The Attenuation of QRS Power in the Frequency Range from 0.05 to 1 kHz

[1]Josef Halamek, [2]Pavel Leinveber, [1]Filip Plesinger, [2]Magdalena Matejkova, [1]Pavel Jurak

[1]Institute of Scientific Instruments of the CAS, Brno, Czech Republic
[2]International Clinical Research Center, St. Anne's University Hospital, Brno, Czech Republic

Abstract

The high-frequency QRS (HFQRS) signal was analyzed in four groups of subjects: healthy, patients suffering from coronary artery disease, heart transplanted patients and patients with left bundle branch block (LBBB). Subjects were measured in the supine position with a high-quality ECG system (fs=5 kHz, ADC 24 bits). The dependency of HFQRS power, maximal amplitude and HFQRS width on the passband used was analyzed.

Results: The dependency between HFQRS power and frequency in logarithmic scales is nearly linear across all groups. Significant differences exist in HFQRS power attenuation in regard to frequency between groups of subjects, P<0.001. This attenuation is maximal in healthy subjects -48.1±3.7 [dB per decade], minimal in LBBB -40.2±2.7. Based on significant differences between healthy and patient groups, we assume that QRS power attenuation may represent new information in ECG analysis. This parameter is independent of the choice of the analyzed frequency band. The dependency of HFQRS shape on frequency is presented by analysis of a healthy subject. Explanation of this significant dependency is a task for the future.

1. Introduction

The first attempts to analyze high-frequency QRS (HFQRS) signals were made more than 50 years ago [1-3]. HFQRS represents a consequence of the steep changes of phase 0 of action potentials (AP), i.e. depolarization [6]. Filtering prevents low frequencies associated with repolarization phases of action potentials and the analyzed HFQRS signals describe the time distribution of electrical depolarization. Different frequency bands of HFQRS are used. Late potentials for diagnostics of sudden cardiac death are analyzed in a frequency band from 40 Hz to 250 or 350 Hz [4], the Reduced Amplitude Zone (RAZ) as a marker of myocardial ischemia is analyzed from 150 to 250 Hz [5], and electrical ventricular dyssynchrony detected from the time shift of signals between leads is analyzed from 150 to 1000 Hz [6]. The results may depend significantly on the passband used, but detailed analysis is lacking. Our aim was to study the dependency of HFQRS power on frequency.

2. Subjects and measurements

We measured healthy subjects, N=85, female 37, age 33 ± 18, 89/20 (mean ± STD, max/min years), patients with left bundle branch block (LBBB), N=73, female 17, age 68 ± 10, 86/31, heart transplant patients (HTP), N=100, female 18, age 55 ± 12, 73/25, and patients suffering from coronary artery disease (CAD), N=144, female 29, age 70 ± 10, 90/34. A standard twelve-lead ECG system, with high dynamicity (24 bit) and high frequency range (sampling 5 kHz, cut-off of low pass filter 1.5 kHz) was used. Subjects were measured in a calm supine position; the length of measurement was about 8 min., the minimal length of measurement was 5 min.

3. Analysis

QRS complexes were detected [7] and clusterized as the first step [8]. Amplitude envelopes in passbands 100 Hz wide, with 100 Hz step from 50 Hz to 1000 Hz, were computed and regular HFQRS complexes were averaged. The next analysis focused on frequency dependency on HFQRS power (HFQRSPW), maximal amplitude (HFQRSAmax) and HFQRS width. All detections were performed automatically. The HFQRS area was defined as the time area ± 100 ms around the HFQRS position. HFQRSPW was defined as the mean power in this area. HFQRSAmax was defined as the maximum in this area. HFQRS width was defined as the distance in ms between 5 and 95 % off the integral level in this area. The level of background noise was defined as the mean level of signal power in the area from 200 to 300 ms after HFQRS. To overcome diverse manifestation of signals in standard 12 leads, the mean level over 12 leads was used in the case of power, width and noise. The maximum over 12 leads was used in the case of maximal amplitude. The best model of dependency on frequency for HFQRSPW and HFQRSAmax is linear in logarithmic scales and dB units.

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The models used are:

$$10*\log(HFQRSPW) = PW0 + PW1*\log(f); \quad (1)$$
$$20*\log(HFQRSAmax) = Amax0 + Amax1*\log(f);$$

where PW0, PW1, Amax0 and Amax1 are optimized parameters of models and f is the mean frequency of the used frequency window.

4. Results

The dependency on the frequency of the analyzed parameters is given in Fig. 1. The mean levels across the groups of subjects are presented. The attenuation of HFQRSPW and HFQRSAmax with frequency is shown in Table 1. The significance of differences between groups was tested by multiple comparisons. The attenuation of each group of subjects is significantly different from others with $p<0.001$.

As the secondary aim, the reproducibility of HFQRS shape and the dependency of HFQRS shape on the analyzed passband were tested. A healthy man, age 38 years, was measured. Three measurements were analyzed. The second and third measurements were both conducted one year and 9 months after the first. The results are presented in Fig. 2.

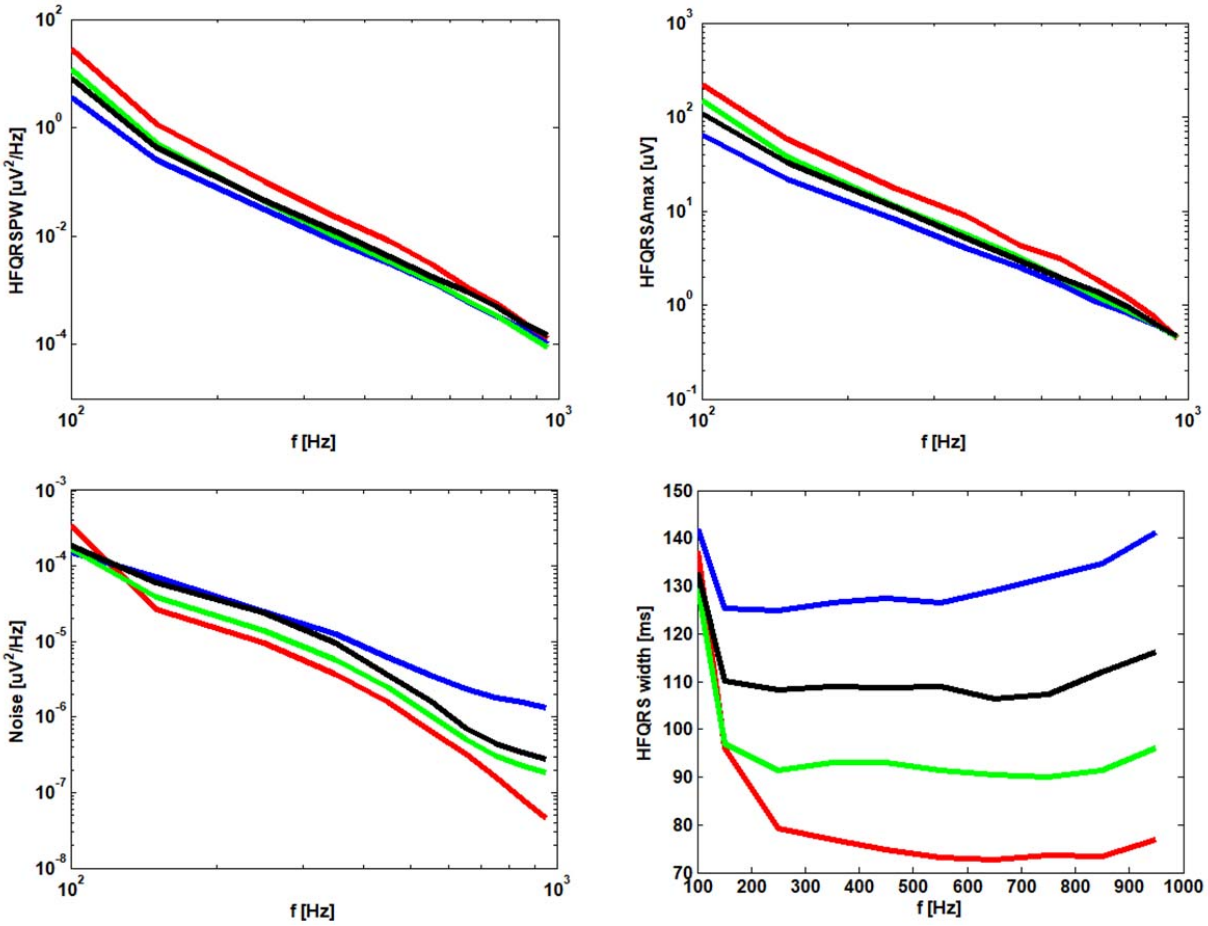

Figure 1. The dependency of HFQRSPW, HFQRSAmax, noise and HFQRS width on frequency. Mean levels across the groups of subjects are presented. Healthy, HTP, CAD and LBBB groups are shown in red, green, black and blue, respectively.

5. Discussion

The averaged HFQRS envelopes in different passbands were analyzed. Envelope analysis has the following properties: i) HFQRS signals phase coherent and not phase coherent are accumulated and no loss of signals occurs. ii) HFQRS shape is not modulated by carrier frequency f0 which is the mean frequency of the analyzed passband. iii) Frequency bandwidth of envelope is one half of the analyzed ECG bandwidth, as the envelope does not differentiate between signals with frequency $f0+\Delta f$ and $f0-\Delta f$.

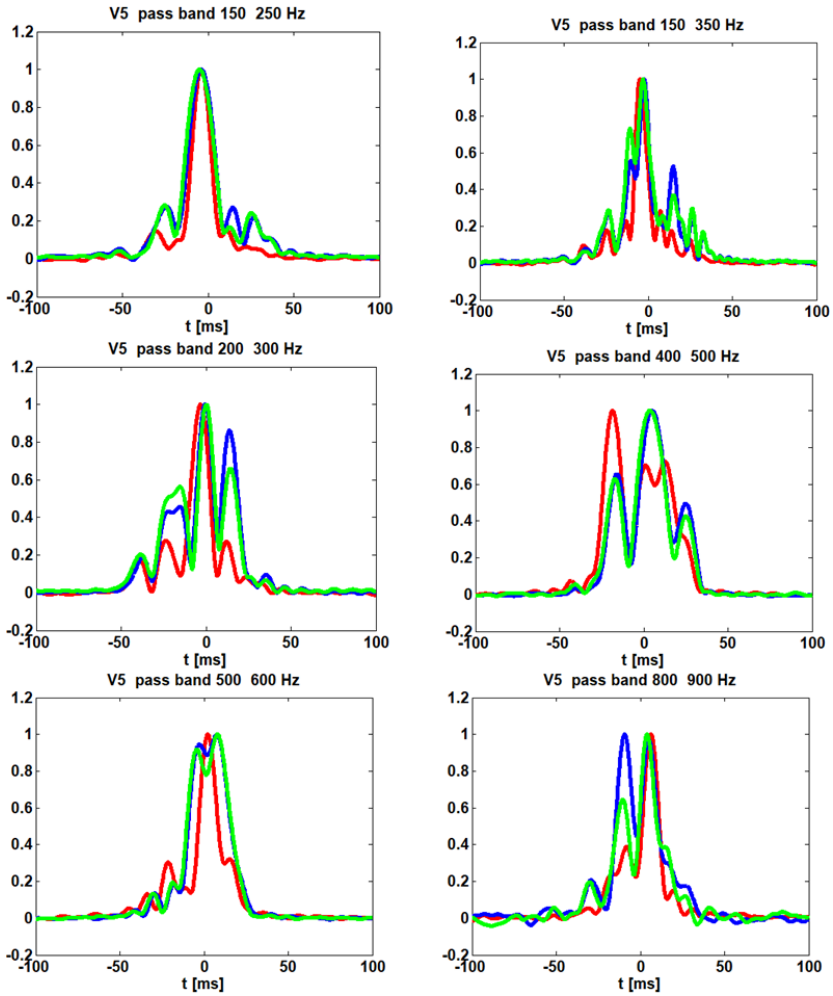

Figure 2. Reproducibility and dependency on analyzed frequency band. Lead V5, HFQRS shape. A healthy man, age 38 years, was measured. Red – the first measurement, blue and green – the second and third measurements, both 21 months after the first. Maximal amplitudes are normalized to one.

Table 1. The attenuation of HFQRSPW and HFQRSAmax with frequency according to models (1). Statistically significant differences exist between all groups, P<0.001.

	PW1 [dB per decade]	Amax1 [dB per decade]
Healthy	-48.1±3.7	-46.9±4.1
LBBB	-40.2±2.7	-39.1±3.8
HTP	-45.9±3.9	-44.7±4.3
CAD	-43.2±5.0	-41.8±5.4

Based on envelope properties, the minimal analyzed ECG passband should be 100 Hz, as for a good shape of HFQRS we need a frequency bandwidth of at least 50 Hz. The maximal analyzed passband is not limited, but considering the attenuation of HFQRS signals with frequency, the increasing of passband may contribute primarily to noise and not to better description of HFQRS shape. There must be some optimum between minimal and maximal ECG frequency. When the analyzed ECG passband is from f1 to f2 frequency, the attenuation (dBK1) of signals with frequency f2 relative to signals with frequency f1 is:

dBK1=log (f1/f2)*Amax1

The dBK1 in the case of ECG passband <50; 150> Hz is about -20 dB, in the case of <500; 600> only -3 dB and in the case of <500; 1000> about -12 dB. Supposing this attenuation and the required passband, the f1 frequency should be higher than 100 Hz. Such a level also preserves better elimination of slower changes in the action potentials and the analyzed HFQRS signal is not distorted by repolarization. The recommended late potentials passband is <40; 350> or <25; 250> Hz [4]. The high-frequency signals are attenuated about 40 dB relative to

signals near f1 with low frequency f1 and may be overlapped. There may be some debate as to whether such a low frequency f1 is really required.

Signal-to-noise ratio (SNR) decreases with increasing f0 and accumulation is needed. An increase of SNR corresponds to the square root of N, where N is the number of accumulated beats. In our data, there were more than 400 regular beats in any measurement and the corresponding increase of SNR was more than 20 dB. Different noise levels in groups of subjects (Fig. 1) result primarily from different conditions of measurement (length of measurement, surroundings…) for which reason they will not be further discussed.

Significant differences exist in HFQRS amplitude and power attenuation with frequency between groups of subjects, $P<0.001$. Attenuation represented by PW1 and Amax1 parameters may have a diagnostic contribution, but more detailed analysis will be needed. Differences of PW1 and Amax1 between groups are significantly higher than differences of HFQRSPW and HFQRSAmax for any frequency band. Parameters PW1 and Amax1 analyze the frequency dependency over a large frequency band which makes them more credible than a parameter based on the ratio of amplitudes analyzed in two frequency passbands. Moreover, the urge of choice of these two frequency passbands is not needed [9].

The HFQRS width is nearly independent in the frequency range 150-1000 Hz. The higher width in low frequencies is given partly by definition based on integral, by filter response and by the high level of dBK1. The HFQRS shape in passband <50,150> is distorted.

HFQRS shape reproducibility and dependency on analyzed passband was presented by 3 repeated measurements on one healthy subject. Significant differences exist in HFQRS shape if different passbands are used. Some shape dependency on the analyzed passband may be seen in all subjects and was presented by time-frequency analysis of the QRS complex [10]. There is no physiological explanation and this is an important task for the future, because the lack of an explanation is a limiting factor for the theory of the Reduced Area Zone (RAZ) [5] and all other theories based on HFQRS shape.

6. Conclusion

HFQRS power and maximal amplitude are linearly attenuated with frequency in the log scale. Attenuations differ significantly between groups of subjects ($P<0.001$) and may be used as a clinical parameter in the future. Maximal attenuation is seen in healthy subjects, minimal in LBBB patients. The level of attenuation is usually higher than 40 dB per decade; such a level limits high-frequency signals if the analyzed passband starts below 100 Hz. The reproducibility of HFQRS shape and significant dependency of HFQRS shape on the analyzed passband was presented on one subject. The HFQRS shape dependency is a task for the future, as it may explain some problems concerning the validity of published clinical markers.

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Address for correspondence.
Josef Halamek
Institute of Scientific Instruments of the CAS
Kralovopolska 147, 612 64 Brno
Czech Republic
josef@isibrno.cz