Feasibility Assessment of Atrial Septal Defect by 3D Echocardiographic Virtual Endoscopy

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Abstract

Congenital heart disease is the most common cause of death in infants. Three-dimensional echocardiography may provide reliable information than two-dimensional methods. The purpose of the study was attempted to evaluate the feasibility and accuracy of the 3D echocardiographic virtual endoscopy in Atrial Septal Defect (ASD). An improved fuzzy C-means clustering algorithm brFCM was adopted to accelerate the speed of the FCM algorithm, as well as the equivalent calculation results of the traditional method. The minimum, maximum diameter and are of ASD measured by VE were correlated well measured data.（r>0.95， P<0.01）In conclusion, 3DE IESS is a new technique in the field of measurement of ASD in congenital heart disease.

1. Introduction

Conventional two-dimensional echocardiography (2DE) is a safe and noninvasive diagnostic tool providing spatial cardiac information. However, 2DE images only provide two-dimensional plane information. The cardiologists make analysis and diagnosis from multiple 2DE images requires a mental 3D reconstruction. Thus, 2DE has limitation in the pinpoint diagnosis of congenital heart disease [1].

Virtual reality computing technique is one of the latest developments by which virtual environment of inner-cardiac structure can be reconstructed and visualized [2] . We have developed a virtual reality simulation system, which we call "three-dimensional echo-cardiographic intracardiac endoscopic simulation system (3DE IESS)" and applied the virtual reality technique in a clinical environment. The purpose of the study was attempted to explore the feasibility of three-dimensional echocardiography in assessment of congenital heart disease in vitro validation by virtual reality computing techniques.

2. Methods

Data processing mainly include the image segmentation procedure. In this paper, the purpose of segmentation is to partition the original image into two parts, the cardiac muscles and the cardiac cavities. The next step, based on the result of the step above, is the three-dimensional visualization of the ultrasound image. The approach to segment the image is based on the improved level set method. To achieve better evolution efficiency of the level set method and to reduce the steps of the iteration, the initial contour of the level set is determined by the membership function. In addition, we combine the area functional of the level set with a stopping function which is helpful for reducing the error rates. (Figure 1)

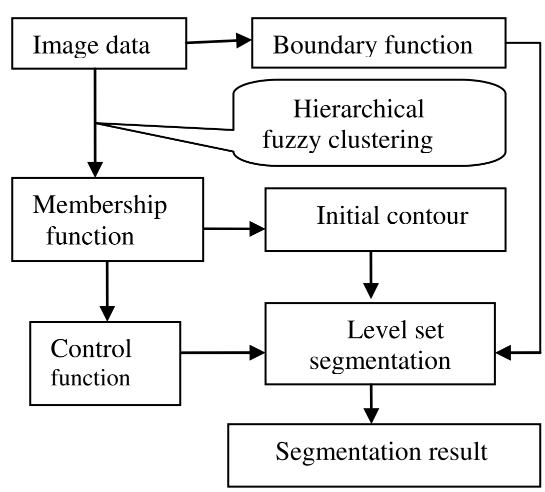

Figure 1. The framework of the segmentation algorithm.

In this paper, an improved fuzzy C-means clustering algorithm brFCM was adopted to accelerate the speed of the FCM algorithm[3], as well as the equivalent calculation results of the traditional method.

3DE measurements for ASD were performed in 10 of porcine heart models and 16 patients. The area, maximum and minimum diameter of defects were compared to direct anatomic measurements linear regression analysis. A value of P<0.05 were considered statistically significant.

3. Results

The results show that all heart models are reconstructed successfully and the image visualization are satisfied. Figure 2-4 shows the site and geometry of ASD obtained from 3DE IESS.

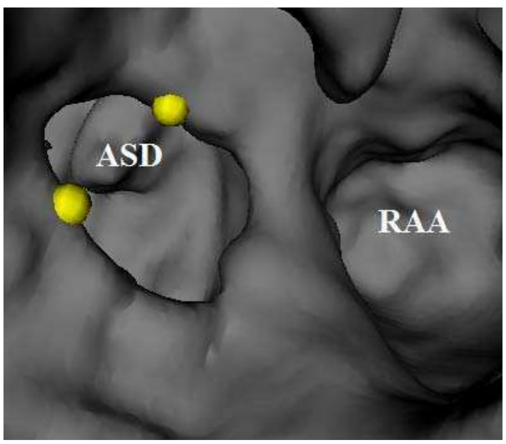

Figure 2. ASD viewed from the right atrium and short axis of ASD measured with 3DE IESS. (ASD=atrial septal defect; RAA=right atrial appendage).

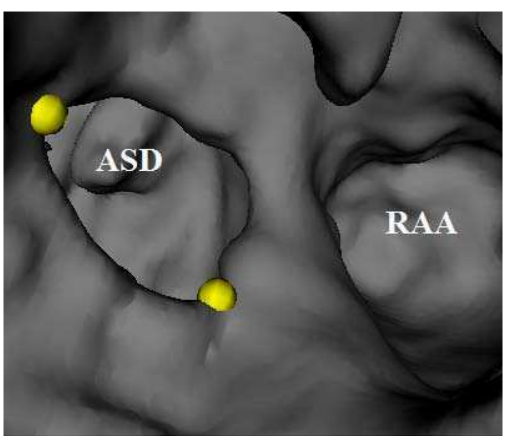

Figure 3. ASD viewed from the right atrium and long axis of ASD measured with 3DE IESS. (ASD=atrial septal defect; RAA=right atrial appendage).

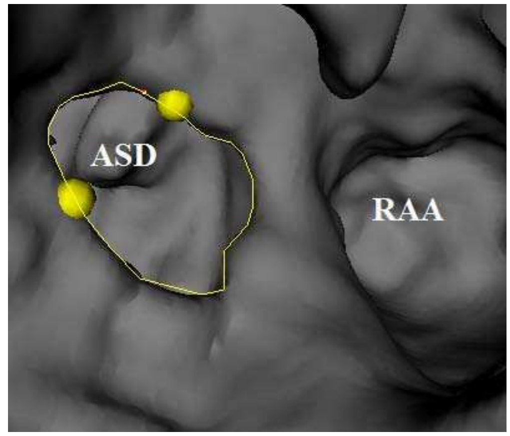

Figure 4. ASD viewed from the right atrium and area of ASD measured with 3DE IESS.

The area, maximum and minimum diameter of defects of ASDs from right atrium are measured in a virtual reality environment. Good correlations were obtained between area measured by VE. The maximum and minimum diameter and area measured by VE were correlated well measured data.（r>0.95， P<0.01）（r>0.95， P<0.01）. (Table 1, 2)

Table 1. The measurements of ASD dimensions from right atrium and correlation between the measurements obtained by anatomic specimen and 3DE IESS.

	dimension of defect (mm)		Area of defect (mm^2)
	Maximum	Minimum	
Anatomic specimen	11.50 (2.39)	7.18 (2.68)	70.15 (34.33)
3DE IESS	11.69 (2.53)	6.72 (2.06)	69.19 (31.47)
r	0.982	0.934	0.986
p Value	0.001	0.001	.0001

Table 2. The measurements of ASD dimensions from right atrium and correlation between the measurements obtained by RT-3DE and 3DE IESS.

	dimension of defect (mm)		Area of defect (mm^2)
	Maximum	Minimum	
RT-3DE	33.36 (8.71)	16.40 (3.94)	459.15 (191.69)
3DE IESS	33.93 (7.63)	16.36 (4.89)	467.96 (198.73)
r	0.965	0.941	0.962
p Value	0.001	0.001	.0001

4. Discussion

Three-dimensional echocardiography may provide reliable information than two-dimensional methods and improve comprehension of anatomic relationship, especially in the case of complex congenital heart diseases [4]. However, 3DE volume rendered images of complex anatomy of congenital heart disease often pose difficulties in understanding both the origin and orientation of the reconstructed tomographic views used for analysis. Thus, it's a puzzle how to establish an optimal method for 3D echocardiography on reconstruction of inner heart structure by which quickly presentation of various heart malformations and defining complex spatial relationships. Virtual reality computing techniques is expected to solve this difficult problem.

By applying the brFCM algorithm to the ultrasound image, the data at the same ultrasonic beam depth can be classified into two clustering centers, the cardiac muscles and the cardiac cavities. Base on these two centers, we can value a membership function to each pixel of the image. By applying the boundary function to the level set segmentation method the gray information of the object should be considered. If the initial contour was inadvertently fall in the inner part of the object, or the object has a fuzzy boundary, such cases may cause the aggravation of the error rates of the segmentation results. Therefore, in our research, the area functional in the level set framework is corrected by a stop function which is controlled by the result of fuzzy c-means clustering to reduce the error rats of the segmentation results.

Visualizing intracardiac structure in virtual reality provide intuitive 3D information. VR produces unconventional views of congenital heart defects and improves understanding of intracardiac malformation since an orthogonal view may be difficult to display by conventional echocardiography. The region of interest (ROI) can be viewed from above, below, and any desired view similar to surgeon's views of the heart. When VR heart model is combined with navigation system, it conveys the illusion of flying through the chamber with specific information on the orientation and viewpoint of the observer. In 1996, Lee reported their study on computer-aided interactive three-dimensional fetal heart model of which is unique for fetal ultrasound training [5]. Interactive visualization of a virtual fetal heart can provide physicians with an unprecedented opportunity retrospectively visualize abnormal fetal heart developmental changes with virtual ultrasound simulation. In 1999, applied by virtual reality compute technique, reconstruction of virtual reality heart model and presentation part structure of heart such as mitral valve and tricuspid valve was reported by Bruining et al [2].After one year, some congenital heart disease such as VSD/ASD were diagnosed, analyzed or assessed within the VR heart model by virtual reality computing techniques [6].

Virtual reality computing techniques in the form of a virtual heart model can be useful by providing spatial cardiac information, holding significant promise for minimizing patient risk and morbidity, and reducing health care costs. The advent of 3DE virtual simulation may lead to a more readily appreciated, intuitive and objective assessment of intracardiac structure that would reduce the subjectivity in image interpretation [7]. Virtual reality computing technique application provides a noninvasive way to examine the interior of the heart. In addition, virtual reality offer great potential for teaching and training, aiding in complex diagnostic situations and assisting in planning surgical procedures[8,9].

5. Conclusions

This paper introduces a novel approach for visualization of three-dimensional echocardiography (3DE) data. Employing virtual reality to capture realistic views of the cardiac anatomy, 3DE IESS is an interesting approach for noninvasive imaging of congenital heart disease.

Acknowledgements

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References

[1] Pepi M, Tamborini G, Maltagliati A, Galli CA, Sisillo E, Salvi L, Naliato M, Porqueddu M, Parolari A, Zanobini M, and Alamanni F. Head-to-head comparison of two- and three-dimensional transthoracic and transesophageal echocardiography in the localization of mitral valve prolapsed. J Am Coll Cardio 2006; 48: 2524-30.

[2] Bruining N, Roelandt JR, Grunst G, Berlage T, Waldinger J, and Mumm B. Three-dimensional echocardiography: the gateway to virtual reality! Echocardiogr 1999; 16: 417-23.

[3] Eschrich S, Ke J, Hall LO, and Goldgof DB. Fast accurate fuzzy clustering through data reduction. IEEE Trans on Fuzzy System 2003; 11: 262-70.

[4] Lu X, Xie M, Tomberlin D, Klas B, Nadvoretskiy V, Ayres N, Towbin J, and Ge S. How accurately, reproducibly, and efficiently can we measure left ventricular indices using M-mode, 2-dimensional, and 3-dimensional echocardiography in children? Am Heart J 2008; 155:946-53.

[5] Lee W. The fetal imaging workstation demonstration project. Comput Med Imag Grap 1996; 20: 459-66.

[6] Bruining N, Lancée C, Roelandt JR, and Bom N. Three-dimensional echocardiography paves the way toward virtual reality, Ultrasound Med Biol 2000; 26:1065-74.

[7] Szpala S, Wierzbicki M, Guiraudon G, and Peters TM. Real-time fusion of endoscopic views with dynamic 3-D cardiac images: a phantom study, IEEE T Med Imaging

2005; 24: 1207-15.
[8] Weidenbach M, Trochim S, Kreutter S, Richter, Berlage CT, and Grunst G. Intelligent training system integrated in an echocardiography simulator. Comput Biol Med 2004; 34: 407-25.
[9] Gallagher AG, and Cates CU. Virtual reality training for the operating room and cardiac catheterisation laboratory. Lancet 2004; 364:1538–40.

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