

Fast Automated Echographic System for 4-D Data Acquisition on Patients Using a Transthoracic Approach

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Abstract

To address physicians' question on left ventricular function, we have built a completely automated system for fast data acquisition to be used on a regular basis in a clinical setting.

The aim of this research is to use the power of a four dimensional data set (3D + time) in order to facilitate border detection of the endocardium throughout the cardiac cycle.

An ECG controlled robot has been designed to rotate the probe around its axis. During acquisition time, all video images are stored directly onto a PC based workstation, along with the probe position and the ECG period. An interface is used to browse through the 4D database to help border tracing. In volunteers, a beating left ventricle can be viewed.

Volume measurement has been validated in vitro using fluid filled balloons and remains to be tested against other cardiac techniques in patients.

1. Introduction

Different existing techniques have proved that it is possible to reconstruct images of the human heart in three dimensions using transthoracic 2D echographic images repositioned in space. The probe can be moved either freely by hand [1,2] or mechanically using translation or rotation [3,4].

However, commercially available systems using a transthoracic or merely a transesophageal approach necessitate a huge amount of data to reconstruct the whole volume of the heart. In order to scan the entire volume very tightly, ECG and respiratory gating is needed. These echo images are then replaced in a voxel base for every period of the cardiac cycle. Echogenicity is the biggest limitation for border detection.

The purpose of this study is to demonstrate that left ventricular reconstruction can be achieved through fast data acquisition technique and the transthoracic approach.

The aim is to develop a tool for cardiologists to evaluate left ventricular function in a clinical setting.

2. Methods

The system is based on a PC based workstation, which controls both the acquisition and the reconstruction:

2.1 Acquisition

For echographic data we used a 5-MHz mechanical probe connected to a VingMed CFM 750 echographic system.

The probe is rotated around its axis by a light, specially designed robot that is controlled by an electronic device triggered by the ECG signal taken directly from the patient. The electronic system is interfaced to the computer to provide both the positions of the step motor and the ECG information. The software control activates the step motor at the end of every cardiac cycle with a defined angle [5].

The three informations: echographic images, position, and ECG are registered on-line continuously through a digitising board onto the PC (Pentium 166 MHz).

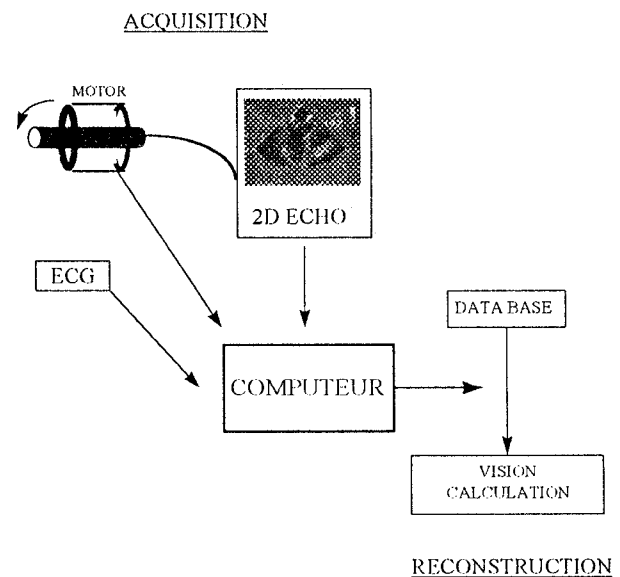


Figure 1. Data acquisition and reconstruction controlled by a PC based Workstation.

2.2. Reconstruction

For patients, the acquisition product is a database, which can be represented in a matrix format.

At every angle of rotation of the probe (α) an entire heart contraction is recorded at a 25 frames/sec rate. The time reference for creating the database is set by the electrical timer of the heart (ECG=t).

The power of this format is that every image in the matrix can be, if needed, extrapolated from the neighbouring images either in the time or in the space sequence.

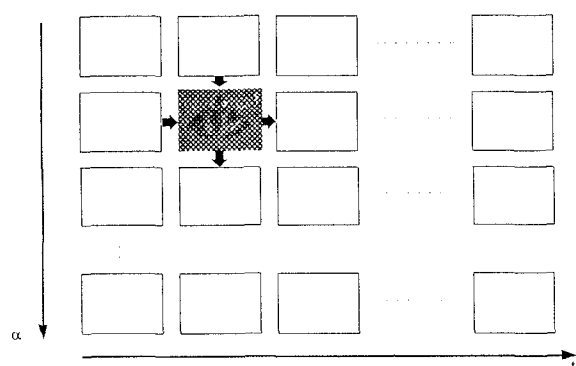


Figure 2. Database in a matrix format (α and t).

This database can be processed in many different ways to extract relevant information, like contours. Our research focused on the left ventricular inner border, the endocardium, from which heart function can be analysed. We developed an expert-model based guidance for contour detection [6].

2.3. Phantoms preparation

In order to validate volume measurements we used 12 fluid filled balloons ranging from 5 to 110 ml. They were scanned through their centre in a water bath with the probe fixed to a support. Two-dimensional views were collected every 9 degrees over a span of 180 degrees. The images were pre-processed for noise reduction.

2.4. Patients scanning

Eight young adults and four patients volunteered for data acquisition. Mean age \pm SD was 41 ± 10 .

The number of acquisition planes was set to 9 for practical purpose. According to the heart frequency varying between 60 and 80/minutes, the acquisition time was reasonably short to stand a short breath hold (less than 9 sec).

The heart was supposed immobile in the chest during the breath hold and the probe was blocked manually to the chest. The axis of rotation becomes the only referential for the reconstruction and the

spatial location of the probe is then reduced to a single parameter: the angle of rotation (α).

3. Results

Before using the system on humans we tested the system for three-dimensional reconstruction ability and volume measurements.

3.1. In vitro study

On surfaces like rubber balloons, ultrasounds are reflected with a strong echo signal creating thick and bright images. In three-dimensional echocardiography, volume measurements have been validated by manually tracing in two-dimensional views the centre line of the echo structures. Using this method in our series of spherical balloons, calculated volumes corresponded almost exactly to the actual volume of fluid calculated with a syringe.

However, automated border detection techniques, in 2-D views, delineate the frontier between bright and dark regions (inner edge) with dependency to the gain setting, potentially reducing the true area.

In 3-D, the underestimation for volume measurements is not known. Using the snakes method [6] with the centreline being initialised in every frame, calculated volume (y) agreed well with true volumes (x): $y = 0.992 x - 3.16$ cc, $r = 0.998$, $SEE=1.44$ cc. These results confirm the tendency of the snakes method to slightly underestimate volumes.

3.2. Left ventricle reconstruction

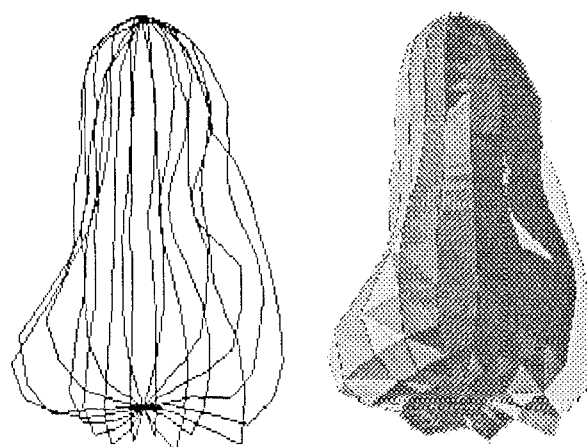


Figure 3. Left ventricle traced (apex at the top) and surface. Papillary muscle indentation on the right side of images.

An interface has been developed to enable easy looking through the database. Every image can be assessed according to its position in the previously defined matrix. The endocardium of the left ventricle is first traced for initialisation by a cardiologist. Then, the expert-model based software is tracking the moving contour over time (during cardiac contraction) [6]. This semiautomatic process is done for every angle of rotation and every trace is replaced in space for visualisation (image on the left; Figure 3). A surface is created (right image; Figure 3). Four-dimensional animation is then possible with viewing from any direction.

The software allows combining 2-D echo images, traces and surface for better understanding of volume features:

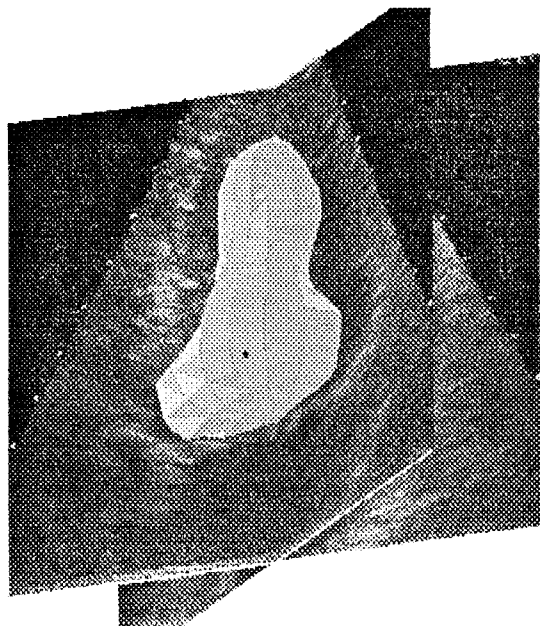


Figure 4. Combination of 2 echo images and surfaces. From bottom to top: Left atrium, mitral valve, surface of the endocardium with papillary muscle indentation, apex.

Setting the distance between two reference points on one echographic image does scaling. Volume computation in end systole ranged between 56 and 101 ml. Ejection fraction ranged between 45 and 70 %. For each patient, a volume curve is traced during the systolic time. This curve could later be used for dV/dt measurements.

4. Discussion

This fast-automated data acquisition system provides an easy way for patients scanning. There is no respiratory gating and no probe to be fixed to any support. The probe is held manually, allowing a perfect freedom for placing the transducer at the best location and in the best position. The best acoustic

window is not necessarily located right at the apex of the heart. We have found in many cases that the chosen axis of rotation was different from the real axis of the heart passing through the apex. Indeed, the apex was recognised only after 3-D reconstruction.

The assumption we made was that the probe remained strictly immobile during data acquisition. This was not verified in some cases. Because the echo signals must remain unchanged at the centre line of the images taken at the same time t (in the matrix), we discarded the data sets when images did not coincide at their intersection line when replaced in space. We hope resolving the problem with the second-generation prototype of the robot.

Since one heartbeat is required for each acquisition plane, the scanning time depends on both the number of planes and the heart frequency. In this first study we used 9 planes (20° of rotation each step), allowing a short (9 sec) acquisition time at a 60/min heart frequency. However the angle of increment for rotation can be set from 9° to 30° in order to find the best combination between precision (the number of planes) and accuracy (no motion or respiratory artefact).

Four-dimensional animation is made possible by adding the time to the 3-D reconstruction. Compared to other techniques, this method of acquisition allows easy, fast and complete sampling of the heart contraction. Except when the probe is quickly rotated, all the images will be used for reconstruction and there is no redundant information in the database.

Any relevant information requested by the cardiologist has then to be extracted from the data base.

Volume rendering using a voxel base can be done but the reconstructed image is poor because of the large angle of rotation. Other techniques produce more appealing images with angles of rotation as small as 1° but this requires long acquisition time with respiratory gating. Images manipulation is usually performed to palliate motion artefacts.

To best take advantage of our database, the heart structure to be analysed has first to be defined. Isolation of the structure (valve, papillary muscle, endocardium...) is done by contouring. This is the most difficult phase of the reconstruction because of poor quality of echographic images (noise). In this work, we used a method based on snakes to trace the endocardium of the left ventricle.

We focused here on the left ventricle function by tracking the endocardium during cardiac contraction.

Volume measurements have been validated in vitro but this promising technique remains to be performed in patients for cardiac evaluation.

5. Summary

The heart function, in a clinical setting, has to be assessed precisely for diagnosis and treatment adaptation. Echocardiography provides only 2-D views, which have to be replaced in space for true calculation of volume.

Therefore, a fast automated system for acquisition has been developed to provide a complete 4-D database from which useful information for clinicians, can be extracted.

The complete contraction of the endocardium surface can be seen and the computed volume provides relevant information on the pump function. Further research needs to focus on segmental wall motions in patients with abnormalities based on the definition of normal cardiac contraction.

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References

- [1] Handschumacher MD, Weyman AE, Lethor J-P, Levine RA. Three-dimensional echocardiography: a new method for real-time integration and computer storage of images and positional data in high volume. *J Am Coll Cardiol* 1991;17:3A.
- [2] Handschumacher MD, Lethor J-P, Siu SC, Mele D, Rivera JM, Picard MH, Weyman AE, Levine RA. A new integrated system for three-dimensional echocardiographic reconstruction: Development and validation for ventricular volume with application in human subjects. *J Am Coll Cardiol* 1993;21:743-53.
- [3] Salustri A, Becker A, Van Herwerden, Vletter WB, Ten Cate F, Roeland J. Three-dimensional echocardiography of normal and pathologic mitral valve: a comparison with two-dimensional transesophageal echocardiography. *J Am Coll Cardiol* 1996;27:1502-10.
- [4] Schwartz SL, Cao QL, Azevedo J, Pandian NG. Simulation of intraoperative visualization of cardiac structures and study of dynamic surgical anatomy with real-time three-dimensional echocardiography. *Am J Cardiol* 1994;73:501-7.
- [5] Tasler M, Lethor J-P, Granjon Y. An automatic data acquisition system for 3D reconstruction in echocardiography. 8th IEEE Symposium on computer-based Medical Systems 1995:299- 306
- [6] Winterfeldt G, Berger M-O, Lethor J-P, Handschumacher MD. Expert-model based 3D reconstruction of the beating left ventricle using echographic images. *Computers in Cardiology* 1997. Lund

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