New Visualisation Methods of Electromechanical Left Ventricular Contraction Asynchrony

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Abstract

Recent attention for asynchronous left ventricular (LV) contraction in various patients generates the need for synchrony assessment. A system for quantitation of electromechanical LV contraction synchrony by three-dimensional echocardiography (3DE) and semi-automatic endocardial contour detection was used.

MatLab™ software was generated to create new visualisation methods of LV asynchrony. In order to make the plots interpretable for doctors, 16 segment bulls eye plots were chosen.

This new methods were evaluated with data acquired in 26 patients, providing quantitation of LV electromechanical contraction synchrony, of which in 8 patients before and after implantation of a biventricular pacemaker.

1. Introduction

The potential improvement of left ventricular (LV) function by correction of asynchronous LV contraction patterns in patients with left bundle branch block and low LV ejection fraction (LVEF) has generated the need to quantify electromechanical LV contraction synchrony, especially the post systolic contraction (PSC). Regional, detailed, and quantitative measurement of LV contraction and timing is only possible when performed completely in four dimensions, i.e. if the entire, three-dimensional heart can be imaged throughout the cardiac cycle with adequate spatial and temporal resolution. The present study describes the feasibility of a system based on three-dimensional echocardiography (3DE) in combination with semi-automatic endocardial contour detection, which has been developed to assess LV asynchrony.

2. Methods

26 patients, among which 18 left bundle branch block (LBBB) patients and 8 patients who received a biventricular pacemaker, underwent transoesophageal rotational three-dimensional echocardiography, using a Philips Sonos 5500™ with a multiplane echo probe (Philips Medical Systems, Best, the Netherlands) [1]. Image loops, with frame rates of approximately 25 Hz, were stored on MO disk and read into a TomTec 4DLV Analysis™ workstation (TomTec GmbH, Munich, Germany) in which semi automatic contour detection was performed. In this method, after positioning apex, mitral valve and aortic valve in a number of image frames in both systolic and diastolic frame, a contour is generated on which corrections have to be performed manually in order to match the contour with the anatomical images. After contour detection, the software performs volume rendering, generating a wire frame consisting of 744 endocardial points. Based on the ultrasound machine's calibration, the TomTec software calculates the LV volume and determines the LVEF. The coordinates of the 744 surface points and the orientation of 1440 triangles forming the faces of the surface formed by the wire frame, are exported and read into MatLab™ (The MathWorks Inc., Natick MA, USA) software to analyse the LV volumes and the synchrony of the LV in time.

The LV centre of gravity (COG) is defined as the spatial average of all surface points in the first frame, and stays fixed in all other frames. With respect to the first frame, in this way the first and second derivative of the distance of each point to the COG can be calculated and plotted in histograms, depicting the surface points' velocity and acceleration. At first movies were generated of the beating LV, in which colour coding was used to indicate a number of parameters: displacement with respect to the first frame, distance to COG, velocity of the surface towards COG and acceleration. Out of this wire frame model, data were plotted into the traditional American Society for Echocardiography 16-segment model [2], commonly used in nuclear cardiology, using a definition shown in figure 1. These bulls eye plots with colour coding to depict parameters are very useful to give quick insight into the LV distribution of parameters.

The next step in the visualisation of synchrony in contraction of the LV was the generation of timing plots. Timing is defined as the time between electrocardiographic R-wave and moment of minimal distance for each LV surface point. Dispersion, as a measure of asynchrony, is defined as standard deviation of timing. Color-coded polar maps were generated to visualise asynchrony by homo-/heterogeneity of colors. In the bulls

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eye drawings, for each surface point the timing is plotted. These plots give a detailed idea about the synchrony of contraction within the LV. To give more regional indication of synchrony, timing was averaged over LV segments. This enables comparison of parameters using different scoring methods.

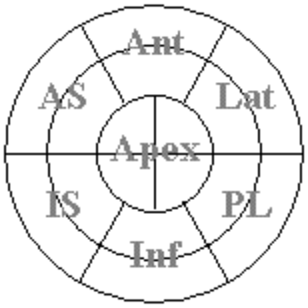

Figure 1. The American Society of Echocardiography 16 segment model in bulls eye plot. Centre to edge depicts apex to base. Segments: Ant = anterior, Lat = lateral, PL = postero lateral, Inf = inferior, IS = inferior septal, AS = anterior septal.

Finally an attempt was made to realize a visually appreciative measure for asynchrony that can easily be judged by clinicians and which is one single measure for the condition of the LV. Therefore we calculated the volumes of all 1440 tetrahedrons, consisting of three surface points (forming the 1440 surface triangular faces) and the COG. The times of the minima of these 1440 time-volume curves were compared to the time of global minimal volume of the LV, the systolic frame. A tetrahedron’s recruitable volume is defined as the difference between the tetrahedron’s minimal volume and its volume in the systolic frame, in case the tetrahedron’s local minimum is *after* mitral valve closure. The sum of all recruitable volumes, e.g. the LV’s recruitable volume, therefore is a measure of inward motion after end systole (which is PSC) and the mean time of all tetrahedron’s local minima forming this recruitable volume is a measure of the duration of this inward motion. These two parameters were plotted in a time-volume rectangle. In the same figure, the ‘missing volume’ and its mean timing *before* mitral valve closure was plotted.

It is clear that in case of a perfectly synchronously contracting LV both missing volumes will be zero, so the plot will look empty. In case of a large dispersion of the contraction pattern, with surface points reaching their most inward position all on different times in the cardiac cycle, the ‘missed volumes’ will sum up large and the mean time of their occurrence will differ from the systole, giving a large rectangle. The area of the rectangles might be a measure of severity of the asynchrony. The axes of the plot of the rectangles are fixed, so the best visual information can be quickly achieved.

Finally the values for the parameter |(‘missed volumes’) x (time to systole)| for all respective tetrahedrons were colour coded and plotted into bulls eye plots, providing a view on the combination of asynchrony and LV localisation.

Intra observer reproducibility of the semi automatic contour detection algorithm in the analysis of different parameters was investigated.

3. Results

Most described successive steps in the attempt to generate new visualization methods of LV synchrony are shown in figure 2. This figure depicts visual representations of data from 1 patient with a biventricular pacemaker off (I) and on (II).

The intra observer reproducibility of the different parameters is shown in table 1 [3].

Table 1. Intra observer reproducibility of the analysis of different parameters.

Parameter	Value *(average ± SD)*	Reproducibility *(bias ± 2SD)*
Displacement (mm)	3,9 ± 2,0	0,1 ± 3,0
Timing (ms)		
All segments	422 ± 73	–5.6 ± 160
Non-apical segments		–1.6 ± 94
Apical segments		0.68 ± 200
Dispersion (ms)	92 ± 30	21 ± 50
End-diastolic volume (ml)	145 ± 54	-1,2 ± 11,9
End-systolic volume (ml)	98 ± 57	-0,3 ± 11,8
Ejection fraction (%)	38 ± 18	-0,3 ± 4,2

4. Discussion and conclusions

The clinician’s appreciation of the different visualisation methods shown in figure 2, is not equal for each method. The appreciation is largely dependant on the circumstances in which cardiologists want to judge the LV synchrony. The ideal situation: the ability to get an impression of asynchrony in real time, which means in this case during acquisition, cannot be achieved up to now. The reason is that contour detection is not yet fully automated. However, big steps are recently being taken by different groups to reach that goal. Only then, the synchrony visualisation can be achieved in real time, e.g. in a catheterisation lab or an echo room.

The movies (figure 2a), made of the endocardial surface, with therein colour coded parameters, give

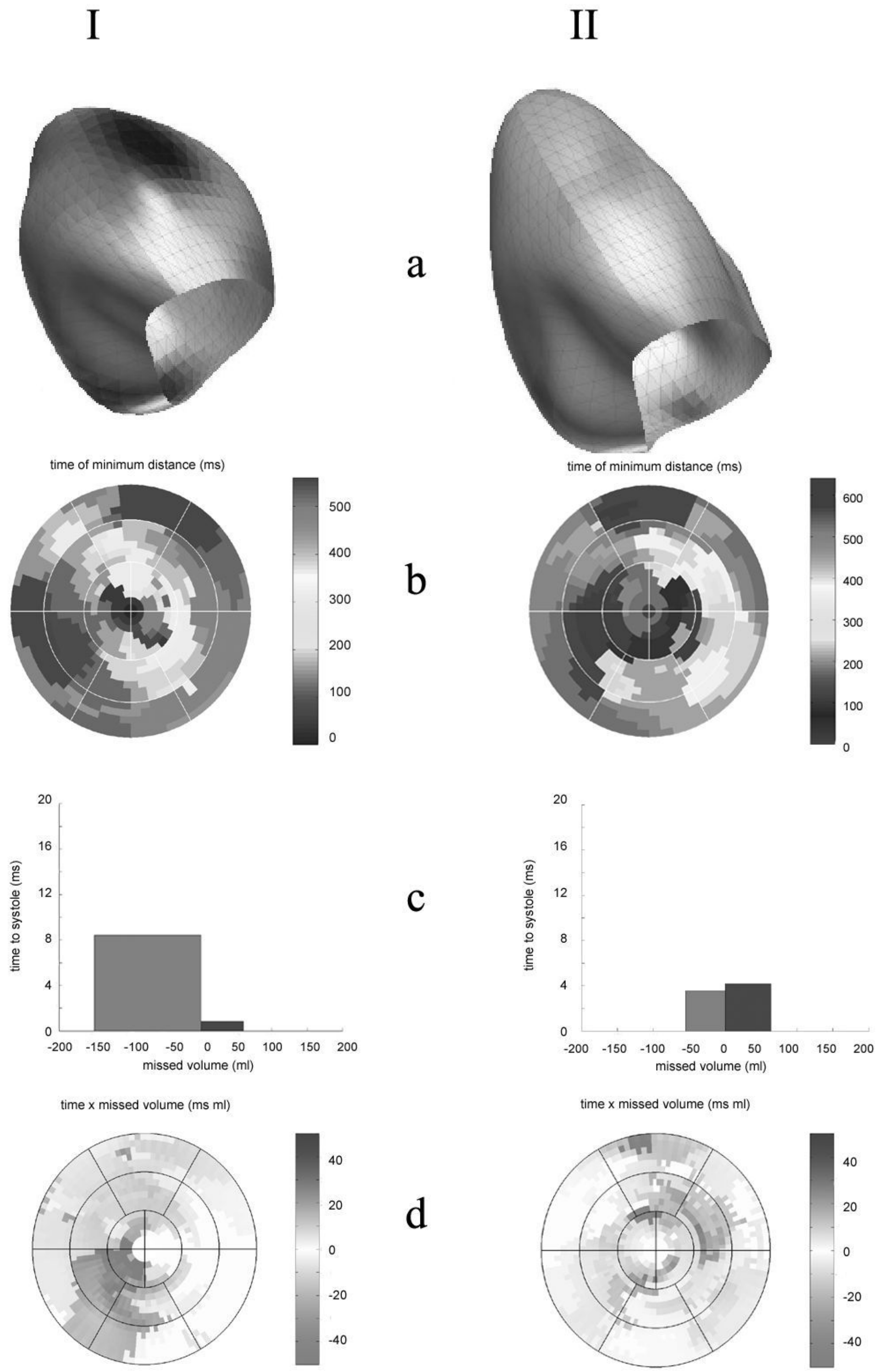

Figure 2. New visualisation methods for LV synchrony, data from one patient, I= biventricular pacemaker off, II= biventricular pacemaker on. a: snapshots from surface movie with color coding, b: timing bulls eye plots (ms), c: synchrony time-volume rectangles, d: recruitable volume per tetrahedron bulls eye plots (ml*ms).

much information. However, using these movies it is hard to determine LV asynchrony, because the human eye is not able to interpret the information that quick. Also, because the movies give a 3D view, not the whole ventricle can be seen from all sides. Building an intelligent graphic user interface could be an option, but that would certainly not allow cardiologists to *quickly* investigate asynchrony. Therefore these colour coded 3-D movies can best be integrated in specialized analytic workstations, as they give a lot of additional information, but it takes some time and skill to handle them.

The bulls eye plots (figure 2b and 2d) are highly appreciated by the cardiologists, not only because they provide a quick look into the whole of the LV, but also because synchrony can be determined in different ways using different parameters. The bulls eye plots for surface velocity and surface acceleration inward appeared to be not so valuable, because jitter in the LV 3D reconstruction algorithm introduces noise which is magnified enormously taking the first and second derivative with a relatively slow frame rate (25Hz, 40ms between frames). Of course the bulls eye plots depicting displacement, surface velocity or acceleration can also be shown as movies. Here the same user interface problems as described above count.

The rectangular plots (figure 2c) can give a quick look into the LV asynchrony, and it can easily be compared to different situations. In both graphs in figure 2c, it is clearly visible that the recruitable volume has decreased after pacemaker implantation, so the synchrony has increased. Further investigations have to be made to clinically evaluate these data and to see whether these parameters are clinically relevant. The same applies for the bulls eye representation of the time-recruitable volume plots of figure 2d, in which the localisation of asynchronous LV parts can clearly be seen.

An issue that can be discussed is the spatial resolution of the data. Cardiac ultrasound, as performed in this study, gives detailed information on the position of the endocardium. However rotational transformations of the LV cannot be tracked, because there are no markers available on which tracking can be performed. Although the bulls eye plots presented in figure 2 imply spatial rotational accuracy of <6° in figure 2b and even <1.6° in figure 2d, in time a LV short axis torsion between about 13° (apex) and –2° (base) is found in healthy volunteers using MRI techniques [4]. This could explain the circumferential 'motion' suggested in most bulls eye plots generated in this study. Meanwhile also the axis length (valve to apex) shortens during systole. As the model draws an equal amount of surface points onto every endocardium, this phenomenon can give a radial 'motion' in bulls eye plots of different parameters. These motion artefacts should be realised by clinicians regarding these visualisation methods.

Further research will be done to compare transoesophageal to transthoracic real time 3D imaging techniques. In the near future also the evaluation of the clinical value of the parameters plotted will be done. However, the bulls eye representation, in which also other parameters can easily be plotted into, gives an easy insight into the asynchrony of the heart.

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