A Primary Exploration of Three-Dimensional Echocardiographic Intra-Cardiac Virtual Reality Visualization of Atrial Septal Defect: In Vitro Validation

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Abstract

To evaluate the diagnostic value of three-dimensional echocardiography (3-DE) in congenital heart disease such as atrial septal defect (ASD) by virtual reality (VR), ten ASDs with different size and shape were created in ten fresh explained porcine hearts. HP SONOS 5500 imaging system was employed for 3-DE reconstructed and visualized by virtual reality computing techniques. The results showed that all ASDs were successfully reconstructed. The site, geometry were well appraised in its true form. The area, maximum and minimum diameter of ASD were measured on 3D reconstruction and compared with independently measured anatomic date. Good correlation was obtained($r>0.95$, $P<0.01$). In conclusion, VR open an exciting opportunity in the field of diagnosis of 3-DE in congenital heart disease.

1. Introduction

Congenital heart defect is a leading cause of children death. Precisely preoperative spatial diagnosis is very important. However, the heart is a complex spatial structure. The images obtained from two-dimensional echocardiography (2DE) only provide two-dimensional plane information. And, conventional three-dimensional echocardiography has the weaknesses of time consuming when searching for desired cutting view for the diagnosis.

Recently, virtual reality (VR) computer techniques could obviate these limitations. This study attempted to explore the feasibility of virtual reality three-dimensional echocardiography in the diagnosis of ASD and assess its initially clinical value.

2. Methods

There were 10 isolated porcine heart models of congenital heart defect with different size and shape in which three of prium atrial septal defect and seven of secundum atrial septal defect, which were suspended in a water bath. A TTO probe, connected to a Hewlett Packard SONOS 5500 echocardiography system, supplied with the 3D acquisition software, was used for image acquisition. After 180 2D echo slices acquired by 1º of density of acquisition, a three-dimensional data volume was established. MATLAB (Matrix Laboratory) software was used for 3D reconstruction and visualization. Digital reformation, interpolation and segmentation of the data set and surface rendering with marching cubes algorithm were subsequently performed. Using sequential pixel information from digital images of echocardiography, virtual heart model was reconstructed. Interactive scenario virtual environment of VR heart model was created and the appropriate observation "route" map was designed for inner cardiac observation. The real explained porcine heart spatial structure and the images of three-dimensional reconstruction and visualized by virtual reality computing techniques were compared. Correlations between the anatomy (area, maximum and minimum diameter) and virtual reality observation results were tested by linear regression analysis. A value of $P<0.05$ were considered statistically significant.

3. Results

The results showed that all ASDs were successfully reconstructed and the image visualization was satisfied. The defects were delineated objectively from many unique directions and angles, by which the ASDs were viewed from right atrium and left atrium.The area, maximum and minimum diameter (Dmax and Dmin) were measured directly on the VR heart model of ASDs from right atrium and left atrium. All data compared with independently measured anatomic data. The site, geometry obtained from VR could be well appraised in their true dissection form (Figure 1). The Dmax and Dmin measured by VR were correlated well with anatomy. Good correlations were also obtained between

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area measured by VR and actual area ($r>0.95$, $P<0.01$).

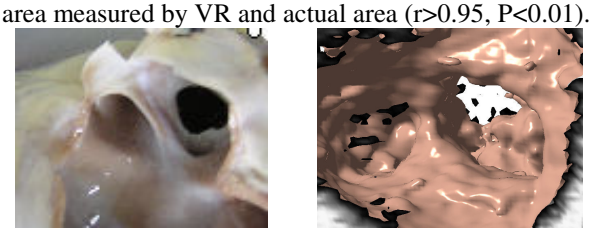

Figure 1. A photo of porcine heart model of atrial septal defect (left). And the picture on the right shows the results of virtual visualization of ASD observed from left atrium at different view angle applied by 3D reconstruction and visualization with virtual reality computing techniques.

4. Discussion and conclusions

With the development of visualization in scientific computing by technique of surface rendering and volume rendering, computer reconstruction of three-dimensional echocardiography has made a great breakthrough. Emerging clinical experience indicates that three-dimensional echocardiography provides cardiac images that more closely mimic actual anatomy than two-dimensional echocardiography in qualitative and quantitative diagnostic appraisal of congenital heart disease. Nowadays, the presentation of three-dimensional echocardiography is based on section of the volumetric 3D data set. However, the heart is a three-dimensional object, and there are a variety of inner heart abnormalities in complex congenital heart disease, it is difficult to comprehend complex three-dimensional spatial relationships. Echocardiography obtains data in slices and presents the images as if they were anatomical sections at various planes. It is time consuming to capture image of ideal section plane. Even in the study for three-dimensional echocardiographic sectional reconstruction on isolated anatomical specimen of congenitally malformed hearts, depending on Vogel's paper, three-dimensional reconstruction, performed off-line, took between 10 and 60 minutes, and selection of the optimal cross-sections to display the anatomy took about 7 to 52 minutes, and from 2 to 3 hours for complex anatomy. In Deng's previous studies about comparison of three-dimensional echocardiographic findings with anatomical specimens of various congenitally malformed hearts, he found that only half of the data sets obtained from the ideal windows offered useful information about cardiac structures and their spatial relationships at the gross anatomical level. Virtual reality is a computer-generated three-dimensional technology that will immerse the user in an interactive simulation. By virtual reality computer technology, virtual environment of inner-cardiac structure can be reconstructed and observed in virtual space. This is a different visualization method which using 2D echocardiography data sets. Virtual Reality is the result of combining computer graphics, image processing, pattern recognition, intelligent interface, artificial intelligence, multi transducer, speech processing, sound technology, network technology, parallel processing and high performance computer etc.

Virtual Reality system basically consists of effect generator (the hardware device that synergy between human and virtual environment), real world emulator (the kernel of system, consisting of computing software system and software developing tools), application system (the concrete problems oriented software and the concrete content describing guideline), geometry constitution system (providing information that describes the physical characteristic of simulated object). When the VR heart model is reconstructed, an interactive scenario becomes possible in which the operator can select any desired view (choices of observation points are infinite), or from a list of standardized echocardiographic views.[2] Because the three dimensional reconstructions can be rotated in space to look at them from different perspectives, as a result, the heart structure can be seen in many new views. These can be achieved by manipulation of the cutting planes and rotation of the three dimensional image to obtain ideal projections.

Based on our study, it appears that virtual reality computing techniques has a potential diagnostic value in assessment of congenital heart diseases, and virtual reality will be becoming an important direction in the field of noninvasive diagnostic tool of congenital heart defect for children by 3D echocardiography in the future.

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