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Computing of Right Ventricle Volume using Orthogonal Contours

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Introduction

Computing of the right ventricle volume is important in the assessment of various heart diseases. The right ventricle is a retrosternally located, asymmetric, of irregular geometric form. Non-invasive evaluation of right ventricle function has remained challenging despite technological advancements and extensive clinical research [1, 2]. However, there is a growing demand for accurate and reproducible measurements of right ventricle function as numbers of patients with grown up congenital heart disease, acute and chronic pulmonary abnormalities, pulmonary hypertension of various aetiology and right ventricle infarction are increasing. Different invasive and non-invasive [3] methods could be used for the characterization of the right ventricle functional status. Being the gold standard, cardiovascular magnetic resonance imaging (CMR) is considered the reference method in assessing accuracy of novel imaging techniques [4, 5]. Cardiac computed tomography (CCT) provides acceptable estimates of the right ventricle volume as well [6]. The techniques which based on active shape model [7, 8], multi-atlas approach [9], triangulation [10], motion model [11], medial axis [12], etc. are used to segment ventricle region and estimate ventricle volume in CMR and CCT images.

In this paper we are continuing another approach for computing right ventricle volume [13]. By using three critical contours we generated ventricle surface and computed its volume.

Methodology

The volume of right ventricle was computed using ventricle model. Such model was automatically generated using critical contours in orthogonal planes, which were manually positioned on in-between ventricle model. Such model was automatically generated using manually segmented ventricle regions in CCT slices (Fig. 1).

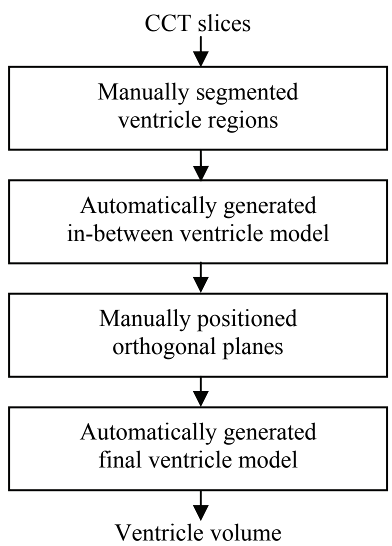


Fig. 1. Methodology for generating ventricle model and computing its volume

Orthogonal planes should meet such requirements:

1. Planes should intersect to reflect basic anatomical parts of the right ventricle.
2. Planes should form system of axes for the ventricle. This system of coordinate system axes should be uniform for all anatomical ventricle variants or its changes should be easily detected.
3. Ventricle images in above mentioned planes should be easily acquired by general imaging methods.

Generation of in-between ventricle model

The in-between ventricle model was generated by using algorithm in Fig. 2. Data sampling, smoothing and triangulation were applied in [15].

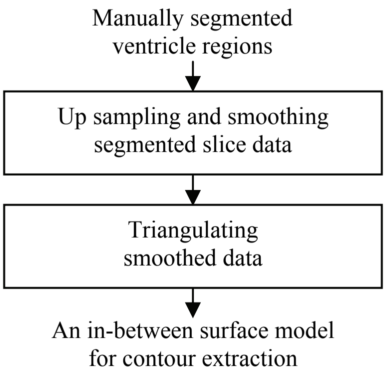


Fig. 2. Methodology for generating ventricle model and computing its volume

Generation of ventricle model

The final ventricle model was generated by using algorithm in Fig. 3.

Fig. 4 shows the manually segmented ventricle region in CCT slice (a), reconstructed volume using set of segmented slices (b) and generated in-between ventricle model using such set.

The input data for this algorithm is the set of critical contours (Fig. 5, c). Such contours are intersections of in-between ventricle model surface and manually positioned orthogonal planes (Fig. 5, d). We defined three orthogonal planes for extraction of critical contours:

1. Four chamber plane (Fig. 5, a). The following are the anatomical landmarks of the four chamber plane. This plane traverses all cardiac chambers in a way that all cardiac chambers are in their maximum cross-section area. Also, it traverses apices of both ventricles and atrioventricular valves at their maximum diameter;
2. Transverse (short axis) plane (Fig. 5, b). This plane is perpendicular to four chamber plane, the former crosswise traversing both ventricles at the same level. This level is from the tricuspid valve at the distance of 1/3 of whole right ventricular long axis;
3. Lateral plane (Fig. 5, c). This plane is perpendicular to four chamber plane as well. This plane intersects at three points of the right ventricle: tricuspid valve, right ventricular apex and pulmonary artery valve. The plane traverses both valves at their maximum diameter.

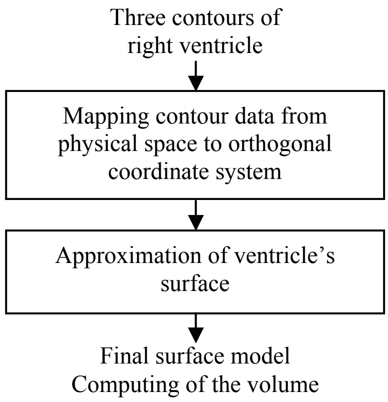


Fig. 3. Methodology for generating ventricle model and computing its volume

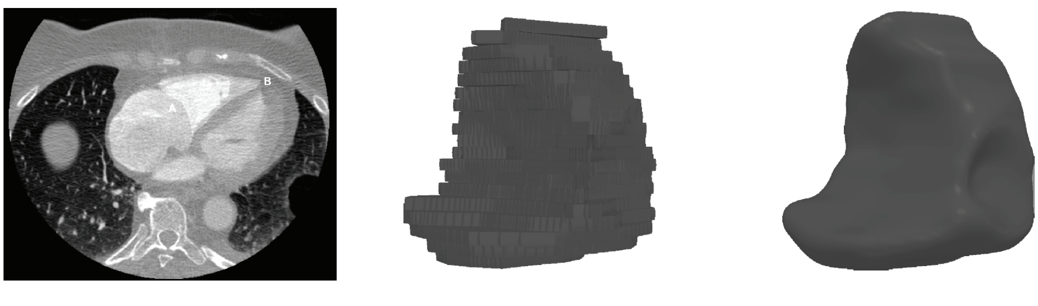
Three surfaces were obtained with following algorithm. Three contours subdivide models space into 8 sections. Each section surface was computed following same procedure.

Two of the section contours stays fixed and one is dragged perpendicularly to the others. It is adjusted according to the fixed contours. If x_1, x_2 and x_3 are coordinates of the contour points and dx_1 is a single moving contour step, then point coordinates at step $k + 1$ are given by equations:

$$\begin{cases} x_1^{k+1} = \sum_{k+1} \mathrm{dx}_1, \\ x_2^{k+1} = f(\Theta)dx_2 + x_2^k, \\ x_3^{k+1} = f(\Theta)dx_3 + x_3^k, \\ \Theta = \tan^{-1} \dfrac{x_3^k}{x_2^k}, \end{cases} \quad (1)$$

where $f(\Theta)$ – weighting function, dx_2 and dx_3 step change in guiding contours.

The ventricle volume was computed using arithmetic mean of three volumes of surfaces based on each critical contour.



a) b) c)

Fig. 4. Generating of in between ventricle model: a – manually segmented ventricle region [14] in CCT slice (A – ventricle base, B – ventricle apex), b – reconstructed volume using set of segmented regions, c – generated in-between model

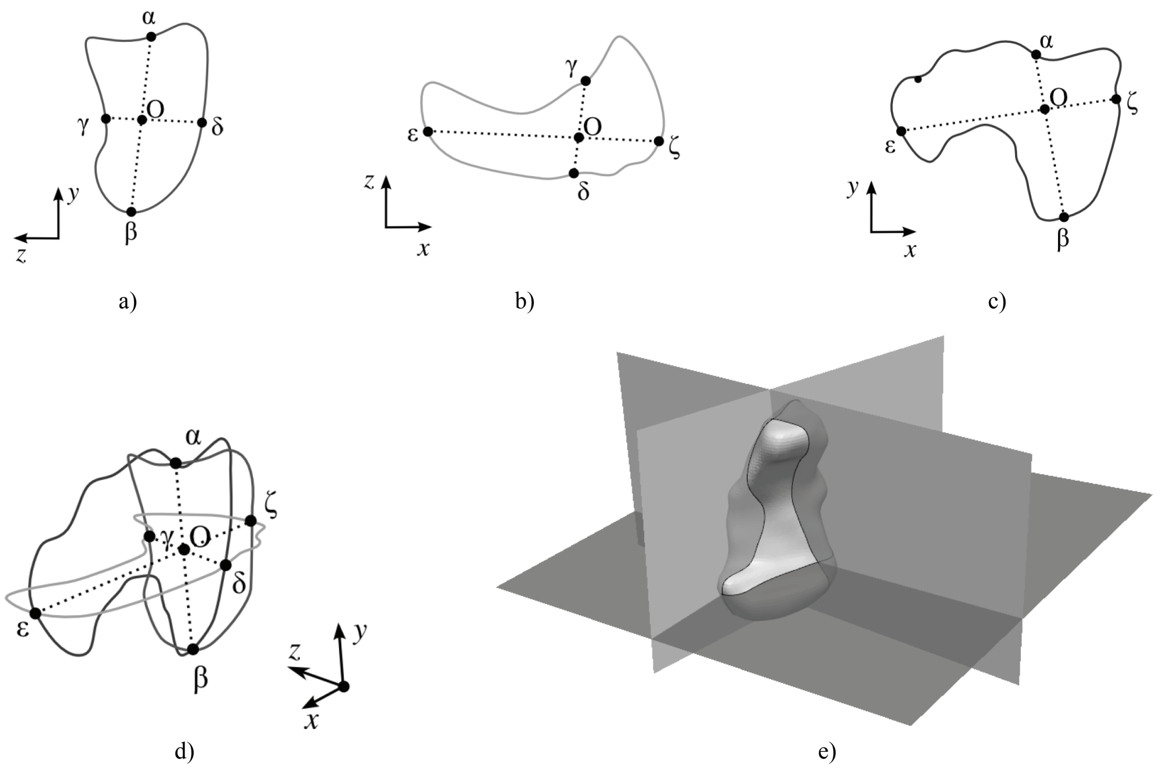


Fig. 5. Manually positioned orthogonal contours using automatically generated in-between model: a – contour in four chamber plane, b – contour in transverse (short axis) plane, c – contour in lateral plane, d –contours position in 3D space, e – visualization of in-between model surface, positioned orthogonal planes and critical contours in them

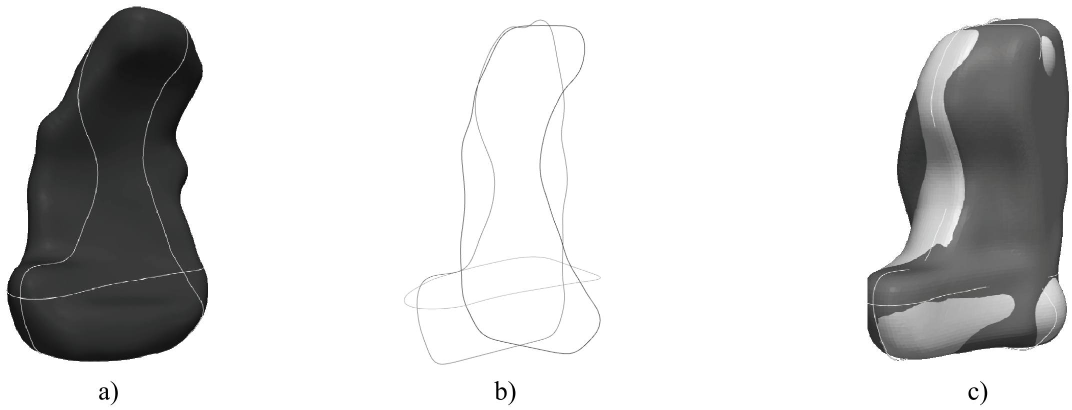


Fig. 6. Generating final ventricle model: a – in between ventricle model with critical contours, b – critical contours in 3D space, c – generated final model using critical contours (light grey colour represents model generation based on contour in four chamber plane, dark grey colour – generation based on contour in lateral plane)

Experimental testing

CCT images were acquired according to standard protocol with ECG gating resulting in raw images dataset of one cardiac cycle. Raw data was reconstructed in axial plane and cardiac cycle was divided into 10 phases (multiphase image series). Depending on right ventricular dimensions each cardiac phase consisted of 18-22 axial slices. Each tomogram was 512×512 pixel size, thickness of 0.3-0.6 mm and interslice gap of 5 mm.

During research two volumes (diastolic and systolic) were calculating for patients manually and using generated ventricle model.

The percent error between computed volume using generated ventricle model and manually segmented ventricle regions was not more than 13 % of diastolic volume and 16 % of systolic volume.

Conclusions and discussions

This paper presents semi-automated methodology for computing of right ventricle volume using critical contours. The positive results of percent error shows the viability of generating ventricle model from three contours using special positioned orthogonal planes. Such planes were four chamber, transverse and lateral planes.

The improvement of percent error could be developed techniques for automatic segmentation of ventricle region in CCT slices and automatic positioning of orthogonal planes using in-between ventricle model. In addition the usage of one or two extra contours in-between model would improve quality of volume computation.

The special application of proposed methodology is echocardiographic imaging. By selecting right planes for transducer probe it is possible to generate ventricle model for computation diastolic and systolic volumes. Such computations will let to reduce pacent examination cost by using less expensive imaging technologies and avoid not necessary dose of ionising radiation or influence of electromagnetic energy.

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This paper presents semi-automated methodology for computing of right ventricle volume using ventricle model, which is generated using three critical contours in orthogonal planes: four chamber, transverse and lateral planes. Such orthogonal planes were positioned using in-between ventricle model, which is generated using segmented ventricle regions in CCT slices. The achieved positive results of percent error show the viability of using generated ventricle model. Ill. 6, bibl. 15 (in English; abstracts in English and Lithuanian).

A. Ušinskas, M. Paulinas, M. Meilūnas, M. Matačiūnas, D. Zakarkaitė, I. Zeleckienė, A. Laucevičius. Dešiniojo skilvelio tūrio apskaičiavimas taikant ortogonalius kontūrus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 9(115). – P. 83–86.

Straipsnyje pateikiama metodika dešiniojo širdies skilvelio tūriui apskaičiuoti. Pusiau automatiškai apskaičiuojama tūrio vertė gaunama iš trijų kritinių kontūrų, esančių tokiose ortogonaliose plokštumose: keturių kamerų, skersinėje ir šoninėje plokštumoje. Šios plokštumos nustatomos tarpiniame skilvelio modelyje, gautame iš segmentuotų skilvelio sričių kompiuterinėse tomogramose. Pasiekti teigiami rezultatai rodo, kad metodika tinka skilvelio tūriui apskaičiuoti taikant sukurtąjį modelį. Il. 6, bibl. 15 (anglų kalba; santraukos anglų ir lietuvių k.).