A Semi-Automatic Method for Left Ventricle Volume Estimate: An In Vivo Validation Study

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Abstract

This study aims to the validation of the left ventricular (LV) volume estimates obtained by processing volumetricdata utilizing a segmentation model based on level set technique. The validation has been performed by comparing real-time volumetric echo data (RT3DE) and magnetic resonance (MRI) data. A validation protocol has been defined. The validation protocol was applied to twenty-four estimates (range 61-467ml) obtained from normal and pathologic subjects, which underwent both RT3DE and MRI. A statistical analysis was performed on each estimate and on clinical parameters as stroke volume (SV) and ejection fraction (EF). Assuming MRI estimates (x) as a reference, an excellent correlation was found with volume measured by utilizing the segmentation procedure (y) ($y=0.89x+13.78$, $r=0.98$). The mean error on SV was 8ml and the mean error on EF was 2%. This study demonstrated that the segmentation technique is reliably applicable on human hearts in clinical practice.

1. Introduction

Nowadays echocardiography represents a low cost, versatile, non-invasive and powerful diagnostic tool. The ability to represent with enough detail the morphology of soft tissues as the heart, the invasiveness and the brief time of investigation are characteristics that have decreed the success of echography: the wide use of such methodology of investigation in numerous clinical fields and particularly in cardiology can be explained by these reasons. Thus, it's not surprising that echocardiography results a daily used modality for imaging the heart.

Echocardiography has suffered a constant improvement due to technological advantages and accuracy and precision of clinical information derived from this technique have increased. This imaging modality is able to produce images of a plain section of the heart but, today, it also proposes itself as method of acquisition of a whole volume. Such extension from 2D to 3D can be obtained in two ways. The first way consists of several plain acquisitions oriented in the space, that, in a second time, are used for the 3D reconstruction, with the aid of computer systems. Electrocardiographic and respiratory gating and long imaging time is required. The second way has introduced methods of volumetric acquisition in real time: the whole heart's volume data within a cardiac cycle are acquired in real-time. A real-time volumetric ultrasound imaging system has been developed by Volumetrics Medical Imaging Inc. in Durham [1,2]. LV cavity volumes, cardiac output (CO) and ejection fraction (EF) are important indexes for serial assessments of LV function. Accurate quantification of ventricular volume offers considerable advantages to manage patients with cardiac disease. Several studies have demonstrated the significant impact of ventricular function on postoperative outcome and long-term prognosis. They represent a strong clinical need and therefore important that such a method of calculating these indexes is non-invasive, rapid, accurate and reproducible. An efficient, fast and effective method to extract LV endocardial surface from RT3DE data could lead to a simple, rapid and therefore clinically applicable and useful calculation of these indexes. The previously described method, based on level set technique has been applied to RT3DE data [3,4]. The aim of this study was to test the accuracy and variability of volume computation obtained with this new computerized and semi-automatic method for LV segmentation and LV volume estimation on RT3DE in vivo data.

2. Method

The RT3DE data processing has allowed to produce some effective visualizations of the cardiac structures (Figure 1) and to apply some semi-automatic methods for the extraction of cardiac parameters as LV volumes and EF.

The method for LV chamber segmentation we aim to validate was presented in [3,4] and it is based on level set

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Computers in Cardiology 2001;28:109-112.

models introduced by Sethian [5,6] and applied to ultrasound data processing by Sarti [7,8].

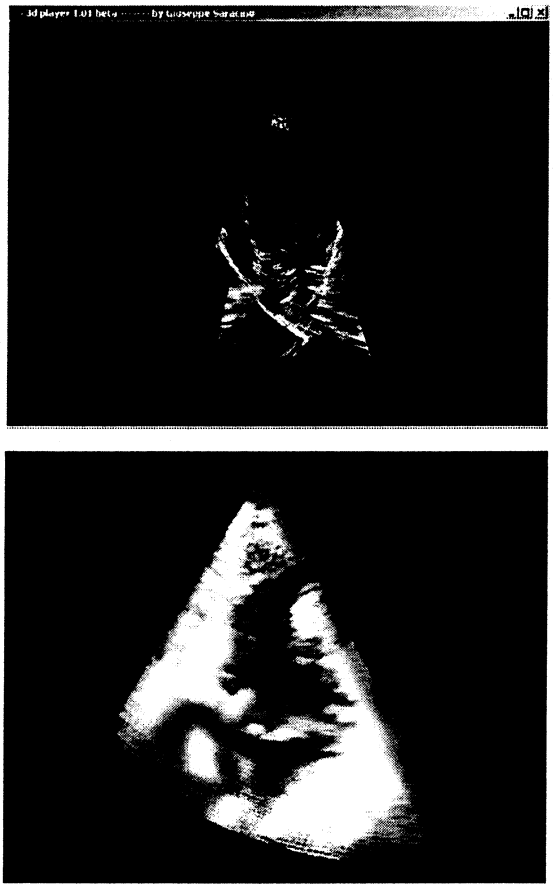

Figure 1. Dynamic visualization of a left ventricle imaged by RT3DE; different planes (b-scanes or c-scanes) of the echo data can be displayed during the cardiac cine-loop.

To confer scientific validity to the proposed method an in vivo validation is necessary.

This segmentation procedure was previously tested on water filled balloons of known volume [9] acquired with the Volumetrics RT3DE system as recommended by the American Society of Echocardiography, Committee on Standards for the standardization of LV quantitation [10]. The results were consistent and justify thus this sequent study.

This study involves nineteen patients who underwent both a magnetic resonance investigation and a real-time three-dimensional echocardiographic investigation. Five patients with low quality RT3DE acquisitions have been excluded.

The semi-automatic segmentation procedure has been applied to in vivo RT3DE dataset and the volume estimates consequently obtained.

For each patient a transthoracic apical view of a cardiac cycle has been acquired and particular care has been set in to include the maximum part of the LV during the whole cardiac cycle.

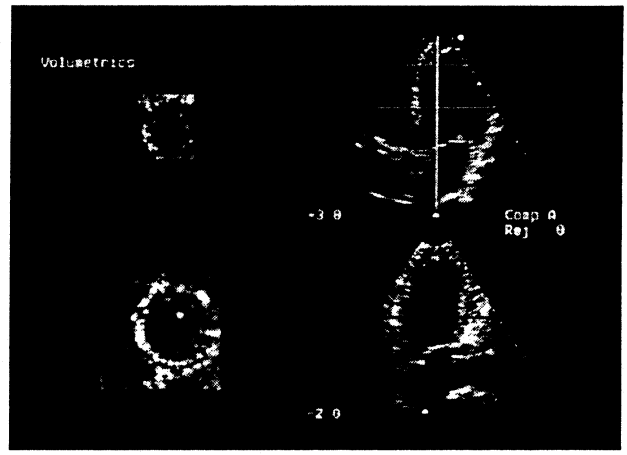

Figure 2. Visualization of data on the real-time volumetric ultrasound imaging system

Manual tracing of magnetic resonance investigation has been employed to calculate LV volume estimates, which we assumed to be the standard reference in our study. The data have been acquired with a commercially available scanner, (Siemens Vision, Erlagen Germany) endowed with a 1.5T spool and able to acquire the whole body. For each patient LV planes along the short axis whose thickness is 8-10 mm have been acquired and manually segmented. Applying the Simpson's method (software by Argus, Siemens Medical System, New Jersey) end diastole (ED) volume and end systole (ES) volume were determined. The MRI measurements have been effected by experienced operators in MRI analysis who didn't know the estimates obtained from the echocardiographic investigation.

The segmentation on echocardiographic data has been performed by two completely independent physicians, using two different computers. Each operator performed two volume mesurements of both ED and ES frames and therefore for each patient four estimates were obtained. These four estimates were mediate and the mean value compared with MRI estimates.

3. Results

In this section we present results that have been obtained applying the model we described above, to in-vivo RT3DE data.

In order to determine the correlation between MRI volume values and those obtained by level set based method a simple linear regression analysis was performed.

An excellent correlation was found between them (Figure 3). The regression equation is $y = 0.89 x - 13.78$ and the correlation between the volume values is $r = 0.98$.

In Table 1 the statistical analysis we performed is shown.

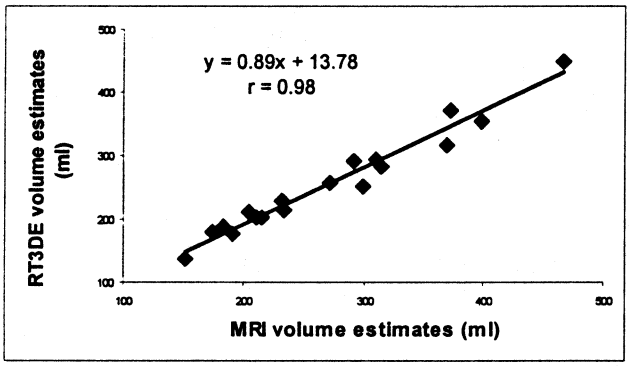

Figure 3. Linear regression analysis between MRI ED and ES volumes and volume estimates obtained by segmentation method based on level set model.

Table 1: Correlation and comparison of the ED and ES MRI volumes and the volume estimates by level set based method

	SEE* (ml)	$\Delta \pm SD°$ (ml)
LV Volume with Level Set Model	16.67	-15.58 ±17.47

*standard error of estimate

°mean difference and standard deviation between LV volume estimates by level set based method and MRI volumes

The use of correlation coefficients and regression lines sometimes appears to be inappropriate and misleading [11] and for this reason we looked at additional parameters describing the accuracy and the variability of the method. For further comparison the Bland-Altman [11] analysis was also performed (Figure 4).

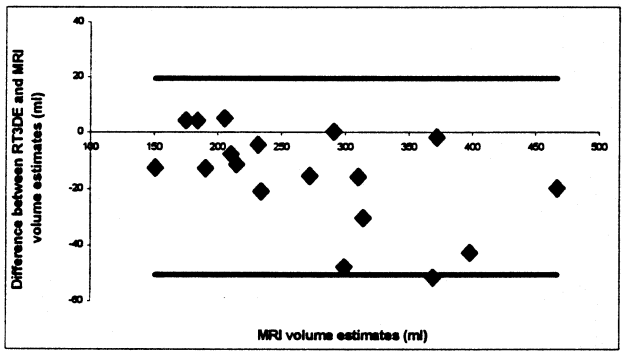

Figure 4. Bland-Altman agreement plot for LV volume estimates obtained by segmentation method in comparison with MRI volumes.

The standard error of the estimate, as a parameter of variability, was 16.67 ml. The concordance between the level set based method and the MRI volume is –15.58 ml; conversely, the standard deviation as a measure of dispersion of a group of values was 17.47 ml.

Differently from other studies, this technique based on level set model does not underestimate the MRI volumes values.

4. Conclusion

The present study was specifically designed to evaluate volume quantification of in vivo data acquired with RT3DE system. The outcome is that there is a high correlation between RT3DE volume estimates and volumes by MRI.

These results demonstrate that the 3D semi-automatic surface detection method for quantifying LV volume is accurate. We expect to test the procedure on a larger data set and also on pathological RT3DE data. In conclusion, the described method implemented in our custom-made software was revealed to be reliable and ready to be used in a clinical environment.

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