Assessing the Wall Motion of Pulmonary Veins of the Left Atrium

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Abstract

Atrial fibrillation is caused by some excited cardiac myocardium re-stimulated by the recurrent impulse that made the left atrium contraction irregularly. The changes of cardiac patterns could be recorded by the CT scan of the multi-slices and multi-frame technology. The abnormal rhythmic wall motion can be analyzed between the systolic of atrium and diastolic of atrium. This study has developed a 4D cardiac image analysis tool to extract atrial wall motion information. Twenty set of 4D CT cardiac images have been tested with the developed program. The motion of interested area could be evaluated with the vector in 3D with magnitude and phase angles. From the statistical analysis of motion vector over root area of four pulmonary veins, the right inferior pulmonary vein has shown abnormal motion significantly.

1. Introduction

This paper is to report the development of 4D cardio-images analysis program and the successful assessing atrial volume and motion of all pulmonary veins and atrium using Multi-Slice Computer Tomography (MSCT) cardiac images non-invasively. Patients with atrial fibrillation (AF) may have the deficiency of ejecting remaining blood into left ventricle after p-wave of ECG. It was hypothesized that the electrical activity arising from myocardial sleeve of pulmonary veins (PV) can trigger AF. However, the role of the sphincter function of these fibers in generation of AF remains to be elucidated.

The treatment for AF patient normally underwent ablation to block the electrical conduction pathway to minimize the extra electrical activity. The improvement of ejection fraction (EF) in left atrium can be consistent with the successful treatment of atrial ablation. To determinate the volumes change of the diastolic phase and the systolic phase of left atrium. The return of regularly atrial function can be evaluated using cardio images. [1-5] From the process and reconstruction of 4D cardiac images, the volume of atrium can be carefully estimated, if one is able to delineate the pulmonary veins and mitral valve in 3D configuration. For left atrial ejection fraction the end diastolic volume of left atrium was at the 30% time of R-R interval. And, the end systolic volume was at the 90% time of R-R interval. Please see Figure 1 for detail illustration. Through the reconstruction and volume extraction and ejection fraction calculation process, one may also process the dimension of superior and inferior pulmonary veins. In this way, one may study if the sleeve of pulmonary veins has an important role that contributes to the atrial fibrillation. One may further study the motion of myocardium adjacent to the pulmonary veins before and after AF ablation. Thus, the more effected method of evaluation the function of left atrium non-invasively using CT cardiac images becomes important.

2. Methods

A self-developed program with a user friendly interface was integrated as a image processing tool for analyzing 4D cardio CT image data set. The program was developed in visual C++ 6.0 that runs on window XP operating system. The 3D reconstruction and the atrial function analysis were able to use a minimal user interface in extracting the contour information.

The CT images were recorded in DICOM format. The cardio images data set at two distinctive time will be reading into the processing system. Then, a 3D cardio image will be reconstructed and displayed for inspection and further process. Two set of 3D cardio image (at ECG gated 30% time and 90% time, see Figure 1) will be registered using the rib bone as reference. The two set of images were aligned with the minimum difference of rib bone images. After the registration process, the two set of cardio images were ready for image re-sampling to extract the atrial contour. The atrial contour information will be used in the reconstruction of 3D wire mesh view display, volume calculation and wall motion. The flow

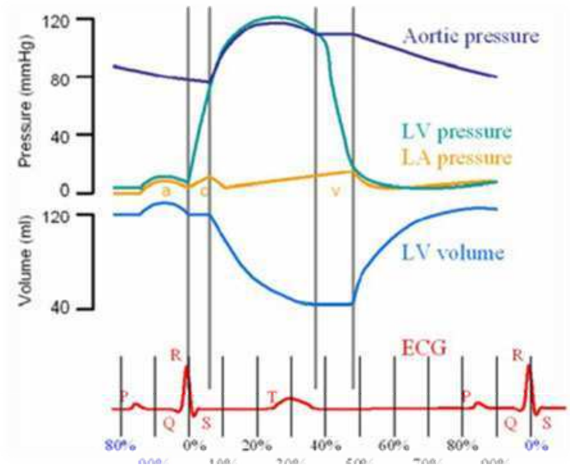

Figure 1. The R-R interval in relation to the percentage of cardiac cycle.

chart of process was illustrated in Figure 2. Twenty sets of cardio 4D images were used in this study with patients' consent.

The atrial contour was extracted using guided active contour method. [7-8] In this study, the atrial volume of two distinct time frames in a heart cycle was evaluated. One was at 30% of heart cycle which was at the end of systole of left ventricle. And, the other one was at 90% of heart cycle which was at the end of diastole of left ventricle. For each patient, there are more than 600 frames of CT gated cardio-images in one data set for processing. The processing flow chart is illustrated in Figure 2. The self-developed image analysis program will read in the data set, for example, the data set at 30% of heart cycle. And, the program will reconstruct 3D volume of heart. Then, using a cutting plane as reference, one may re-sample images for accurately cutting at the root of 4 pulmonary veins from the atrium and set the boundary (as shown in Figure 3 and Figure 4). Then, the user may select few slices of CT image as the seed to make a starting delineation. The self-developed heart function evaluation program will be starting to delineate the completed data set using given active contour method and seeded regional growth to delineate the atrial contour. A cubic spline procedure was performed to better fitting the atrial contour.

The method of active contour is to calculate the minimal cost function to determine the delineated contour and the edge of image. [6-7] In the case of endocardial atrial chamber, the cost function of E_{snake} is integrated from the weighting product of internal energy and the weighting product of external energy. The internal weighting, $w_i = 0.3$, in this process is set to 0.3. And, the external weighting, w_e, in the process is set to 0.5. Patients with suspected AF normally underwent an ECG-gated, multi-detector computed tomography (MDCT) before or after the ablation. The objective of the program is to obtain the dimension and wall motion at ostial areas of four pulmonary veins (PVs). The volume of atrium (LAV) obtained at the end-diastolic phase (ED) and end-systolic phase (ES) of left atrium (LA). The paradoxical dilatation of PV might indicate the poor sphincter function of PV area (PVA) [1]. The wall motion of the atrium at the root of four pulmonary veins will be calculated from the normal vector of surface between two timings of cardiac cycle. The resulting vector will be representing by the magnitude and phase. The program will calculate the dimension of the PVs area (PVA) at ED and will compare the dimension PVA at ES. The contractility of PV was defined as (PVA ES-PVA ED)/PVA ES. The atrial ejection fraction (EF) is defined as (LAV ED – LAV ES)/LAV ED. It will be calculated from the reconstructed atrial 3D volume representation.

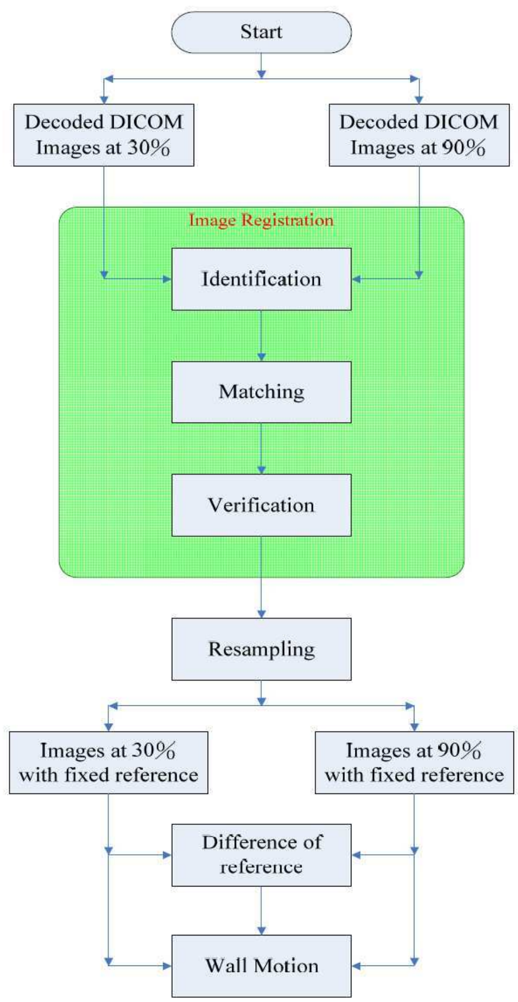

Figure 2. Processing Flow Chart

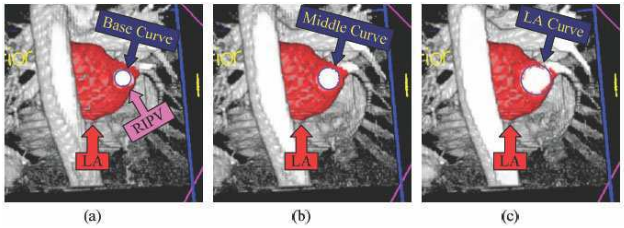

Figure 3. Cutting the plane pulmonary vein.

The red color is the atrium and white color is pulmonary vein shown with arrow. The first cut plane was shown in (a). The second cut plane was cut at 1mm away from atrium (b). The third cut plane was 1mm further away from second cut plane.

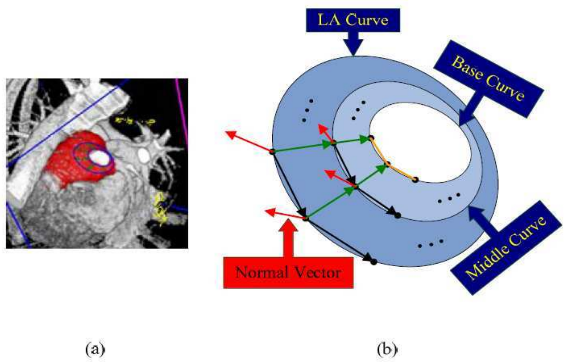

Figure 4. Illustration of the procedure for finding the motion vector at the root of pulmonary vein.

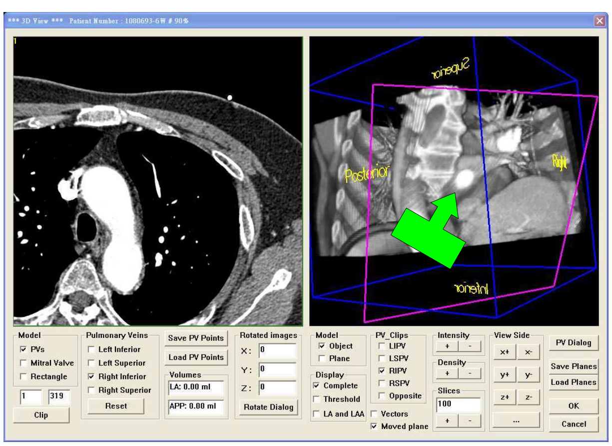

Figure 5. Illustration of the user interface and result.

The left panel shows the 2D cut plane image of purple cut plane in the right panel. The right panel is the 3D reconstruction of cardiac volume.

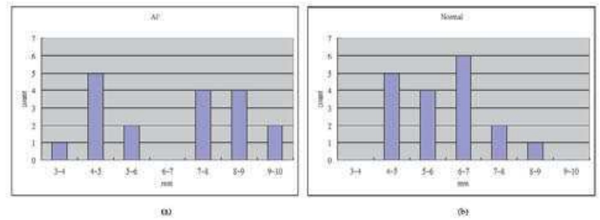

Figure 6. The histogram of wall motion magnitude at the root of pulmonary veins.

The left panel was showing the data from AF patients. The right panel was showing the data from subject without AF symptom.

3. Results

The procedure of the program will be, first, reconstructing the 3D volume of heart. Then, a cut plane method is utilized to accurately delineate the 4 pulmonary veins and set the boundary at mitral valve for the left atrial contour extraction. The delineated information can be mapped onto the original CT images. The contour information will be re-sampled for the reconstruction of wire-mesh display. Then, the atrial volume and the dimension of pulmonary veins can be accurately assessed. The efficiency and accuracy of the developed method was reported previously. [8] The user interface and process result was illustrated as in Figure 5.

In result, twenty sets (20 patients) of MSCT cardiac images were acquired at 30% and 90% of RR interval. One set of images was excluded for its poor quality for analysis. The left atrial volume, the dimension of PV and the wall motion at root of pulmonary veins were evaluated.

This report will be concentrating on the discussion of atrial wall motion at the root of pulmonary veins. The data was divided into two groups. Group I included 11 patients (mean age 56±11 years) with drug refractory paroxysmal AF. Group II included 8 patients (mean age 57±14 years) without any history of AF. The wall motion of four pulmonary veins of two group's patients was examined at ED and ES. The previous result shows that the paradoxical dilatation of PV was indicating the poor sphincter function. [8] It was defined as the PV area (PVA) at ED was larger than that at ES. The wall motion at ostial areas of four PVs were obtained at the end-diastolic phase (ED) and end-systolic phase (ES) of left atrium (LA). The wall motion at the root of pulmonary vein was tallied and shown in Figure 6. For the patient without AF symptom, the distribution of movement was concentrated between 4 to 7 mm. For the AF patient, the movement was either small (< 5mm) or larger than 7 mm.

The distribution was at two extreme of spectrum. This indicated that the abnormal wall motion of AF patient.

The wall motion at PV ostial areas except left inferior PV was significantly larger in AF patients. The higher incidence of paradoxical dilatation at ED of right superior PV (82% versus 37%, p<0.05) and left superior PV (82% versus 43%, p<0.05) were observed in AF patients. In addition, poorer contractility of right superior PV was noted in AF patients (30% versus 1%, P<0.05). Whereas, the incidence of paradoxical dilation and contractility of right inferior and left inferior PV were similar between the two groups. However, the motion vector of left inferior PV did not show significant different between two groups, whereas, the motion at the inferior and posterior quadrant of right inferior pulmonary vein for the subject without AF symptom was significantly less than AF patient. See Table 1 for reference. This result is paralleling to the previous finding.

4. Discussion and conclusions

This paper is to report the development of 4D cardio-images analysis system that successfully assesses atrial volume and wall motion of pulmonary veins using multi-Slice CT (MSCT) cardiac images non-invasively. The procedure of the program will be, first, aligning the 3D CT images dataset, then, reconstructing the 3D volume of heart. A cut plane method is utilized to accurately delineate the 4 pulmonary veins and set the boundary at mitral valve for the left atrial contour extraction. The delineated information can be mapped onto the original CT images. The method of active contouring and seed region growth were implemented in the program for 3D atrial segmentation. The contour information will be re-sampled for the reconstruction of wire-mesh display. Using cut plane method, we were able to visualize and delineate intersection of the pulmonary veins. The volume of atrium was accurate estimated.

Acknowledgements

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Table 1. Comparison of magnitude of atrial wall motion at the root of pulmonary vein. (* indicate the significant different of two groups).

		Right Inferior Pulmonary Vein				Left Inferior Pulmonary Vein			
		Inferior	Anterior	Superior	Posterior	Inferior	Anterior	Superior	Posterior
AF Patient	Average	0.09	0.05	0.06	0.08	0.08	0.09	0.07	0.08
	SD	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.05
Patient without AF Symptom	Average	0.05	0.08	0.08	0.05	0.09	0.06	0.07	0.06
	SD	0.02	0.07	0.06	0.02	0.03	0.04	0.03	0.04
	t-Test (p value)	0.01*	0.31	0.28	0.01*	0.66	0.11	0.97	0.38