From 2D to 4D in Quantitative Left Ventricle Wall Motion Analysis of Biplanar X-Ray Angiograms

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Abstract

Accurate assessment of regional myocardial function after infarction is a challenging task in biplanar X-ray cineangiography. An estimate of motion is given by tracking contours of the left ventricle (LV) in projection images. In conventional clinical practice, LV wall motion analysis is done in 2D, based on end-diastolic and end-systolic contours. Our work, by contrast, presents novel methods for analyzing left ventricular motion in 4D, making possible the evaluation of myocardial function in any region of the ventricle rather than at artificial boundary areas in the projection image.

4D LV models are reconstructed from a biplanar image sequence. The centerline and radial method, originally developed for analysis in 2D, are extended to 3D for assessment of cardiac motion based on our 4D ventricular model. Color-encoded ventricle models and 2D maps of heart wall dynamics are developed for visualization. Results obtained by using the methods presented herein are in correspondence with clinical findings.

1. Introduction

Interventional X-ray angiography is state of the art in diagnosis and treatment of cardiovascular diseases. To diagnose viability of myocardium after infarction, for instance, X-ray images of the left ventricle are acquired with biplanar cineangiography equipment. A major drawback of the underlying imaging modality is the loss of 3D information, as objects are projected onto a 2D image plane. Consequently, only motion of the outer ventricular shape is visible in the images.

In clinical practice, quantitative left ventricle analysis is based on end-diastolic and end-systolic contours. For wall motion analysis (WMA) in 2D, several methods have been developed in the past [1, 2, 3]. But as no 3D information is available, myocardial function is only assessed at the ventricular boundary area projected to the image. This work, however, illustrates how myocardial activity can be evaluated in 4D based on 3D models of the LV evolving in time.

2. Material and methods

2.1. Data

Angiography data is recorded with a Siemens BICOR system, capturing 8-bit gray level images of size 512x512 pixels at a frame rate of 25fps. A 4D model of the contracting ventricle, reconstructed from a biplanar image sequence, provides the basis for quantitative analysis of LV wall motion.

2.2. LV model reconstruction

Accuracy of X-ray image acquisition is affected by pincushion distortion and spiral distortion [4]. Thus, distortion correction is performed prior to segmentation and reconstruction, based on an approach using control points obtained from a reference image. For semi-automatic segmentation, statistical shape models of the LV are deduced from a set of expert-segmented images [5]. Principle Component Analysis (PCA) of the shape model determines a circumferential region of interest where the contour of the LV is most likely detected.

A 3D LV contour model is reconstructed slice-by-slice from biplanar images. The algorithm [6] utilizes contour information obtained from segmentation to define the location of X-ray attenuation profiles of the ventricle, see Figure 1. Reconstruction of a ventricular cross-section is based on deformable models [7]. A parametric super ellipse is deformed using three outer and three inner parameters to fit the projection profiles of the LV. The quality of the fit is controlled by a least squares cost function.

In 40ms intervals the intermediate states of the heart are reconstructed. From this data set, a continuous parametric 4D model of the contracting ventricle is derived. An

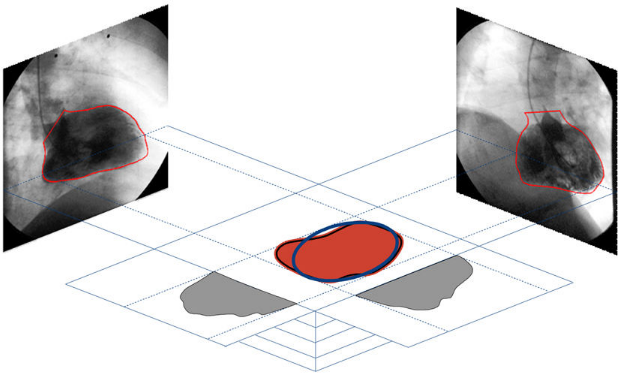

Figure 1. 3D LV reconstruction approach.

adapted version of the iterative closest point algorithm establishes correspondence between model points. Movement of a point from ED to ES in space is approximated using cubic spline interpolation.

2.3. Quantitative motion analysis

Two analysis methods, originally developed to quantify wall motion in 2D, are extended for evaluation of the newly developed 4D model.

The radial method [2, 3] interprets myocardial motion as contraction towards the ventricular center. In our implementation, the 3D centroid of the ES model is defined as the contraction center. From this center, rays are emitted and intersected with ED and ES models, see Figure 2. Aligning the rays to coincide with ED model points reduces computation time since only intersection with the ES model has to be found. The distance between an ED model point and its corresponding ray model intersection point is normalized and measured as the extent of wall motion.

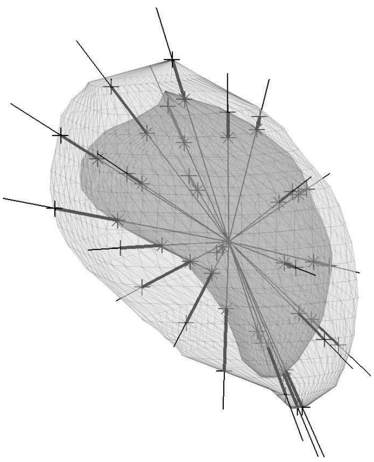

Figure 2. 3D radial motion analysis.

The centerline method [1, 3] assumes that the contraction of the ventricle is orthogonal to its surface. In the 2D approach, motion is measured along 100 chords drawn orthogonally to the centerline of the ED and ES contour. Accordingly, a "centerline model" is required for WMA in 3D. The points of this model are found by calculating the center of the lines from ED points to their corresponding ES points. At each centerline model point, the surface normal is determined and intersected with the ED and ES models. The distance between the ED intersection point and the ES intersection point is normalized and measured as the extent of wall motion, see Figure 3.

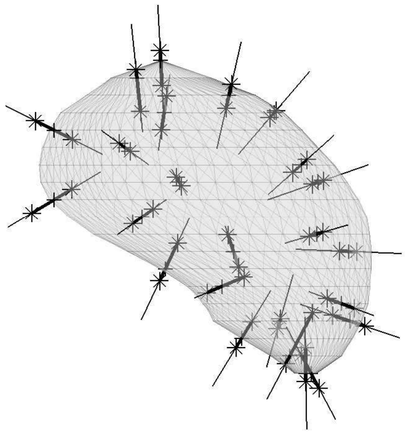

Figure 3. 3D centerline motion analysis.

A third method, additionally applied to radial and centerline analysis, quantifies wall motion based on point trajectory. The Euclidean distance covered by a model point during ED to ES transition is measured as the extent of wall motion. In contrast to the first two methods, motion is evaluated for the full contracting phase since data of intermediate heart states is incorporated.

The diagnostic value of a model point obtained from a WMA method provides the basis for clinical interpretations. For classification into hypo-, hyper- and akinetic motion, thresholds have to be defined by medical experts based on detailed patient studies.

2.4. Visualization of heart wall dynamics

The complex LV motion pattern in 4D makes it difficult to assess myocardial function visually. This implies the use of advanced visualization techniques. Color-encoded ventricle models, for example, are obtained by projecting the extent of wall motion activity to color space and thus highlight areas of low and high contraction. In order to provide a quick and more compact view of heart wall dynamics, results of WMA are presented as 2D maps.

The color-encoded ventricular surface is projected to the 2D map by utilizing an ellipsoid as an intermediate model. The ellipsoid is translated to coincide with the ED centroid. Eigenvectors obtained from PCA represent its preferred 3D orientation. The length of the three ellipsoidal axes is found by minimizing the sum of squared distances of LV model points and their corresponding points on the ellipsoid. Once the ellipsoid optimally fits the 3D LV shape, color information obtained from WMA is projected onto its surface and then projected to 2D.

3. Results

4D LV models of 10 patients were reconstructed and both radial and centerline motion analysis were performed. Results of WMA were visualized on the 3D surface model and as complementary 2D color wall motion maps. Figure 4 shows the color-encoded ventricle model of one patient from two different views after 3D centerline WMA, with dark colors highlighting the areas of low contraction. The corresponding 2D map is presented in the upper left part of Figure 5.

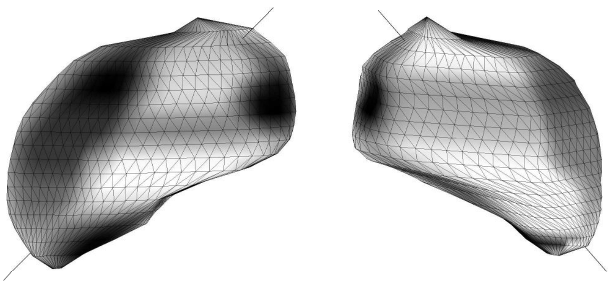

Figure 4. Color-encoded heart wall dynamics.

Results of 3D centerline and 3D radial method were compared. The diagnostic values obtained from a WMA method were normalized to $[0, 1]$, with zero defined as the lowest contraction. Spatial distribution and frequency of WMA values were investigated based on 2D maps and histograms, respectively. An example is shown in Figure 5. In seven of ten cases, areas of low and high contraction identified by the centerline method were in accordance with areas found by the radial method. The corresponding histograms showed only minor differences.

Further comparisons of 3D analyses with both clinical findings and 2D WMA results, obtained from Siemens QuantCor system currently used for diagnosis, showed good correspondence.

The 2D maps of heart wall dynamics provide a more compact view than color-encoded LV models. To improve orientation, anatomical information, for example ventricular regions or coronary vessels, will be integrated in future.

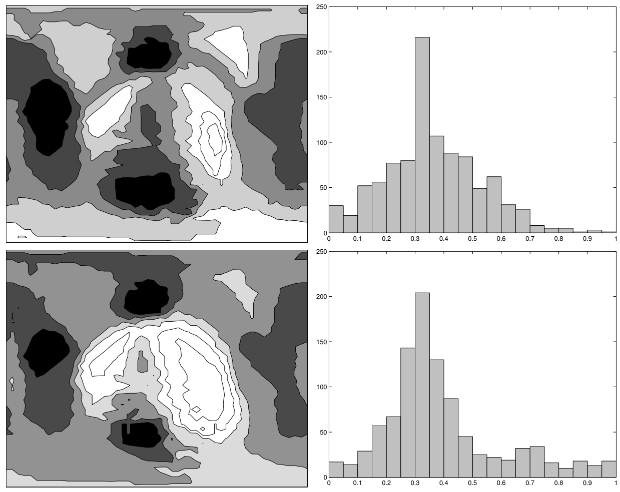

Figure 5. 2D color wall motion maps and histograms of 3D centerline WMA (top) and 3D radial WMA (bottom).

4. Discussion and conclusions

In this paper we illustrated the application of 4D LV models for quantification of wall motion analysis in biplanar X-ray angiography. Presented algorithms show accurate results for both model reconstruction and quantitative analysis. The newly developed methods overcome limitations of original image data: myocardial function is quantifiable in any region of the ventricular surface rather than at artificial boundary areas in the projection image. The 4D models enable physicians to visually inspect ventricular shape and function in 3D and offer an improved visualization for cardiac diagnosis. Compared with image analysis in 2D, more information is gained from raw angiography data.

In quantitative 2D left ventricle analysis, LV motion of a patient is often referred to non-pathological motion data. This aspect still has to be taken into account for the proposed analysis methods. Collection of non-pathological ventriculographic data is already in progress. Statistical three-dimensional LV motion data is not available and thus has to be derived from this data set. Subtraction of normalized motion pattern from patient LV motion pattern may be based on developed 2D projection maps.

Future work will further focus on incorporating data from X-ray images showing coronary vessels, acquired complementary to ventriculograms. Algorithms for reconstruction of a 3D coronary tree model are currently under development. Assuming that the LV and the coronary tree model are registered, evaluation of myocardial wall motion in relation to supplying vessels becomes feasible. Information thus obtained provides valuable feedback for cardiac diagnosis and is hardly extractable from raw image data.

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References

[1] Sheehan F, Bolson E, Dodge H, Mathey D, Schofer J, Woo H. Advantages and applications of the centerline method for characterizing regional ventricular function. American Heart Association Circulation 1986;74:293–305.

[2] Ingels N.B. J, Daughters G, Stinson E, Alderman E. Evaluation of methods for quantitating left ventricular segmental wall motion in man using myocardial markers as a standard. American Heart Association Circulation 1980;61:966–972.

[3] Gelberg H, Brundage B, Glantz S, Parmley W. Quantitative left ventricular wall motion analysis: A comparison of area, chord and radial methods. American Heart Association Circulation 1979;59:991–1000.

[4] Toennies K, Oishi S, Koster D, Schroth G. Accuracy of distance measurements in biplane angiography. In Proc. SPIE, Medical Imaging 1997: Image Display, volume 3031. 1997; 19–30.

[5] Carpella M. Model-based segmentation of cine-angiograms. Master's thesis, Medical Software Engineering, University of Applied Sciences Hagenberg, Austria, June 2004.

[6] Backfrieder W, Carpella M, Swoboda R, Steinwender C, Gabriel C, Leisch F. Model based lv-reconstruction in biplane x-ray angiography. In Proc. SPIE, Medical Imaging 2005: Physiology, Function, and Structure from Medical Images, volume 5747. 2005; 1475–1483.

[7] Metaxas D. Physics-based deformable models: Applications to computer vision, graphics, and medical imaging. Kluwer Academic Publishers, 1996.

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