomella, Mark Rakobowchuk*, Christina Kolyva and Ashraf W. Khir

Background: Non-invasive Wave Intensity Analysis (WIA) uses diameter (D) and flow velocity (U) waveforms to offer an insight into the cardiovascular physiology. D and U are commonly filtered to eliminate noise; however the filter settings affect WIA parameters. This study aims to assess the alterations of such parameters with varying Savitzy-Golay (SG) filter settings. Methods: Ultrasound-measured single-beat D and U from the human carotid artery of a healthy individual, sampled at 1000 Hz, were filtered with 42 SG settings, derived from combining 6 polynomial degrees (p) 2-7 with 7 window lengths (w) 9-119. Pulse wave velocity (PWV) was calculated through the lnDU-loop method and WIA was performed. PWV, maximum values, energies and durations of forward compression (FCWmax, FCWe, FCWtime), backward compression (BCWmax, BCWe, BCWtime), and forward expansion (FEWmax, FEWe, FEWtime) waves were compared between the 42 settings. Results: PWV increases with increasing w and decreasing p (12% at p=2, 6% at p=7). FCWmax and FEWmax decrease with increasing w and decreasing p (400% at p=2, 400% at p=7 for FCWmax, 400% at p=2, 500% at p=7 for FEWmax). BCWmax increases with p up to 600%. FCWe and FEWe decrease with increasing w and decreasing p (100% at p=2 and 8% at p=7 for FCWe , 160% at p=2 and 900% at p=7 for FEWe). BCWe increases with increasing w for low p (250% at p=2) and decreases for high p (100% a p=7). FCWtime, BCWtime and FEWtime increase with w and decrease with p (25%, 100%, 80% at p=2 and 60%, 40%, 25% at p=7, respectively). Conclusions: WIA parameters are highly affected by SG filter settings, showing a broad spectrum of variations. The correct choice of w is critical, as it affects the signal more than p. Energy parameters (FCWe, BCWe, FEWe) show less variation than their corresponding intensities.

299-506 **Denoising and Automated R-peak Detection in the ECG Using Discrete Wavelet Transform**

Jonathan Goodfellow*, Omar Escalona, Vivek Kodoth, Ganesh Manoharan and Antonio Bosnjak

Introduction: Automated detection of ECG features is a useful tool in areas such as heart rate variability analysis and arrhythmia detection. This study investigates the efficacy of a novel R-peak detection method based on Discrete Wavelet Transform (DWT), and evaluates performance through calculation of Sensitivity, Specificity and Accuracy. The capability of the algorithm to differentiate between normal sinus rhythm (NSR) and atrial fibrillation (AF) ECG is also investigated. Aim: Investigate the efficacy of a novel DWT R-peak detection algorithm and assess its effectiveness at differentiating between AF and NSR. Methods: 18,647 beats of Lead II ECG data, recorded from patients with AF who underwent DC cardioversion are analysed using DWT R-peak detection. The algorithm extracts the D5 coefficient, which is modified to create a reference window, in which R-peak points are located. The reference window generates a localisec area around QRS regions which mitigates the possibility of other ECG features being falsely detected. The algorithm was tested on AF-ECG, prior to shocks and also on NSR-ECG, when the patient had successfully cardioverted. The efficacy of R-peak detection for both NSR and AF-ECG using Sensitivity, Specificity and Accuracy was calculated. Phase two investigates how effectively the RR interval data can differentiate between NSR and AF by classifying ECG segments based on the mean RR interval. Results: The Sensitivity, Specificity and Accuracy of the algorithm for 18, 647 beats was 99.61%, 99.88% and 99.50% respectively. The algorithm was able to produce high performance of R-peak detection when analysing both NSR and AF-ECG data. Additionally, derived RR interval data correctly classified 100% of ECG signals tested. Conclusions: The proposed algorithm shows high performance in preliminary results in detecting R-peak points in both NSR and AF-ECG. RR interval analysis also indicates that this algorithm can be utilised in practical applications, such as arrhythmia detection.

300-288 **Prolonged QT Interval in Neurodevelopmental Rat Model of Schizophrenia**

Tibor Stracina*, Marina Ronzhina, Tibor Stark, Jana Ruda, Eva Olsanska, Petr Vesely, Vincenzo Micale and Marie Novakova

Introduction: QT prolongation is an independent risk factor for development of arrhythmias. It is common side effect of various medications including antipsychotics. Drug-free schizophrenic patients have also increased QT interval compared to healthy controls. Possible mechanisms of QT prolongation connected with schizophrenia are unclear. Studying of the QT lengthening in schizophrenic patients is rather complicated due to their frequent comorbities and certain incapability to co-operate. The need of suitable model for such studies is apparent. The present study aimed to evaluate heart rate (HR) and QT interval duration in methylazoxymethanol acetate (MAM) rat model of schizophrenia. Methods: Hearts of nine schizophrenia-like (MAM) and six control (CON) rats were perfused according to Langendorff. After 20-min stabilisation, hearts were exposed to haloperidol (10 nmol/L) for 40 minutes followed by 40-minutes-lasting washout. Three orthogonal leads were continually recorded. HR was measured from the window of 10 consecutive RR intervals at the end of each experimental phase. In the same window, QT intervals were detected manually and corrected according to Bazett's formula. Incidence of arrhythmias was assessed as the total number of ventricular premature beats (VPBs) and supraventricular premature beats (SVPBs) calculated for each experimental phase separately. Results: In HR, no significant difference between groups was found. MAM hearts exerted significantly longer QTc interval than CON (64.8±1.9 ms in CON, 69.5±4.8 ms in MAM; $p<0.05$). This difference was more significant during haloperidol administration (63.2±2.5 ms in CON, 72.7±5.4 ms in MAM; $p<0.01$). The parameter values remain significantly different in washout. There is no difference in total number of VPBs and SVPBs between MAM and CON groups. Conclusion: The description of precise mechanisms of QT prolongation associated with schizophrenia and antipsychotic treatment need further investigation. Research on the highly translational neurodevelopmental MAM rat model of schizophrenia can bring new insights into these problem.

301-194 **Novel Algorithm for Estimation ST-segment Parameters**

Maria Reshetnikova*, Sergei Akulov, Aleksandr Fedotov and Anna Akulova

In modern cardiac practice estimation of ST-segment parameters is widely used for myocardial ischemia diagnosis. The conventional algorithm includes the following steps: low-pass filtering, QRS-complex detection, baseline drift correction, ST-segment averaging, determination of K and J points. However, it does not provide the ability for estimation of each ST-segment as well as stability to baseline wander correction. In this paper we propose the novel algorithm for ST-segment estimation based on "asymmetric" wavelet transform. The point is in the different mother wavelet functions for direct and inverse wavelet transforms. Application of proposed algorithm for ECG analysis results in baseline wander removal and amplification of ST-segment's frequency components. Comparative analysis of standard and proposed algorithm was made. Ten records from MIT/BIH ECG database were tested. Random noise was added to the initial signals to obtain different value of signal-to-noise ratio. We used the value of variance estimate dependent on the value of signal-to-noise ratio as a criterion of efficiency. The results of the research show, that the mean variance estimate of ST-segment parameters for proposed algorithm was less than 70% compared with a standard in the wide range of signal-to-noise ratio values. Algorithm of "asymmetric" wavelet transform proposed in this paper might also be used for various purposes in automatic ECG analysis, e.g. QRS-complex shape determination, T-wave parameters estimation and signal denoising.

302-444 **Electrocardiographic Measurements of the QT Interval During Embryonic Development in Fertilized Chicken Eggs**

Tanveer A. Bhuiyan, Cristian Sevcencu, Johannes J. Struijk, Jørgen K. Kanters and Claus Graff*

Introduction: The fertilized chicken egg (embryonic chicken) shares the basic mechanism of electrophysiology and ionic currents with mammalian hearts. During embryonic development, the IKr channel develops gradually from complete to partial block, and later to fully open on day 21 when the chick hatches. Repolarization measurements in chick embryos are therefore dependent on the stage of development. Methods: ECGs were recorded from 4 fertilized chicken eggs for 6 days (day 13 to day 18). Eggs were kept in an incubator with an optimal temperature of 37.40 (±0.4). Chronic electrodes were implanted and 5 minutes ECG was recorded each day from at a sample frequency of 1000Hz. Three 10-second median beats were calculated from each 5-minute recording and QT intervals were measured and corrected by heart rate using Fridericia's correction. Results: The QTcF interval decreased during embryo development, Fig 1. On day 18 QTcF was significantly shorter than QTcF on day 13 (340±3 ms versus 417±29 ms, p=0.037). Discussion: As the IKr channel gradually opens during embryo development, the repolarization phase shortens. In fertilized eggs this shortening of the repolarization phase can be quantified by a gradually changing heart rate corrected QT interval.

303-511 **Novel Biomarker for Evaluating Ischemic Stress Using an Electrogram Derived Phase Space**

Wilson Good*, Burak Erem, Jaume Coll-Font, Dana Brooks and Rob MacLeod

The underlying pathophysiology of ischemia is poorly understood, resulting in poor clinical performance diagnosing this disease. Such limited knowledge of underlying mechanisms suggests a data driven approach, which seeks to identify patterns in the ECG data that can be linked statistically to induced conditions such as ischemia. We have applied such a data driven approach to signals recorded during episodes of controlled, acute ischemia in animal models. Previous studies suggest that an approach known as “Laplacian eigenmaps” (LE) can identify relevant trajectories or “manifolds” that are sensitive to different spatiotemporal consequences of ischemic stress. We applied the LE approach to measured transmural potentials, recorded during sinus and ischemic conditions and discovered there are regions on the manifold that show sensitivity to ischemia. It was determined that the change in the area under the curve (AUC) of the QRS was driving the observed change in the manifold. The QRS-AUC metric shows a similar degree of sensitivity as ST derived metrics in detecting ischemic regions. Each region of the manifold corresponds to a specific phase of the ECG and by noting how the manifold changes in response to ischemia we can then determine what region of the signal contributed to the observed change to the manifold. The changes to the QRS-AUC were identified as a source of the change in the manifold’s trajectory. This suggests that the QRS-AUC metric can be used along with ST metrics to determine whether tissue within the myocardium is ischemic. The QRS-AUC metric exhibits hysteresis and typically does not return to baseline after the heart is allowed to recover following an ischemic intervention. This hysteresis could be brought on by irreversible tissue death that has a lasting effect on the propagation through the tissue but does not produces the injury currents responsible for ST segment changes.

304-499 **Effect of Sample Rate on saECG Spectrum**

Jacob Melgaard*, Claus Graff, Peter Sørensen, Kasper Sørensen, Samuel Emil Schmidt and Johannes Struijk

Introduction: Signal-averaged ECG (saECG) has been used to show delayed ventricular activation and myocardial infarction, but alignment jitter acts as a low-pass filter. We seek to investigate the influence of the sample rate on the jitter-induced filtering of saECG. Methods: ECGs were recorded with a sample rate of 8000 Hz. An initial beat template was formed, and beats were found by cross-correlation between template and ECG. The template (and lag of each beat) was updated itera-tively until convergence, including only beats with a correlation coefficient above 0.99. For each beat, the FFT was computed, and the average of these spectra was calculated. The saECG was formed, and the FFT of the saECG was computed as well. The attenuation of the saECG spectrum, compared with the average spectrum, was calculated at certain frequencies. The ECG was then downsampled by a factor 2, and the process was repeated, until a sample rate of 500 Hz. Results: Results from one subject is shown in table 1. For all sample rates, an attenuation of at least 3 dB at 125 Hz is found. This effect is dependent on the sample rate; lower sample rate generally gives higher attenuation. Discussion: It is unlikely that a jitter with standard deviation of 1 ms oc-curred at a sample rate of 8000 Hz, unless it originates from variation in the ECG. Since high frequencies are found to be attenuated, they are likely noise, or at best uncorrelated from beat to beat, and therefore not likely to carry significant diagnostic information.

305-451 **Applying Quality Index Criterion for Flexible Multi-Detection of Heartbeat Using Features of Multimodal Data**

Mohammad Javad Mollakazemi, Farhad Asadi, Shadi Ghiasi* and S. Hossein Sadati

Introduction: In many conditions contaminated signals and noises can distort electrocardiogram (ECG) signals, so synchronously measured signals could enhance analyzing the heart rate variability. Therefore, the algorithm should be able to identify reliable and optimal segment of these multimodal signals in order to locate the heart beat detection. Aims: This paper presents a flexible, and multichannel feature extractor and classifier for the purpose of locate heartbeats by using the multi-channel recording from PhysioNet challenge 2014 database. Methods: Firstly, after the preprocessing of the ECG, the ECG is segment-ed to some numbers and the autocorrelation function for each segment is evaluated and the length with maximum self-similarity were chosen. Next, Fast Fourier Transform (FFT) was implemented, and after normalizing to the fixed variance, signal variance and variance of the peak distances were evaluated. These quality criterion enable us to locate and detect the external disturbances and exploiting the better decomposition functions and range of frequencies for the next step. In this step, adaptive thresholding and different discrete wavelet transform functions (DWT) were applied to each segment and lead to the extraction of the beat position. So, in this step the location of the beats in each channel were extracted by different combination of decomposition functions in order to attain to more exact morphologies of ECG and ABP. Then, the dynamic delay correlation approach for compensating the transition time among the channels were used in order to merge the beats in the multichannel fusion. Finally, RR distance were employed for obtaining the accuracy in order to candidate the best beat within two possible beat positions. Results: The presented approach was evaluated on datasets provided for the PhysioNet/Computing in Cardiology Challenge 2014. The 170 recording of the multi modal training set of PhysioNet were used and the average accu-racy of the 89.53% obtained.

306-528 **Comparison of Intensity-based B-splines and Point-to-Pixel Tracking Techniques for Motion Reduction in Optical Mapping**

Jaime Yagüe-Mayans, Conrado J. Calvo, Antonio Cebrián and Jose Millet*

Introduction: Suppression of motion artifacts (MA) in OM requires uncoupling of cardiac contraction by restriction techniques, which have important effects on cardiac physiology and deteriorates the quality of acquisitions and their interpretation. In this study, we propose to assess the performance of two independent intensity-based methods for efficient registration minimizing MA. Methods: A method based on based point-to-pixel block matching similarity with tracking with displacement interpolation approach (PPBMA) was compared to a classical non-rigid registration algorithm where the deformation field is obtained using cubic splines (DFCS). Both alternatives were tested under controlled conditions using phantoms and real image sequences (n=5). Trajectory loops and total directional displacement were compared before and after registration to assess tracking compensation. Computation of action potential duration (APD) and activation properties were obtained to evaluate the accuracy of reconstructed AP and its reliable interpretation. Results: Our results showed that motion was greatly suppressed at automatically preselected key-points. Maximum displacement after registration was in the sub-pixel to pixel range (0.97±0.26 vs 0.93±0.52 px). DFCS showed better performance by reducing MA in larger areas by an average of 13.13% greater extension (63.36% vs 76.49%). The latter allowed for more accurate estimation of APD across the epicardium (APD80 (ms): 109.53±3.94 and 109.89±2.69 vs uncorrected 120.5±27.42 ms) reducing the coefficient of variance to that observed in presence of the uncoupler blebbistatine (CoV: Uncorrected: 22.75%, PPBMA: 3.6%, DFCS: 2.45%, Blebb:1.75%). Even though both methods show minimization of MA, DFCS had a negative effect on upstroke velocities and spatial smoothing on the activation isochronal maps greatly affecting its interpretation depending upon spatiotemporal resolution of acquired sequences. Conclusions: Intensity based methods are useful for MA correction via registration due to its accuracy tracking frame-to-frame geometrical displacements in large areas of the heart. Yet, special care must be taken to preserve upstroke information intact.

PB6 **Cellular and Tissue Models**

Room: Pinnacle I

307-284 **In Silico Assessment of Antiarrhythmic Effects of Drug Ranolazine on Electrical Activity in Human Ventricular Myocardium**

Mitra Abbasi* and Sebastian Polak

The objective was to determine the antiarrhythmic effects of ranolazine on the human ventricular electrophysiology and to describe the ionic mechanisms of these effects. The aim of this study was to simulate the electrophysiological modifications by the ranolazine drug at the left ventricular wall level by using in vitro electrophysiological measurements from canine ventricular myocytes to generate early information on cardiac safety in the human heart. The antiarrhythmic effect of ranolazine on two proarrhythmic drugs was examined. We used the Cardiac Safety Simulator (CSS V2.0, Simcyp, Sheffield) to evaluate the cardiac electrophysiological effects of ranolazine compound in a virtual human population (i.e. North European Caucasian) using the drug concentrations as reported in experimental studies (Antzelevitch et al. 2011; Okada et al. 2015) with HEK cell system at physiological temperature. We used half-maximal inhibitory concentrations (IC50) of ranolazine, dofetilide and d,l-sotalol for different ionic channels together with Hill coefficient to describe the drug triggered ionic current modifications. Maximum plasma drug concentration (Cmax) was utilized to describe exposure. Inhibitory actions (i.e. the dose-inhibition relationship) of these compounds were specified at ion channels by using multiple drug concentrations (µM). The computational models for endocardial cell type were derived from ORd (O'Hara et al. 2011) human ventricular cell model. Action potential duration (APD) was measured to investigate the variability of cardiac electrophysiological behaviour in response to antiarrhythmic effects of drug ranolazine. The sensitivity of ionic currents to ranolazine was described as APD variations in response to different therapeutic concentrations. The observed results can be explained by inhibition of the physiologic INaL and IKr contribute to the anti-arrhythmic effects of ranolazine. Simulation results are in agreement with in vitro and in vivo studies of arrhythmia and confirmed the antiarrhythmic properties of ranolazine which may be utilized for suppressing ventricular arrhythmias.

308-319 **A New Defibrillation Mechanism: Termination of Reentrant Waves by Propagating Action Potentials Induced by Nearby Heterogeneities**

Shuyue Han*, Niels Otani, Valentin Krinski and Stefan Luther

Introduction. Recently, there has been a major effort to develop new, low-energy defibrillation methods. These methods would be less damaging and less traumatic for the patient, and would save battery energy. However, these methods have not been entirely successful, due in part to an incomplete understanding of all the mechanisms present that may help or hinder the process of terminating the rotating waves present during fibrillation. Here we describe a new mechanism whereby a far-field electric field pulse terminates waves that are rotating in the vicinity of a blood vessel, plaque deposit or other heterogeneity in the gap junction conductivity. Method and Results. We ran a series of two-dimensional computer simulations based the Barkley model of the excitable electrical dynamics of the heart. The parameters used (a = 0.6, b = 0.075), put the simulations in the regime of stably rotating spiral waves, between the sub-excitation and meandering spiral wave regimes. A rotating spiral wave was initiated in the vicinity of a non-conducting obstacle representing the heterogeneity. Conditions mimicking the application of an electric field pulse caused a semicircular action potential wave to be launched from the heterogeneity. The interaction of this wave with the rotating wave resulted in termination of all wave activity. Conclusion: These simulations demonstrate a new mechanism by which a low-energy electric field pulse can interact with structures within cardiac tissue to terminate the reentrant waves associated with fibrillation. The mechanism studied here only requires the spiral wave to be nearby, but not necessarily, pinned to an obstacle, and thus extends the effectiveness of the electric field pulses used in low-energy defibrillation. Consideration of this mechanism alongside those already discovered could result in the development of improved, low-energy defibrillation protocols.

309-527 **Virtual Reality Visualization of Arrhythmias on a Smartphone**

Joachim Greiner, Tobias Oesterlein, Gustavo Lenis* and Olaf Doesse

Computer simulations and medical imaging can be effectively used for diagnostic purposes and are currently a focus of scientific research. An effective application of such techniques is the preoperative planning of cardiac surgery, percutaneous coronary intervention or catheter ablation. In this work, we developed a visualization scheme based on a conventional mobile device and virtual reality (VR) goggles (Google Cardboard and Samsung Gear VR) that was especially created for the representation of cardiac arrhythmias. As of now, computer simulations of sinus rhythm, atrial fibrillation, three types atrial flutter (AFLU), ventricular ectopic beats (VEB), and cardiac muscle contractior (CMC) can be compiled for presentation. For this purpose, the simulations are imported into the Visualization Toolkit (VTK) and rendered using a game engine. The system has been optimized to display geometries with up to 150.000 vertices with at least 60 frames per second. The user can see the heart anatomy in 3D in different modalities and the spread of cardiac depolarization, color-coded on the surface, as a function of time (4D movie). In the orbital mode, the camera can be rotated around the heart to visualize, for example, a depolarization wave traveling from one side to the other (e.g. anterior to posterior). In first person view, the user can move into the chambers of the heart and observe the depolarization wave from the endocardial perspective (e.g. catheter's point of view). Thus, the understanding of the complex nature of a cardiac arrhythmia become intuitive. A demonstration of the system can be seen in figure 1. In future projects, more powerful hardware will be acquired to accelerate data transfer and interact in a more complex manner with the 4D movie. On the long run, the system should be used for better planning and guidance of medical procedures.

310-412 **Effect of Multi-Electrode Configurations on Accuracy of Rotor Detection in the Atria**

Laura Martínez, Lucia Romero, Ana Ferrer, Jose Jalife, Omer Berenfeld and Javier Saiz*

Background: Atrial fibrillation (AF) is suggested to be driven often by rotors which have become the target of ablation to terminate the arrhythmia. Multi-electrode catheters are increasingly being used to localize those rotors. Our objective is to analyze the effects of the multi-electrodes geometrical configuration on the accuracy of localizing rotors using computer simulations. Methods: We simulated and analyzed rotor detection in: 1) A 3D cube of tissue and various multi-electrode array configurations, varying the electrodes-to-tissue distance (d=1 to 20 mm) and the inter-electrode distance (die=0.9, 4.5 9 and 18 mm), and in 2) A 3D realistic atrial model and an intracardiac basket-type mapping catheter (8x8 electrodes) positioned at two locations inside the right atrium. Rotors were detected by localizing phase singularity points (PSs) on phase maps based on the Hilbert transform. Results: Our simulations showed that for the 3D block, the best PS trajectory detection (sensitivity ~85%) was obtained at d=die=0.9 mm. Increasing d decreased the sensitivity (58% at d=19.8 mm). However, for the highest die (18 mm) the sensitivity increased from 30% to 53% by increasing d. For a single rotor simulated in the right atrium (3D atrial model), a basket-type catheter achieved 90% accuracy in detection of the rotor for a basket positioned such that the average distance between the electrodes and the rotor PS's trajectory was 0.96 cm. The accuracy decreased to 35% when the distance increased to 3.05 cm. Conclusion: Localization of a rotor in a 3D cube with high accuracy can be achieved with high density multi-electrode arrays placed close to the endocardium. For low density arrays, accuracy can be maintained by increasing the distance to the tissue. Additionally, atrial rotor detection by basket catheter is most accurate when the average distance between the electrodes and the rotor's trajectory is less than 1 cm.

311-458 **Hierarchical Bayesian Modelling of Variability and Uncertainty in Synthetic Action Potential Traces**

Ross Johnstone*, Rémi Bardenet, David Gavaghan, Liudmila Polonchuk, Mark Davies and Gary Mirams

There are many sources of uncertainty in the recording and modelling of membrane action potentials (APs) from cardiomyocytes. For example, there are measurement, parameter, and model uncertainties. There is also extrinsic variability between cells, and intrinsic beat-to-beat variability within a single cell. These combined uncertainties and variability make it very difficult to extrapolate predictions from these models, since current AP models have single parameter values and thus produce a single predictive AP trace. We wish to re-parameterise existing AP models to fit experimental data, and to quantify uncertainty associated with measuring and modelling these APs. We then wish to propagate this uncertainty into model predictions, such as ion channel block effected by a pharmaceutical compound. We use a Bayesian inference approach to quantify the parameter uncertainty by treating the maximal ion current conductance parameters as random variables, and fitting distributions of these parameters via Markov chain Monte Carlo (MCMC) methods, instead of fitting single-point values to these parameters. These parameter distributions will allow us to make a range of cell-specific predictions, along with their associated probabilities. To model the beat-to-beat variability seen in cardiomyocytes, we use a hierarchical Bayesian approach, where we assume that each separate AP has its own distributions of parameters, but these distributions are connected by a higher-level parameter distribution. We perform an in silico study using synthetic data generated from different sets of parameters. We then 'forget' these parameter values and re-infer their distributions using these hierarchical MCMC methods. We find that we can successfully infer the 'correct' distributions for most ion current densities for each AP trace, along with the higher-level distribution from which these parameter values were sampled. There is, however, some level of unidentifiability amongst some of the

312-180 **Combination of Quantitative Changes in Ionic Components to Enhance the Contractile Force during T-tubule Development**

Maiko Wakita*, Hitomi Sano, Yasuhiro Naito and Masaru Tomita

Spontaneous action potentials have been reported for the early embryonic (EE) stage in developing rodent ventricular myocytes, eventually disappearing to passive contracting cells in the late embryonic (LE) stage. The sarcoplasmic reticulum (SR) is scarce and poorly organized in EE ventricular cells, and Ca(2+) transient in embryonic ventricular cells depends mostly on Ca(2+) influx through L-type Ca(2+) channels; in rats, the transverse tubules (t-tubules) of the ventricular cells begin to form postnatally. As such, Ca(2+)-induced Ca(2+) release (CICR), in which ryanodine receptor channels on the SR are activated via Ca(2+) influx through L-type Ca(2+) channels on the t-tubules, is not established in embryonic ventricular cells.Here, we integrated developmental changes in various characteristics of ventricular cells based on a mathematical model. First, we have quantitative changes in the ionic currents, pumps, exchangers, and sarcoplasmic reticulum (SR) Ca(2+) kinetics were integrated to the Kyoto model. The simulated action potential of the EE ventricular cell model exhibited spontaneous activity, which ceased in the simulated action potential of the LE and neonatal ventricular cell models. We modeled developmental changes in guinea pig ventricular cells and identified the factors that enhance contraction of the cells with an increase in CICR. From the middle to late embryonic stages in guinea pig ventricular cells, almost all factors, except for an increase in the L-type Ca(2+) current density, contributed to increasing the amplitude o half sarcomere length along with an increase in the CICR parameter.

313-270 **Computational Modelling of Cardiac Electrophysiological Changes in Acute Malaria.**

Alan Benson, Michael Colman*, Arun Holden, George Kagugube and Eleftheria Pervolaraki

Aims: In adults the fever of malaria is associated with tachycardia and QT prolongation in the ECG. In children malarial fever is associated with QT shortening and its treatment by quinine by QT prolongation. We aim to (a) construct a 1D computational model of normal sinus rhythm in the adult and child <2 years old and (b) incorporate known and putative changes in repolarisation conductances associated with malaria and with quinine to reproduce ECG RR, QT intervals during malaria and its treatment by quinine. Methods: A 1D computational model for propagating activity during human normal sinus rhythm was constructed, with cell models based on the Courtemarche-Ramirez –Natel atrial and the O'Hara-Rudy ventricular cell models. Parameters for the sinoatrial node cell model (a modified CRN model) adjusted to give appropriate rates for observed RR intervals, diffusion coefficients to give ventricular conduction velocities of 0.42 m/s, and lengths of strand components adjusted to reproduce PR and QT intervals of the ECG. The effects of malaria were modelled by metabolic acidosis and changes in extracellular cation concentrations, with values from the clinical literature. The effects of quinine were modelled by changes in ventricular conductances Results: For the adult mean clinical data (model), malaria reduced the RR interval from 0.82(0.81) to 0.78 (0.79), in the child from 0.57(0.57) to 0.42 (0.52) ; the QT interval in the adult from 0.28 (0.27) to 0.25 (0.25), in the child 0.42 (0.41) to 0.38 (0.32). Quinine prolonged the QT interval from 0.38 (0.32) to 0.41 (0,40) Conclusion: The model approximates the NSR mean RR and QT intervals seen in adults and children, with malaria, and the QT prolongation produced by quinine. It may be used to evaluate the relative roles of physical biophysical, and electrochemical factors in the ECG during malarial fever.

314-259 **Two Aspects of Cardiac Alternans – Difference and Correlation Between Them**

Wei Wang, Dominic G Whittaker*, Haibo Ni, Kuanquan Wang and Henggui Zhang

Introduction: Cardiac alternans are always observed in two aspects: one manifested as action potential duration(APD) alternans and the other as Ca2+ transition(CaT) alternans. This study aims to investigate the mechanism underlying the genesis of the two aspects of alternans, their difference and correlation. Method: We used two human ventricle models, the O'Hara-Rudy model(ORd model) and the Ten-Tusscher model modified by Adeniran et al.(TNNP-IS model), for generating cardiac alternans. All related contributing factors were analyzed; CaT-SR content and APD restitution curves were constructed to investigate possible different mechanisms underlying the two aspects of alternans. ICaL current were recorded for ICaL clamp simulations, aiming to evaluate the impacts of ICaL on cardiac alternans. Results: Alternans produced by ORd model sustained with significant CaT but no obvious APD alternans, whereas alternans generated by TNNP-IS model manifested as obvious APD but insignificant CaT alternans. CaT alternans in the ORd model was correlated with a much steeper CaT-SR content curve, demonstrating the importance of the instability of intracellular Ca2+ in generating CaT alternans. However, the APD alternans in the TNNP-IS model was correlated with a steeper restitution curve, indicating the important role of refractory excitability in generating APD alternans. Furthermore, APD alternans were found to be strongly related to INa, and ICaL clamp simulations showed the magnitude of ICaL was crucial for generating the CaT alternans as a large ICaL could change its status. Conclusion: This study investigated two different kinds of cardiac alternans using two valid human ventricle models. Our results suggested that each of the APD or the CaT alternans has its own primary mechanism, and a sustained CaT alternans is not necessarily related to APD alternans. These findings are consistent with pervious experimental studies, providing a theoretical explanation for some controversial experiment phenomena, and contribute to elucidate the mechanism of cardiac alternans.

315-372 **Comparison of Ion Channel Gene Expression in the Sinus Node of the Human, Rabbit, Rat and Mouse**

Jue Li*, Halina Dobrzynski, Ming Lei and Mark Boyett

Small animal species (e.g. mouse) have a faster heart rate than large animal species (e.g. human). We have looked for the reason from the functional level to the gene level in the human, rabbit, rat and mouse using a ‘meta-analysis’ approach. For example, review of the literature shows that, in isolated sinus node myocytes, the spontaneous rate is 4.6× faster and the action potential is 2.4× shorter in mouse than in human. Although data on ionic currents are limited, data suggests that the density of the funny current (If) at least is 6.5× higher in mouse than in human, (Q10 of 1.38 was used to correct temperature differences among studies). Data on ion channel mRNA expression (qPCR) in the sinus node for the four species were collected from different research groups. To compare data, we either normalised to the Nav1.5 mRNA level (in atrial muscle) or the Cav1.2 mRNA level (in sinus node). Although different housekeeper genes were used (18S, 28S, HPRT), comparison of different data sets on the same tissue but with different housekeeper genes suggests that this is unimportant. In the sinus node, many ion channels were more highly expressed in mouse than in human, for example, HCN1 (by 18×; partly responsible for If), HCN2 (by 26×; partly responsible for If), HCN4 (by 7×; partly responsible for If), Cav3.1 (by 16×; responsible for the T-type Ca2+ current, ICa,T), RyR2 (by 6×; Ca2+-handling molecule) and SERCA2 (by 70×; Ca2+-handling molecule). It is concluded that the mouse heart rate is faster, because sinus node ion channel expression is higher in mouse.

316-196 **Computer Model for Determining the Localized Changes in Ventricle Wall Thickness as a Function of Changing Wall Stress as Determined by Laplace's Law**

Richard Summers*

Introduction: There are a variety of conditions in which there is a consequential change in ventricular mass due to either hypertrophy or atrophy. The ventricular myocardium remodels in an attempt to normalize local wall stress (σ) created by physical forces and optimize cardiac function. This σ is considered a major driving determinant of growth or regression of myocardial cells that in turn change the local ventricular myocardial wall thickness (h) and area stress. A computer model was developed that describes the magnitude and time course of changes in h in response to variations in physical factors (pressure, geometry) that are considered the determinants of σ. Methods: An algorithm that describes the driving changes in myocardial protein synthesis and h was based on a stimulus of wall stress (Δs) outside of the normal range (σo). Changes in the segmental wall thickness (dh/dt) are considered directly related to the differential in σ integrated over time. As h changes, the actual wall stress (σa) also changes as defined by Laplace's Law. The iteratively determined σ continues to drive the growth/atrophy of the ventricle wall until an equilibrium is reached and Δs = 0. Results: The model performance was compared to values derived from the literature that examine changes in σa during some clinical perturbation. The absolute loss in h after intervention was found to closely map changes in σa as predicted by the model with an exponential approach to a maximum. The maximum loss is about 35% of total h at 60 days with a k value of 0.0006 that best fits the timeframe for equilibrium. Conclusion: These results suggest that this model can serve as a driving algorithm for defining myocardial plasticity in a FEM of the heart and can be used to study the effect of various conditions on cardiac remodeling.

Wednesday, September 14, 2016 **12:15**

PB7 **ECG Miscellaneous**

Room: Pinnacle I

317-267 **Design and Implementation of a 2.45 GHz RF Sensor for Non-contacting Monitoring Vital Signs**

Hongrui Bo*, Qiang Fu, Lisheng Xu, Yuanzhu Dou and Fleming Lure

The design and implementation of a non-contact RF (radio frequency) sensor that can monitor vital signs-respiration rate and heat rate is proposed. The designed low-cost system operates at 2.45 GHz by using one single Yagi antenna system to transmit and receive RF signals, realizes a miniaturized design of PCB that integrates both microwave transceivers and receivers. The gain of the sensor is 8.96 dB. The return loss is -22.87 dB at 2.45 GHz and the directionality of the antenna is satisfactory for monitoring vital signs. In comparison with pulse sensor and respiration sensor, it has been validated that the sensor could detect the respiration and heartbeat with mean error for the respiration rate within 0.5 beat/min and the heart rate within 1.9 beat/min.

318-306 **Computational Model for Prediction the Occurrence of Steam Pops during Irrigated Radiofrequency Catheter Ablation**

Ana González-Suárez*, Enrique Berjano, Jose M. Guerra and Luca Gerardo-Giorda

Introduction: Steam pop is a serious complication that can occur during irrigated radiofrequency catheter ablation (RFCA). Pops are caused by tissue overheating above 89ºC, and may cause explosive rupture of myocardium. Today, it is still very complicated to predict the occurrence and location of steam pops into the tissue during RFCA. Our aim was to use a previously validated computational model to address these issues. Methods: The 3D model is based on an open-irrigated electrode surrounded by blood and placed over cardiac tissue. We considered different power settings, from 20 to 50 W, and two catheter tip designs as used in clinical practice (6-holes and multi-holes). Simulated ablation was terminated after a pop or at 60 seconds. From previous experimental findings, a pop was predicted by both, a maximum volumetric tissue temperature of 89.3ºC and a rate of volumetric tissue temperature greater than 1.5ºC/s. Results: Steam pops occurred at power setting higher than 35 W for both catheter designs, such as reported in previous experimental studies. The time at pop was about 30, 15 and 10 seconds for 35, 40 and 50 W, regardless of the catheter design. The pop was located in all cases at approximately 2 mm depth from the tissue surface under the electrode tip. Conclusions: The computational findings are in close agreement with previous experimental results since they reproduced the same conditions in which steam pops occur. This suggests that this model could predict the occurrence of steam pops in different simulated clinical situations.

319-505 **Monitoring the Heart Rate in Cerebral Oximetry Signals**

Iraia Isasi, Unai Irusta*, Elisabete Aramendi, Goiuri Peralta and Erik Alonso

Aim: Cerebral oximetry of the frontal lobes based on Near InfraRed Spectroscopy (NIRS) is used to monitor brain tissue oxygen saturation, for instance during cardiac surgery. Saturation is recorded every 2-4s, but higher time resolutions may enable additional monitoring. This study evaluates heart rate monitorization based on NIRS measures of high time-resolution. Materials: The experimental setup comprised a prototype NIRS probe (PortaLite, ArtinNIRS) and a synchronized BioPa ECG (lead II) recording system. NIRS signals of the left frontal lobe, the oxyhemoglobin (O2Hb) concentration, were sampled at 50Hz and the ECG at 250Hz. 29 subjects were enrolled in 40min recording sessions at different breathing conditions, after approval by the UPV-EHU ethics committee. Methods: Manually audited heartbeats annotated using the wqrs detector (ECG) were used as gold standard (GS). The O2Hb signal was bandpass filtered (0.65-6Hz) and an ad-hoc peak detector with outlier correction was designed. Sensitivity (Se) and positive predictive value (PPV) were used to assess the accuracy. The heart rate was computed in intervals of 10s with 50% overlap, and compared to the GS using Bland-Altman plots and 90% levels of agreement (LOA). A second heart rate monitor based on the average magnitude difference function (AMDF) pitch detector was developed and evaluated. Results: The median heart rates in 10s intervals for ou data were 65 (IDR, 55-79)bpm with a coefficient of variation of the RR intervals of 0.06 (IDR, 0.02-0.13). The Se/PPV of the NIRS beat detector were 99.73/99.85%, respectively. The Bland-Altman plots for the heart rate monitors (Figure 1) showed LOAs of (-0.9, 0.9)bpm and 2.8, 1.4)bpm for the peak-detector and for the AMDF based heart rate monitors, respectively. Conclusion: Accurate heart rate monitoring and beat detection on cerebral frontal lobe oximetry signals is feasible for stable heart conditions when the NIRS signals are sampled at high rates.

Wednesday, September 14, 2016 **12:15**

PB8 **Physionet Challenge II**

Room: Point Grey

320-363 **Classification of Normal and Abnormal Heart Sound Recordings through Robust Feature Selection**

Chetanya Puri*, Arijit Ukil, Soma Bandyoapdhyay, Rituraj Singh, Arpan Pal, Ayan Mukherjee and Debayan Mukherjee

We aim to develop a reliable and robust algorithm that accurately analyses a single short PCG recording (10-60s) from a single precordial location to determine the presence of heart abnormality for the Physionet/ Computing-in-Cardiology 2016 challenge. We extract timing information for the fundamental Heart Sounds i.e. S1 and S2 using Hidden Markov Model based Springer's improved version of Schmidt's method.. These values are then used to generate statistical features set in temporal, frequency, time-frequency and wavelet domain. We choose the optimal feature set out of the pool of overall 54 features using mutual information based minimum Redundancy Maximum Relevance (mRMR) technique. In order to cope with bad signals, we also check the signal quality of the PCG signal and reject such signals for further normal abnormal classification when the outside/background noise has rendered signal useless for processing. Then, non-linear radial basis function based Support Vector Machine (SVM) classifier is trained with the reduced optimal feature sets, where balanced training set of 630 normal and 630 abnormal PCG datasets are considered. Our algorithm is tested with hidden Physionet Challenge 2016 datasets and performance achieved is: Sensitivity = 0.778, Specificity = 0.768 and Overall Score calculated as mean(Se, Sp) = 0.773.

321-252 **PCG Classification Using a Neural Network Approach**

Iga Grzegorczyk*, Mateusz Soliński, Michał Łepek, Anna Perka, Jacek Rosiński, Joanna Rymko, Katarzyna Stępień and Jan Gierałtowski

Phonocardiography (PCG) is the one of non-invasive ways to diagnose condition of human heart. The mechanics of heart muscle contractions and closure of the heart valves generates vibrations hearable as sounds and murmurs, which can be analysed by qualified cardiologists. Developing an accurate algorithm to determine whether patients' heart works properly or exhibits some pathological rhythms that should be referred for expert diagnosis would significantly improve the quality of healthcare system, allowing to perform less unnecessary, expensive and time consuming examinations. We analysed over than 3 000 heart sound recordings from the PhysioNet Challenge 2016 training set. It contained very short PCG signals lasting between 5 and 120 seconds. Each signal was already labelled as normal or requiring the expert consult. Our task was to create an algorithm which will divide set of signals into such two groups. All signals were provided as *.wav format and were sampled at rate of 2 000 Hz. We propose the machine learning algorithm based on neural networks. The segmentation of the PCG signals is performed with algorithm suggested in Sample Submission, which is based on Hidden Markov Model. Whereas, the features necessary to define whether the signal looks normal or should be further analysed were carefully chosen by our team, than their optimal values were found during the process of learning of our algorithm. In unofficial phase, best overall score of the PhysioNet Challenge 2016 is 0.74 with specificity 0.83 and sensitivity 0.66.

322-249 **Morphological Determination of Pathological PCG signals by Time and Frequency Domain Analysis**

Márton Áron Goda* and Péter Hajas

With the development of diagnostic devices for the past few decades, the algorithmic classification of heart sound recordings have become possible. Although this field has been under research for a relatively long period, the classification of such recordings is not evident yet. We were given a manually classified large database of heart sounds with the challenge. In order to find the aspects concerning the classifications we worked together with an experienced cardiologist. To algorithmically classify a heart sound recording as normal or abnormal, it is necessary to accurately localize both the fundamental heart sounds and the systolic and diastolic regions in most cases. For this purpose we used Springer's method provided in the example entry. Minor modifications were applied such as the tuning of some of the parameters in order to make them fit closer to the database parameters. Regarding the classification of the heart sounds, we were looking for the morphological features of the abnormal signals, for example mitral stenosis, mitral insufficiency, aortic stenosis, aortic insufficiency, tricuspid stenosis and tricuspid insufficiency. For this purpose we extracted several features from both time and frequency domain. These were for example the frequency properties of systolic and diastolic segments and subsampled wavelet envelope features. The wavelet decomposition of the segmented heart sound recording was tested with several envelopes and several normalizations. The extracted features were classified by the help of support vector machine. In order to train the classifier, we used a reduced, sorted data-set with a more balanced ratio of abnormal and normal signals. During the unofficial phase our best scores on random subset were 77.2% sensitivity, 85.2 % specificity and 81.2% final modified accuracy. Our scores for the entire data-set are the following: 93.08% sensitivity 84.70% specificity and 88.70% final modified accuracy.

323-127 **Robust Detection of Heart Beats in Multimodal Data using Neural Networks and Boosted Trees**

Sachin Vernekar, Deepu Vijayasenan and Rohit Ranjan*

This work describes a novel approach designed for Physionet 2014 Challenge Robust Detection of Heart Beats in Multimodal Data. The objective here is to detect the location of R peaks from the QRS complex. Robust detection of heart beats in a noisy ECG signal is a difficult task. Besides ECG other physiological signals are also recorded at the same time, so the idea here is that if a segment of a signal is noisy, the peaks in that segment can be replaced by peaks found from the other signal if good. The approach is based on machine learning techniques and makes use of ECG and BP signal inputs. Peaks from each signal are found separately using neural networks/boosted trees and the best result of the two is chosen in final peak prediction based on short-time variance comparison techniques. The performance of system on the training data is 99.95%. The performance on competition dataset which is hidden for phase I, phase II and phase III respectively are 93.27%, 90.28% and 89.74%. The submission resulted in 1st place in all the three phases of the competition. (Note: 1. The github link to the code is here: https://github.com/sachinvernekar/drambuie (not documented) 2. The abstract was selected for a presentation in 2014, but I was not able to attend the conference to present it for personal reasons.)

324-144 Classification of Normal/Abnormal Heart Sound Recordings using Temporal Feature Extraction and Machine Learning

Sachin Vernekar, saurabh nair, Deepu Vijayasenan and Rohit Ranjan*

This work describes a novel approach designed for Physionet 2016 Challenge Classification of Normal/Abnormal Heart Sound Recordings. The objective here is to classify phonocardiogram(PCG) recordings into normal and abnormal categories. Usually, statistical features such as means, standard deviations of systole, diastole intervals, and signal complexity features are used as features for classification and these are enough to give significantly good results. But these features fail to completely capture the temporal information of the signal. This could be very important since it represents how each heart beat changes over time. To capture the temporal dynamics, we take PCG signal beat by beat and assign each beat a symbol/category based on different thresholds set on features(ratios of systole intervals to RR interval, diastole intervals to RR interval, absolute amplitude ratios between systole period and S1 period etc). Thus a sequence of symbols for the entire signal is obtained. We then extract features out of this sequence for classification. One of the ways we employed is to create a Markov chain with symbols being the states of the Markov chain and the resulting transition probabilities are used as features. These features along with n-gram features and rest of the statistical features are used to train an ensemble/bag of 2 class boosted tree classifiers(or neural networks). The results are very promising and as of now the classification accuracy is close to 90% on the validation data-set provided in the competition.

325-210 **Using Time-Frequency Features to Recognize Abnormal Heart Sounds**

Hsuan-Lin Her* and Hung-Wen Chiu

Disease of the heart accounts for 6% of all death. Heart sound is a routine in physical examination clinically, and is sensitive in detecting a subset of heart diseases. In the current study, we build up a model to classify heart sounds for preclinical screening. Heart sounds are recorded under uncontrolled environment, and each sample can range from 5 to 120 seconds. This is a work raised by annual PhysioNet/CinC Challenge. Because of timing and tonic natures of heart events, we used time-frequency features to classify heart sounds in this study. Firstly, each heard sound recording was segmented into cycles using Springer’s improved version of Schmidt’s method. Each cardiac cycle was cut into 10 partitions and data points were obtained by zero-padding in each partition. Spectral features were extracted from each partition using fast-Fourier Transform (FFT) thus a 3,500 feature matrix was created. Using filter method, 40 features were selected for the final classifier. The average feature matrix of each cycle was then applied to a classification system using 2-means clustering and artificial neural network (ANN). By clustering the unsure class was recognized. The discrimination of normal and abnormal heart sound were performed by a well-trained ANN model. The results showed that our proposed method got a performance with an accuracy 86.5%, a sensitivity 84.4%, a specificity 86.9%. Here we show that classifying abnormal heart sound is a really difficult task due to the heterogeneity of “abnormal events” and intra-sample deviation.

326-130 **Improving Classification Accuracy of Heart Sound Recordings by Wavelet Filter and Multiple Features**

Xinpei Wang* and Yuanyang Li

This study aimed to improve the accuracy of classifying heart sound recordings into normal or abnormal. In order to get the main element: of the first heart sound (S1) and the second heart sound (S2) for segmentation, the Butterworth filter with the pass-band of 25-400Hz was replaced by the wavelet filter with the pass-band of 31.25-250Hz. The pre-process in example entry was modified to improve the accuracy of the heart sound segmentation. The re-sampled heart sound was segmented into S1, systole, S2 and diastolic using a duration dependant logistic regression-based hidden semi-Markov model (HSMM). Then, twenty basic time domain features were calculated. Based on the above twenty features, four frequency domain features, four entropy features and two time domain features were added to improve the accuracy of classification. Using the logisti regression, the heart sound recordings were classified into normal anc abnormal using the obtained features. To evaluate the modified program, the sensitivity (SE) and specificity (SP) of the classification results were presented. For the hidden test set in PhysioNet's scoring environment, the best results were SE 71.6%, SP 78.2%, and the overall score was 74.9%, as well as the highest accuracy was 82%.

327-134 **Classification of Heart Sound Recordings Using Convolution Neural Network**

Heechang Ryu*, Jinkyoo Park and Hayong Shin

Aims: This study aimed to develop a cardiac diagnostic model using convolution neural network (CNN). Various classification methods, such as support vector machine, hidden Markov model, and artificial neural network, have been employed to develop a classification mode for heart sound recording. These methods generally require carefully designed input features to obtain high classification accuracy. Furthermore, these methods have been validated using data sets collected from well-controlled experiments. CNN, employed in this study, autonomously extracts abstract features from training data sets by using a deep neural network and, at the same time, regulates the complexity of the model by employing convolution operation on input data. A CNN-based heart sound classification model was constructed using training data set provided by Physionet and showed superb prediction accuracy on the test data set. Methods: We first filtered heart sound recordings in the training data set by using Windowed-sinc Hamming filter algorithm. The filtered sound recordings were scaled and segmented, from which features were extracted by employing CNN. The extracted features and the output labels, i.e., normal, abnormal and uncertain, were then used to train a CNN classification model. The trained CNN classification model was then used to classify heart sound recording from the hidden test data set and the corresponding score was measured. Results: An entry was scored to the 2016 Physionet/CinC Challenge in Official Phase. The proposed model achieved an overall score of 0.795 with a sensitivity of 0.708 and a specificity of 0.882. Conclusion: The heart signal classification model constructed using CNN can classify heart sound time series with a modest degree of accuracy.

328-341 **Identification of Abnormal Heart Sounds**

Sasan Yazdani*, Silas Schlatter, Seyyed Abbas Atyabi and Jean-Marc Vesin

Purpose: Pathology classification from heart sound recordings has been an active research topic over the last decades, but still presents challenges. The goal of this work is to classify phonocardiogram (PCG) recordings into normal and abnormal classes using tape-long and beat specific features. Methods: We used the CinC2016 challenge PCG database, which contains a large public collection of PCG recordings from a variety of clinical and nonclinical environments. In this database, the recordings last from several seconds to more than one hundred seconds. All recordings have been resampled to 2 kHz and labeled into either normal or abnormal classes. The PCG classification in this work is performed in two steps. The first step consists in performing a classification based on tape-long features. These features consist of basic signal measures such as spectral purity index (SPI), wavelet transform (WT) energy across different scales, and Gabor transform (GT). Also, a second set of features are extracted from the heartbeats in the PCG. Heartbeats are segmented and markers such as the beginning and the end of S1 and S2 are delineated. Then, a series of morphological features based on the beginning and end of S1 and S2 as well as energy-based features are extracted from the segmented heartbeats. Finally, a multivariate discriminant analysis is performed to evaluate the performance of the extracted features. Results: The evaluation on the training set led to an overall score of 96 (sensitivity=0.96, specificity=96). Also, a score of 80 was achieved on the test set (sensitivity=0.70, specificity=0.90). Conclusions: Preliminary results show that tape-long features can already identify abnormal PCGs to some extent. However, the results can be improved by the fusion of tape-long and beat-driven features in an ensemble of classifiers.

329-234 **Classification of Normal/Abnormal Heart Sound Recordings by Using Wavelet Feature Extraction and SVM Classifier**

Cheng Shi*

Classification of Normal/Abnormal Heart Sound Recordings by Using Wavelet Feature Extraction and SVM Classifier Cheng Shi, Savio Monteiro, Tamil Lakshman University of Texas at Dallas The 2016 PhysioNet/CinC Challenge is developing the algorithms to classify heart sound recordings collected from a variety of clinical or nonclinical environments. The challenge is to identify, from a single short recording (10-60s) from a single precordial location, whether the subject of the recording should be referred on for an expert diagnosis. The main issue for heart sound classification is non-stationary character of phonocardiography signals with a wide variety of distinguishable pathological heart sounds. We are developing a discrete wavelet transform feature selection algorithm to extract features combining with a SVM classifier. We totally extracted 50 features both from signal morphology as well as the time-frequency domains. A trained SVM classifier will classify all of these features into normal and abnormal categories. In terms of the accuracy, the current algorithm can achieve 92% overall for all validation data. In the future, we will try to find a more reliable classifier or deep learning classifier to future increase the accuracy. Also, we will train the individual classifier for each A-E classes to learn the difference of each collecting method.

330-467 **Detection of Abnormal Heart Sounds by Machine Learning Classifiers**

Adriana Leal*, Diogo Nunes, Ricardo Couceiro, João Ramos, Jorge Henriques, Paulo Carvalho and César Teixeira

Introduction: Heart sound analysis is challenging due to the broad range of abnormal sounds affecting the heart as well as inter-subject and inter-signal variability. The aim of the current study is related to the robust and accurate classification of normal and abnormal hearts sounds that have been acquired in different clinical and non-clinical settings and in distinct auscultation areas. The algorithms decision will determine if subject being assessed should be submitted to a second diagnosis performed by a clinician. Methods: A dataset comprising 3126 phonocardiograms (PCGs), lasting from 5 to 120 seconds, was inspected. Three steps were followed and included PCG's segmentation, feature extraction and classification. First and second heart sounds' detection was performed using a state of the art logistic regression hidden semi-Markov model segmentation algorithm. Different features from both time and frequency domains were extracted from heart cycle signal segments. After a feature selection process, the most discriminant features were provided as input to a multiplex classifier that selects among five distinct patterns characterized by the feature space. Each cluster has a specialized classifier provided by a dedicated neural network. Results: The performance of the proposed algorithm was evaluated using seven different metrics such the area under the curve (AUC) and the geometric mean (G-mean) in order to account for the class imbalanced data. The results for the validation dataset, table at the left, indicate a lower value of specificity compared to sensitivity. This can be explained by class imbalance. Despite that unpredictability inherent to real-time situations, the algorithm has good generalization capabilities when dealing with different types of abnormal sounds.

331-332 **PCG Classification Based on Empirical Mode Decomposition and Entropy**

Zhao Yizhang*, Yuan Cheng and Wang Lisha

Cardiac clinical diagnosis is taking on more intelligence by medical instruments analyzing the features of PCG signals in recent years. In this paper, a method used to extract the features of PCG signal consisting of multiscale analysis and entropy will be proposed. PCG signal is Nonlinear and nonstationary time series. Multiscale analysis divides the PCG signals into multi-layered frequency scales and retains most partial details of original signals in the meantime, which can get the connotative information of PCG signals. Entropy can evaluate the chaos of a system or a signal. So the features of PCG signal can be obtained. In this work, at first a kind of multiscale analysis method named Empirical Mode Decomposition(EMD) is used to divide a signal into different Intrinsic Mode Functions(IMF), and just retain the first to the seventh IMF to restrain noise jamming in PCG signals. Next, calculating the instantaneous frequency of each IMF and entropy of each instantaneous frequency. Features of the signal can be expressed with the seven-dimension vector which is comprised of the entropies. Then, with the method of machine learning, we choose Fisher Linear Analyzer to classify normal PCG signals, abnormal PCG signals and PCG signals containing too much noise. The results of the test show that the sensitivity, specificity, the overall evaluation index of this method is 72%, 83% and 77%, respectively which means our method is feasible

332-333 **Analysis of the Clinical Utility of Algorithms in the 2009 PhysioNet/Computing in Cardiology Challenge for the Prediction of Acute Hypotensive Episodes**

Grace Mirsky and Maria de la Salud Guillem Sánchez*

An Acute Hypotensive Episode (AHE) typically indicates an impending life-threatening event for an ICU patient. Therefore, the accurate prediction of AHEs has clear clinical merit and was the focus of the 2009 Challenge. Of the 11 papers submitted to the Challenge, some o the top performers were very successful while using simplistic techniques based on a single observed parameter; this paper analyzes if those methods actually provide clinical utility. This analysis was accomplished using the portion of the training set that included records not containing any AHEs. In this training set, the 10 hours prior to the forecast window were analyzed for 15 records using the algorithms described by Chen, Mneimneh, and Langley. Chen's method used the mean of the Diastolic ABP over the 5-minute segment immediately before the forecast window. The results were sorted and split according to the known distribution of expected AHEs per event. When evaluated using a sliding 5-minute window (15 records, 10 hours each), since in a real clinical setting there is no "forecast window", this method generated 884 false alarms. Mneimneh's algorithm classified an AHE by checking if the 20-minute segment prior to the forecast window had a MAP < 71.1mmHg. Using this technique, there were 131 false alarms. Though both Chen and Mneimneh scored 10/10 in Event 1 and 36/40 in Event 2, these results indicate that these methods could never be used practically. Interestingly, though Langley's algorithm did not perform as favorably in the Challenge, 8/10 in Event 1 and 28/40 in Event 2, it had zero false alarms in the training set used in this study. This indicates that some potential may exist for a relatively simple method to be clinically useful, but performance must be considered both in terms of predictive accuracy as well as low false alarms rates.

333-117 **Heart Sound Classification with Autocorrelation Feature without Segmentation**

Shi-Wen Deng*

Heart sound classification, used for the automatic heart sound auscultation and cardiac monitoring, plays an important role in primary health center and home care. However, one of the most difficult problem for the task of heart sound classification is the heart sound segmentation, especially for classifying a wide range of heart sounds accompanied with murmurs and other artificial noise in the real world. In this study, we present a novel framework for heart sound classification without segmentation based on the autocorrelation feature. The current result is as follows. Scores for a random subset: Sensitivity = 0.58 Specificity = 0.90 Overall = 0.74

334-430 **Anomaly Detection in Phonocardiogram Recordings of poor Sound Quality using Hierarchical Temporal Memory**

Marek Otahal*, Olga Stepankova, Jiri Spilka, Vaclav Chudacek and Roman Cmejla

Hierarchical Temporal Memory (HTM) is a biologically inspired neural network model of neocortex, a region also responsible for sensory processing, temporal prediction and anomaly detection. The model uses a novel semantic encoding - Sparse Distributed Representation (SDR), which is highly robust to noise, making the model fit for the purpose of anomaly detection of noisy audio recordings, which we demonstrate on PCG data. The advantage of the model is unsupervised online learning that can be used in personalized medicine. We further extend the HTM theory to provide "confidence" information along with anomaly, used for extension to 3 class (normal/anomalous/ambiguous) classification. We compare our results with state of the art method used for analysis of speech recordings for traces of Alzheimer disease.

335-264 **Development of the Phonocardiogram Signal Analysis and Classification Using Intelligent Techniques**

Fatima Almarshad*, Haya Alaskar and Amal Zaki

Heart sound is considered as an essential component of cardiac diagnosis. The condition of the heart can be detected by analyzing the Phonocardiogram (PCG) signals. PCG signals provide very useful information which can help in early detection and diagnosis of heart diseases. Many studies have attempted to provide automated tools for analyzing heart sounds, by applying different kinds of artificial techniques (AI), data mining and machine learning algorithms. Although a tremendous efforts have been made in this area, yet there is no successful framework can detect pathology in signals exhibit noise or of poor quality. The 2016 PhysioNet/CinC Challenge aims to encourage the development of algorithms to classify heart sound recordings collected from a variety of clinical or nonclinical environments. This paper is aimed to develop the work that has been done by PhysioNet challenge (models and algorithms) for signal processing and classifying Normal and Abnormal PCG signal. We are implementing support vector machines (SVM) for heart sound classification as well as K- nearest neighbors classifier (KNN), to achieve accurate results. In addition, we are attempting to use noise to signal ratio (NSR) to detect noise in PCG signals. Furthermore, more features will be extracted from signals such as the entropy feature from the PCG signals. All results and developed Matlab code will be available for the PhysioNet challenge program. In the meanwhile the outcomes and comparison with other works for PCG classification will be presented in the paper. our score from phase one in phyisonet challenge is 0.6043

336-225 **A Multi-Modal Classifier for Heart Sound Recordings**

Xulei Yang*, Feng Yang, Like Gobeawan, Si Yong Yeo, Shuang Leng, Liang Zhong and Yi Su

Motivations: Different techniques in classifying heart sound recordings outperform each other for various heart sound patterns with unique features. It is desirable to develop a multi-modal classifier by fusing the classification results from various techniques based on various features. Methodology: Using the data obtained from the 2016 PhysioNet/CinC Challenge, we assess the performance of various classifiers (classification techniques) by feeding them with the best features selected from various feature sets: (1) features calculated from segmented results by peaks finding method (2) time-and-frequency features extracted by audio signal analysis (3) features automatically learned by a deep learning approach We evaluate five machine learning techniques as the classifiers: support vector machines (SVM), gradient boosting, extreme learning machines (ELM), random forests, and artificial neural networks (ANN). These tech-niques classify heart sound by using the chosen features. The final heart sound classification result (normal/abnormal) is determined by ensembling the five classifiers with voting. If the votes for normal and abnormal classes are both lower than a certain number, it will be classified as unsure. Results: In the current preliminary studies, we trained the SVM and ELM (10-folder cross-validation) using the features selected from feature sets (1) and (2) of the training datasets. The best performance out of five online entries achieved overall score of 0.83 with sensibility=0.70 and specificity=0.96. We will continue to investigate the performance by fusing more classification techniques and feature sets. Conclusions: We are currently doing a preliminary study of the multi-modal classifier on heart sound classification in terms of various features and machine learning techniques. It will be interesting to evaluate our approach by comparing it with other state-of-the-art methods through the PhysioNet/CinC Challenge for heart sound classification.

337-235 **Power Spectrum Analysis for Classification of Heart Sound Recording**

Soo Kng Teo*, Bo Yang, Ling Feng and Yi Su

Aims: This study assessed the feasibility of using power spectrum analysis to compute additional features from heart sound recordings that can be used for normal / abnormal classification in the PhysioNet/Computing in Cardi-ology Challenge 2016. Methods: Our approach relies on the ratio between the sum of the powers in the Ntl highest peaks in the power spectrum to that of the entire power spectrum. The motivation is that the most dominant frequencies in the heart sound recording contains relevant information for classification. The de-tailed step for our approach is as follows: (i) The heart sound recording is segmented into 4 distinct Fundamental Heart Sounds (FHS) states, namely S1, systole, S2 and diastole. This seg-mentation is performed using the algorithm of Springer et al. (ii) Based on the FHS states, the heart sound recording is divided into segments - each segment corresponds to 1 FHS state for 1 cardiac cycle. (iii) A fast Fourier transform is then performed on each of these seg-ments. (iv) We compute the sums S_N, where S_N is the sum of the N highest peaks in the power spectrum. Ratio of S_N to the sum of the entire power spectrum are also computed. The mean and standard deviation of these rati-os for the entire recording are then used as additional features for classifica-tion. In this way, we have 2N *4 additional features (2N features for each FHS states) for each heart sound recording. The number of sums, N, can be optimized to increase the accuracy of the training prediction. (iv) A feedforward neural network with regularization is trained using combined features from the power spectrum analysis and the segmentation interval analysis. This network is trained on the whole training data-set. Results (Unofficial Phase): Sensitivity = 0.55 Specificity = 0.96 Overall = 0.76

338-244 **Characteristics of Phonocardiography Waveforms that Influence Automatic Feature Recognition**

Scott Stainton, Matthew Dyson, Charalampos Tsimenidis and Alan Murray*

Phonocardiography is a very common diagnostic test, especially relating to the study of heart valve function. However, this test is still almost entirely manual using a stethoscope because of the difficulties in analysing waveforms with excessive acoustic noise, and with subtle clinical characteristics requiring good hearing for detection. The PhysioNet phonocardiography data were analysed to assess the characteristics that related to successful detection of normal or abnormal characteristics. After processing to reduce the effect of noise, the mean signal level in comparison to the processed peak valve sounds was 45±15%. There was a tendency for the noise level to be higher in the abnormal recordings, but this was significant only in one of the five PhysioNet databases by 8% (p=0.002). It was noted that one database had significantly higher noise levels than the other four. Autocorrelation was used to analyse the processed waveforms, with successful automated detection in 58% of recordings of peaks associated with the first and second heart sounds. This was more effective in the normal group with a 5% (p=0.01) greater success rate than in the abnormal group. For all the data analysed, there was only one small significant difference between the normal and abnormal groups, and so combined data are reported. The autocorrelation time to the third peak (heart beat interval) was 0.83±0.19 s (mean ± SD). The first and second sounds relative the third sound (subsequent beat has a timing of 37±6% and 64±6%, and an amplitude 43±21% and 37±20% respectively. We cannot claim success in identifying abnormal from normal, but have shown that noise is a significant problem, and that first and second heart sounds can be identified automatically with 58% success.

339-176 **Abnormal Heart Sounds detection based on the Scaled Time-Frequency Representation and Feature Selection**

Wenjie Zhang*, Shiwen Deng and Jiqing Han

The aims of the 2016 PhysioNet Challenge are to make a pre-diagnosis based on the heart sound recordings. It is of great significance to identify whether the recordings are normal or murmur which provide a reference to a further diagnosis. At the first step, the recordings are segmented into cardiac cycles using the logistic regression-HSMM-based heart sound segmentation method. Then the spectrum of each components, i.e. S1, Systole, S2 and Diastole are extracted. All the spectrum are normalized to the same size using a bi-linear interpolation method. Convolution Neural Networks (CNN) is well known for its abilities to scan parts of the objects and robust to scaling and rotation. CNN is used to capture the parts of the spectrum and thus extract the features of the spectrum. At last, the identifying results are obtained by the trained CNN. The overall performance on a random subset of the data set in the unofficial phase is 76%.

Wednesday, September 14, 2016 **14:00**

MC **Plenary**

Chairs: Guy Carrault and Andrew Blaber

Room: Pinnacle II & III

340-521 **Using Machine Learning to Predict if a Profiled Lay Rescuer can Successfully Deliver a Shock using a Public Access Automated External Defibrillator?**

Raymond Bond*, Peter O'Hare, Hannah Torney, Laura Davis, Bruno Delafont, Hannah McReynolds, Anna McLister, Ben McCartney, Rebecca Di Maio, Dewar Finlay, Daniel Guldenring, James McLaughlin and David McEneaney

Introduction The application of an automatic external defibrillator (AED) within the first few minutes of cardiac arrest significantly increases the likelihood of survival (from 5% to more than 75%.) There is a challenge to optimise the design of the AED's machine interface so that it is user-friendly for a lay rescuer. This study investigated if machine learning can be used to predict if a profiled lay rescuer is likely to succeed in using an AED. Methods 362 subjects were recruited and profiled at a shopping mall. They attempted to use an AED in a simulated emergency situation. The environment included a 'sensorised' mannequin and an AED. A range of features were extracted during each session (i.e. age, gender, education, prior CPR training, prior AED training, Time-to-Place-Electrodes and Time-to-First-Shock). Odds ratios (ORs) were calculated using logistic regression in order to identify features that contribute to the likelihood of successfully delivering a shock. The data was also split into training (70%) and testing datasets (30%) to train and test an ensemble decision tree to predict whether a lay rescuer will successfully deliver a shock. Results The features Time-to-First-Shock [OR= 8.97], Prior Defibrillation Training [OR= 8.37], Prior CPR Training [OR= 6.76], High School Education [OR= 5.71]) had the largest ORs, which could have indicated that lay rescuers who have such features have greater odds in successfully using an AED. However, neither OR had statistical significance ($p<0.05$) indicating that successful AED use cannot be easily predicted. And whilst the decision tree (trials=10) had a 96.33% (CI:90.87, 98.99%) accuracy rate in predicting shock success, this accuracy rate was not significantly different in comparison to the No-Information Rate ($p=0.09$). Conclusion: This supports the hypothesis that the profile of a lay rescuer is independent of their success in using an AED.

341-286 **Spatiotemporal Activation Time Estimation Improves Noninvasive Localization of Cardiac Electrical Activity**

Matthijs Cluitmans*, Jaume Coll-Font, Burak Erem, Dana Brooks, Pietro Bonizzi, Joël Karel, Paul Volders, Ralf Peeters and Ronald Westra

Electrocardiographic imaging reconstructs epicardial potentials and electrograms from body-surface electrocardiograms and a torso-heart geometry. For clinical purposes, local activation and recovery times are often more useful than epicardial electrograms. However, noise and fractionation can hamper estimation of activation and recovery times from reconstructed electrograms. For this study, we have employed a method for local activation and recovery time estimation that detects the simultaneous presence of spatial and temporal features associated with a passing wavefront. We compared this spatiotemporal approach to temporal-only estimation in four canine experiments (93 beats), where simultaneous recordings of body-surface (184+ electrodes) and epicardial potentials (99 electrodes) were obtained. Activation times estimated with the temporal-only approach had a Pearson's R of 0.73, and improved significantly when the spatiotemporal approach was used (R = 0.78) and improved further after additional post-estimation spatial smoothing (R = 0.82). Spatial smoothing of temporal-only estimates yielded less improvement (R = 0.74). Recovery times were best determined with a temporal-only approach with additional spatial smoothing. Localization of paced beats with temporal-only criteria had a median error of 33 mm, and was most accurate when the spatiotemporal approach was combined with additional spatial smoothing (10 mm). In conclusion, spatiotemporal estimation of epicardial activation times with post-estimation spatial smoothing significantly reduced beat origin localization error to only one centimeter, which could expedite catheter-based diagnostic evaluation and ablation in clinical settings.

342-232 **A Population of In Silico Models to Face the Variability of Human Induced Pluripotent Stem Cell-derived Cardiomyocytes: the hERG Block Case Study**

Michelangelo Paci*, Elisa Passini, Stefano Severi, Jari Hyttinen and Blanca Rodriguez

The potential of human induced pluripotent stem cell-derived cardiomyocytes (hiPSC-CMs) and in silico models as new technologies to support safety pharmacology assays has been largely recognized by the scientific community and regulatory agencies. However, one challenge that hiPSC-CMs pose is the extreme variability of the experimental data. A standard in silico model, reproducing the average behavior observed in a cell population, is consequently inadequate to capture such variability. Therefore, here we applied the new populations of models (POM) paradigm to generate a population of in silico models of hiPSC-CM spontaneous action potentials (APs). We sampled the maximum conductances of eleven ionic currents to generate 10000 hiPSC-CM models based on the Paci2015 model. Through an experimental data-based calibration, we then selected only those models in agreement with six datasets of biomarkers measured on spontaneous hiPSC-CM APs, e.g. AP duration (APD90), amplitude (APA) and spontaneous rate (RATE). Finally, we tested the effect of a 90% block of IKr on the population, to assess the different responses of the models. The calibration selected 1355 models, reproducing the experimental variability (mean±STD: APD90 = 384±84 ms, APA = 111±9 mV, RATE = 54±12 bpm). IKr block showed three AP classes: 562 models produced normal spontaneous AP after 800 s since IKr block, 336 generated EADs and 457 failed to repolarize. To assess the differences underlying these behaviors, we compared the three classes, showing significant differences (p-value < 0.01) for six ionic currents: ICaL, IKr, IKs, IK1, the Na+/Ca2+ exchanger and the Na+/K+ pump. Our study shows that POM allows studying the hiPSC-CM variability, overcoming limitations of traditional models and making in silico modeling even more suitable for safety pharmacology assays. Moreover, we identified the ionic currents affecting the most the development of arrhythomgenic phenomena consequent to a hERG block.