Assessment of Left Atrial Function Using Multi-Slice CT Images

WC Hu[1], MH Wu[1], HM Tsao[3], CC Lin[2],
LY Shyu[1], JJ Wang[4]

[1]Chung Yuan University, Chung Li, Taiwan, ROC
[2]Lunghwa University of Science and Technology, Taoyuan, Taiwan, ROC
[3]I-Lan Hospital, I-Lan, Taiwan, ROC
[4]I-shou UniversityI-Shou University, Kaohsiung, Taiwan, ROC

Abstract

The function of left atrium can be accurately estimated non-invasively using 4D CT cardiac images. A self-developed image analysis program will first reconstruct 3D volume of heart. Then, one may re-sample images for accurately deleting the 4 pulmonary veins from the atrium and set the boundary. With the prior processed information, the active contour methodology and seed regional growth methodology were implemented to delineate the atrial contour. With a calibration standard of 500 ml saline with contrast medium in bag, both methods were able to estimate volume within 5% of error. Thirty sets of patient's CT cardiac images that were acquired at 30% and 90% of RR interval. The dimension of pulmonary veins and the left atrial volume was evaluated. The contractility of pulmonary vein and the Ejection Fraction (EF) of atrium was calculated. The result shows that the left atrium with a larger volume will have a poor ejection fraction.

1. Introduction

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 return of regularly atrial function can be evaluated using cardio images. [1-6] The evaluation of atrial function is to determine the outcome of atrial ablation. [2] Therefore, to assess the outcome of atrial ablation non-invasively is to determine the change of volume at the diastolic phase and the systolic phase of left atrium.

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 in 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. 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. This abstract is to report the development of 4D cardio-images analysis program and the successful assessing atrial volume using multi-Slice Computer Tomography (MSCT) cardiac images non-invasively.

2. Methods

A self-developed program will be reading CT images in DICOM format. The program for reconstruction and analysis of atrial function is able to use a minimal user interface in extracting the contour information. The atrial contour information will be used in the reconstruction of 3D view and volume calculation. The program was developed in visual C++ 6.0 that runs on window XP operating system. 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

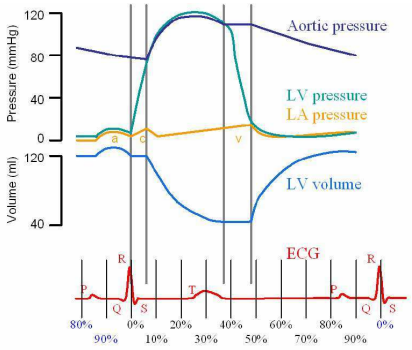

Figure 1. R-R interval in Relation to percentage of cardiac cycle.

was at 90% of heart cycle which was at the end of diastole of left ventricle (as shown at Figure 2). 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, one may re-sample images for accurately deleting the 4 pulmonary veins from the atrium and set the boundary (as shown in Figure 3). Then, the user may select few slices of CT image to make a starting delineation seeded. 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

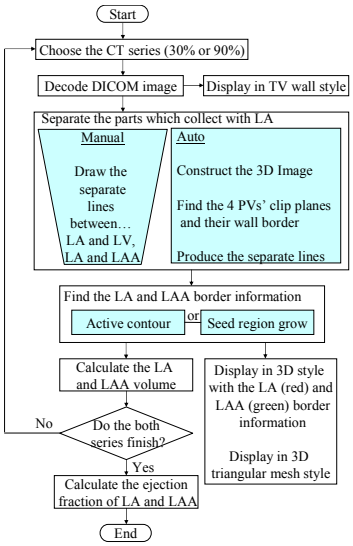

Figure 2. The flow chart for the self-developed program

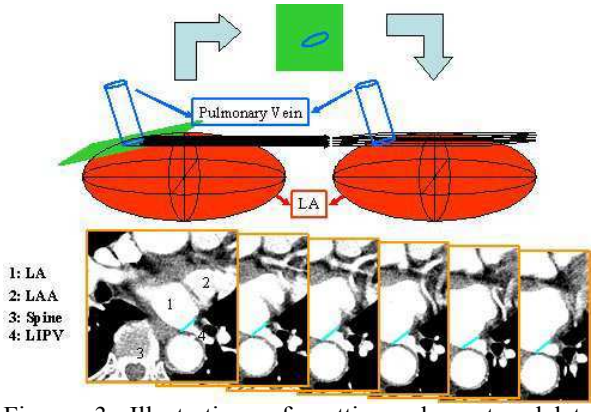

Figure 3 Illustration of cutting plane to delete pulmonary veins

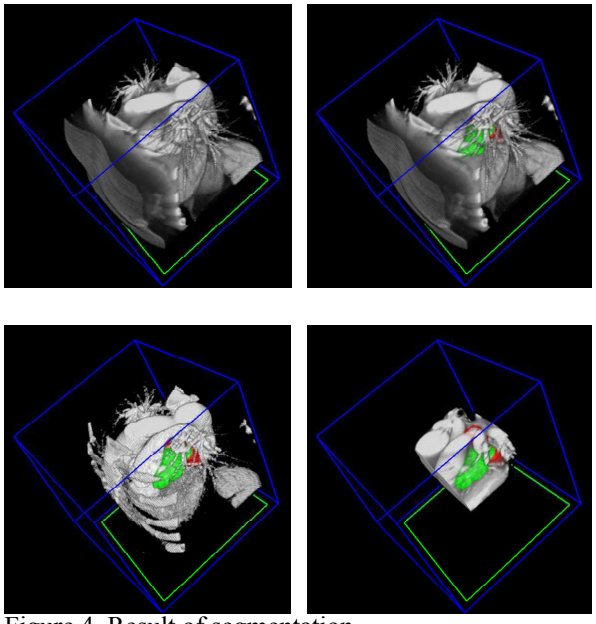

Figure 4. Result of segmentation
Upper left: reconstructed original cardiac volume
Others: result of segmented artrium and appendage.

delineate the atrial contour. A cubic spline procedures 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. [7-8] 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, 16-slice multi-detector computed tomography

(MDCT) before or after the ablation. The objective of the program is to obtain the dimension at ostial areas of four pulmonary veins (PVs) and 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 program will calculate the dimension of the PVs area (PVA) at ED and will compare the dimension VA 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 will be calculated from the reconstructed atrial 3D volume representation.

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 (as shown in Figure 3). 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. Then, the atrial volume and the dimension of pulmonary veins can be accurately assessed. The evaluation the accuracy of volume calculation of the developed

program was using a volume of 500 c.c and a volume of 470c.c. saline bag that was injected with contrast medium. The volume of saline bags was evaluated using the seeded regional growth and the active contour method as the contour extraction. The calibration result was showing table at right column. The accuracy of volume calculation using the self-developed program was within 5% different of actual volume.

Table 1 The dimension of pulmonary view at end systole and end diastole (* indicates P<0.05)

		Group I	Group II
RSPV	ES	2.64±1.33	2.38±0.81
	ED	3.23±1.74	2.38±0.89*
LSPV	ES	3.02±1.27	1.91±1.06 *
	ED	3.31±1.38	2.35±1.33*
RIPV	ES	1.97±1.25	1.19±0.51*
	ED	1.94±1.17	1.33±0.39*
LIPV	ES	1.99±0.78	2.01±1.04
	ED	2.36±0.97	1.94±0.79

For the efficiency and accuracy, the method of seeded regional growth was better than the active contour method for contour extraction. The methods of active contouring and seeded area growth for volume calculation were able to estimate volume within 5% actual volume. In result, thirty sets (30 patients) of MSCT cardiac images were acquired at 30% and 90% of RR interval. The left atrial volume and the dimension of PV were evaluated and the atrial Ejection Fraction (EF) was also calculated. We have also examined PVA and atrial volume of 30 patients in two groups at ED and ES of atrium. Group I included 22 patients (18 male, mean age 56±11 years) with drug refractory paroxysmal AF. Group II included 10 patients (8 male, mean age 57±14 years) without any history of AF. The preliminary result was shown in Table 1.

The dimension of four pulmonary veins of two group's patients was examined at ED and ES. The result shows that the paradoxical dilatation of PV indicating the poor sphincter function was defined as the PV area (PVA) at ED was larger than that at ES (Table 1). The ostial areas of four PVs were obtained at the end-diastolic phase (ED) and end-systolic phase (ES) of left atrium (LA). The result shows that the paradoxical dilatation of PV indicating the poor sphincter function was defined as the PV area (PVA) at ED was larger than that at ES. The PV ostial areas except left inferior PV were significantly larger in AF patients (see Table 1). 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.

The statistic for the dimension of the pulmonary veins shows that the two superior veins are larger than the two inferior veins (LSPV: 2.76±1.33mm^2, RSPV: 2.58±1.21mm^2, LIPV: 1.74±1.14mm^2, RIPV: 1.97±0.84mm^2, $p < 0.05$). This result is paralleling to the previous finding. The result also shows that patient with

	Actual Volume	Active Contour	Region Grow
Phantom 1 (ml)	500	519.68	514.39
Accuracy (%)	-----	96.06	97.23
Phantom 2 (ml)	470	462.12	455.76
Accuracy (%)	-----	98.32	96.92

		Phantom 1	Phantom 2
Active Contour (ml)	Triangular Geometry	519.68	462.12
	Secant	520.94	462.04
Region Grow (ml)	Secant	514.39	455.76
	Accumulate Pixels	519.16	461.66
	Mean	518.54	460.40
	SD	2.87	3.10

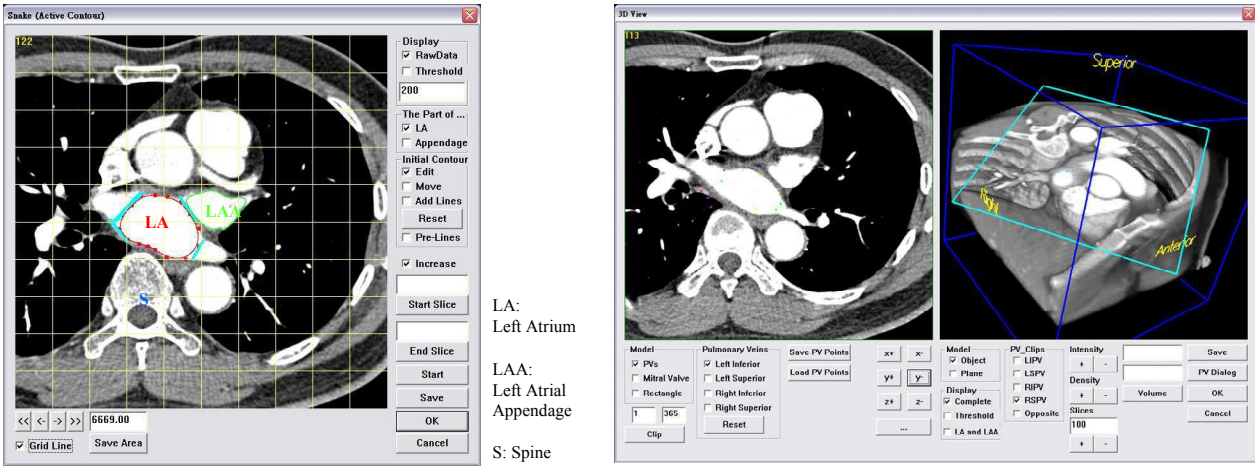

Figure 5. The result of image processing showing segmentation at left and cutting plane display at right.

AF, the ejection function is much lower than the control group (30.81±13.61% vs 36.69±19.95%, $p < 0.05$).

4. Discussion and conclusions

In this report, we have shown that the self-developed program, first, reconstruct 3D volume of heart. Using cut plane method, we were able to visualize and delineate intersection of the pulmonary veins. The volume of atrium was accurate estimated. From the difference of atrial systolic volume and atrial diastolic volume, we were able to evaluate the Ejection Fraction of atrium that determined the performance of atrium before and after AF ablation. The program will extract the dimension of Pulmonary veins. Using this developed program, we have observed superior PVs manifested with higher incidence of paradoxical dilatation and lower contractility was observed in patients with AF. These results from MDCT may provide further evidence to support the stretch mechanism of AF.

Acknowledgements

This study was supported by a grant from Nation Science Foundation, Taiwan, Republic of China (NSC-92-2218-E-033-004 and NSC-94-2213-E-033-040).

References

[1] Tsao HM, Wu MH, Yu WC, Tai CT, Lin YK, Hsieh MH, Ding YA, Chang MS, and Chen SA. Role of Right Middle Pulmonary Vein in Patients with Paroxysmal Atrial Fibrillation. Journal of Cardiovascular Electrophysiology, 2001; 12: 1353-1357.

[2] Tsao HM, Yu WC, Cheng HC, Wu MH, Tai CT, Lin WS, Ding YA, Chang MS, and Chen SA. Pulmonary Vein Dilation in Patients with Atrial Fibrillation: Detection by Magnetic Resonance Imaging. Journal of Cardiovascular Electrophysiology. 2001; 12 (7), 809–813.

[3] Verma A, Kilicaslan F, Adams JR, Hao S, Beheiry S, Minor S, Ozduran V, Elayi SC, Martin DO, Schweikert RA, Saliba W, Thomas JD, Garcia M, Klein A, Natale A. Extensive Ablation During Pulmonary Vein Antrum Isolation Has No Adverse Impact on Left Atrial Function: An Echocardiography and Cine Computed Tomography Analysis. J Cardiovasc Electrophysiol, 2006; 17: 741-746.

[4] Pappone C, Rosanio S, Oreto G, Tocchi M, Gugliotta F, Vicedomini G, Salvati A, Dicandia C, Mazzone P, Santinelli V, Gulletta S, and Chierchia S. Circuferential Radiofrequency Ablation of Pulmonary Vein Ostia: A New Anatomic Approach for Curing Atrial Fibrillation. Circulation, 2000; 102: 2619-2628.

[5] Kim YH, Marom EM, Herndon JE, McAdams HP. Pulmonary Vein Diameter, Cross-sectional Area, and Shape: CT Analysis. Radiology, 2005; 235: 43-50.

[6] Hauser TH, Yeon SB, McClennen S, Katsimaglis G, Kissinger KV, Josephson ME, Rofsky NM, Manning WJ. Subclinical pulmonary vein narrowing after ablation for atrial fibrillation. Heart, 2005; 91: 672-673.

[7] Kass M, Witkin A, Terzopoulos D. Snakes: Active Contour Models. International Journal of Computer Vision. 1988; 1(4): 321-331.

[8] Wolf I, Hastenteufel M, Simone RD, Vetter M, Glombitza G, Mottl-Link S, Vahl CF, Meinzer HP. ROPES: A Semiautomated Segmentation Method for Accelerated Analysis of Three-Dimensional Echocardiographic Data. IEEE TRANSACTIONS ON MEDICAL IMAGING, 2002; 21(9): 1091-1104.

Address for correspondence
Weichih Hu, Dept. of Biomedical Engineering, Chung Yuan Christian University, Chung Li, Taiwan, ROC
weichih@be.cycu.edu.tw