Distinctive Features of the Functional Geometry of the Left Ventricle in Newborn Infants

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Abstract

Significant structural and functional development of the heart occurs during the ontogenesis. Age-related features of the left ventricular (LV) functional geometry (FG), i.e. changes in the LV shape during the cardiac contractile cycle, are insufficiently studied. We assessed the differences in quantitative characteristics of LVFG between healthy adults and newborn infants of the first five days of life.

We used classical 2D apical four-chamber position in ultrasound video loop to evaluate the following quantitative characteristics of the LVFG: spatial and temporal distributions of the two-dimensional estimate of the regional ejection fractions (REF) and respective indexes of heterogeneity of LV wall regional movements; dynamics of shape indexes (sphericity, conicity, shape-power index).

We conclude that LVFG develops during the ontogenesis: LVFG mainly determines by heterogeneous developmenst of longitudinal and circular fibers of the myocardium.

1. Introduction

This study is focused on the functional geometry (FG) of human heart during an early ontogenesis.

FG is a coordinated dynamical change in the geometry and functional state of LV during contraction and relaxation. Spatial and temporal patterns of the changes in the LV configuration during the cardiac cycle play the crucial role in the LV mechanical function [1]. Alterations of the patterns appear to be essential for the diagnostics, prognosis and treatment strategy of the heart pathology. The evaluation of the FG parameters is also important for understanding of the normal processes of heart remodeling in ontogenesis. The nature and role of different triggers of remodeling in the developing heart are still to be uncovered. The sequential closing of fetal communications, which dramatically changes the intracardiac hemodynamics, may play a role of such triggers. The knowledge and understanding of mechanisms of the trigger's action, and the data on FG in intrauterine and postnatal periods of early human ontogenesis are limited [2]. The aim of this paper is partially to fill in the lack in the data on FG in the developing heart.

2. Methods

2.1. Population

We have evaluated 2 groups of patients. First group is consisted of 42 adults without any heart problems in the histories (age 31±9 years, mean EF 71±10%, heart rate 68±2 b/min). The second group has 37 newborn babies without any abnormalities in fetal development (age 1-5 days of life, mean EF 60±3%, heart rate 134±5 b/min). Ultrasound diagnostic machines: Vivid 7 PRO (General Electric Co) and Philips HD 15 were used for echocardiography in adults and newborn babes group respectively.

2.2. Indexes of heterogeneity

LV images in classical 2D apical four-chamber position were recorded during the entire cardiac cycle simultaneously with ECG recording. All echocardiographic images were digitized and analyzed off-line with using custom made software [1]. End-diastole was defined as the frame with largest left ventricular (LV) area before the onset of QRS and end-systole as the frame with smallest LV cavity area. The endocardial LV contours were delineated manually in each frame.

Ventricular ejection fraction was derived from 2D end-diastolic and end-systolic images, using a modified Simpson's rule approach. We used also a 2D estimate of the ejection fraction that is the fractional difference between the end-diastolic and end-systolic image areas.

To characterize local movements of the wall we calculated the dynamical change in the segmental area for each segment during entire cardiac cycle. Regional left ventricle wall motion was assessed with using one of the conventional methods – that is so called radial method. Every contoured image (frame by frame) was overlapped by aligning their centers of mass (or center moments) with the end-diastolic one, that is used as the origin for radii drown to the digitized points of the contours. Total end-diastolic area was divided into 20 radial sectors of equal area (Fig. 1).

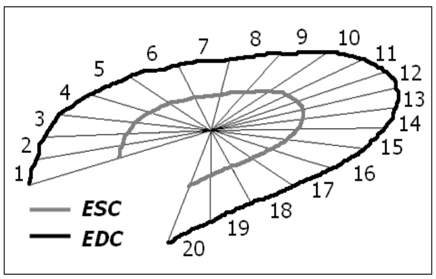

Figure 1. Radial method. EDC and ESC is end-diastolic and end-systolic contour respectively. Segments 1-8, 9-15 and 16-20 is lateral wall, apix and septum respectively.

The time dependent changes in the sector area during the cardiac cycle were calculated. Maximal relative (%) decrease in the sector area during the cardiac cycle against the end-diastolic area was evaluated for each sector and used as a two-dimensional estimate of the regional ejection fraction (REF). The ratio between the time required for approaching the REF and the time required for the global end-systole was used as an asynchrony index (AI) of the regional movement. Coefficients of variation for the REF and AI in one patient were used as the measures of spatial and temporal heterogeneity in the regional contraction.

2.3. Functional geometry indexes

To describe left ventricular functional geometry we used several shape indexes.

First of all we use conventional sphericity index (SI) [3] and Gibson index (GI) [4] which characterize a degree of shape circularity. We also used an apical conicity index (ACI) suggested earlier by DiDonato and co-authors [5] which shows the degree of conical shape in apical zone. ACI was calculated as ratio between the curvature radius of the parabola approximating apical zone of the LV contour to the half of the short Axis. The lesser the ACI means the more conical shape of the apical zone (more narrow).

Also we applied Fourier analyses suggested by Kaas and co-authors [6]. The contour is converted in polar coordinates and approximated with Fourier series. As confirmed in the processing of our data, eight terms in the Fourier series provides an approximation with an error less than 1%. This approximation is then used to calculate Fourier shape-power index, showing complexity of the LV shape as compared to the circle:

$$FSPI = \sum_{2}^{8} \left(\frac{C_n}{A_0}\right)^2 \qquad (1),$$

where $C_n^{\ 2} = A_n^{\ 2} + B_n^{\ 2}$ – is the amplitude of the corresponding harmonics in the expansion. The complexity of the contour shape and the degree of deviation from the circle is characterized by non-zero terms in the series, starting with the second.

2.4. Statistical analysis

Statistical analysis of data and group comparison was performed by “Statistica 7” and “StatGraphics plus 5.0” software packages. All calculated indexes were expressed as means ± Std.Error of the entire group of subjects. To compare groups a Mann-Whitney W test was used. Statistically significant difference between groups was since the P-value was lesser than 0.05, at the 95.0% confidence level.

3. Results

In our previous study we have characterized the spatio-temporal heterogeneity of LV regional movements in healthy adult subjects [1]. The regular nonlinear dependence of the REF mean value on the LV segment position (number) along the LV contour in a clockwise direction is shown in Fig.2 (solid line). The minimal REF value (48±2%) is performed by the apical segment. Two local REF maxima (60±2% and 63±2%) are located in the middle parts of the lateral LV wall and interventricular septum (Fig.2). The maximal and minimal values of REF were significantly different ($p<0.05$) not only between each other, but each of them differed from the 2D-estimate of the global ejection fraction (2DEF = 51±2%). The dependence of AI mean values on the segment number also demonstrated several local extremes, and resembled the REF dependence but only in mirror representation (Fig.2 solid line).

The heart rate of newborn infants was significantly higher than that of adults (134±5 vs 68±2 bpm). However, both the ejection fraction and 2DEF estimate in adults were higher than in newborn babes (71±2 and 56±2 vs 51±2% and 46±2%correspondently), but it did not differ significantly from each other. The mean REF dependence on the segment number was not as regular in newborn babes as in adults, with the range of mean REF values from 42±2% to 57±2% in different segments (Fig 2, dotted line). In contrast to adults, the dispersion analysis in newborn babes showed a significant ($p<0.05$) elevation of the mean REF over the mean 2DEF in only the middle septum segments (12-14 segments with mean REF).

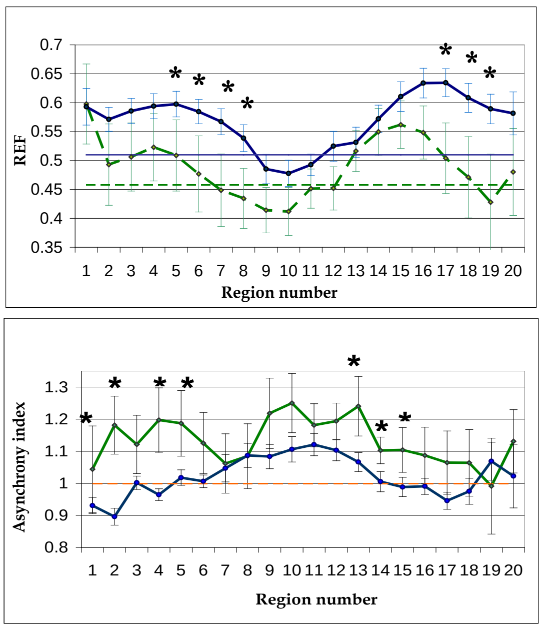

Figure 2. The dependence of the average REF and asynchrony index on the LV sector position along the LV contour (sector numbers are shown on the horizontal axis according to the numbers on figure 1). Thick solid line shows the data for the group of adults, newborn babes' data is presented by thick dotted line. Thin lines show the mean values of the 2D estimate of global ejection fraction in the groups.

The average coefficient of variation in individual REFs (which reflects a measure of spatial heterogeneity of regional LV wall movement) was significantly higher in newborn babes than in adults (24±2% vs 15±2%, correspondingly). This fact (together with earlier described lack in regularity for the regional segmental area changes along the LV wall) allows us to speculate that regular patterns of regional wall movements are not developed yet in newborn babes in contrast to adults.

The dependence of mean AI values (which characterized the temporal heterogeneity in regional LV wall movement) on the segment location in the wall was also non regular (chaotic) in newborn infants (Fig 2, dotted line). There was not found any significant difference in the AI between regions and between any of them and 1 either (which suggests deviations of the time for local end-systole from that of global end-systole are not appear to be statistically significant). Average coefficient of variation in individual AIs was also significantly higher in the group of newborn infants than in adults (19.6±1.6% vs 16.5±1.5 %). As distinct from adults with a significant negative correlation between the time of local systole and the systole value [1], such correlation was not found in the group of newborn infants. Therefore, the above data suggest that the regular coordination of regional LV function in time and space is not completely developed in newborn infants.

These results show significant spatial and temporal heterogeneity in the regional LV wall motion in adult heart, which acquires regular character during ontogenesis. The data show the higher contribution of septal segments to LV contraction suggesting its earlier maturation.

Examining indices of LV geometry, we found the following. First of all the value of both SI and GI was larger in infants group (Fig. 3). We can suppose that theirs shape is more spherical. In both groups the indexes of circularity decrease from the end-diastole to the end-systole. So the LV shape appears to become less spherical during systole. In newborn babes the relative change of indexes was statistically smaller than that in adults (2.2±2% vs 10.5±2 %). In other words, the LV shape appears to become less spherical during systole in adults, while it tends to keep the spherical shape in newborn babes.

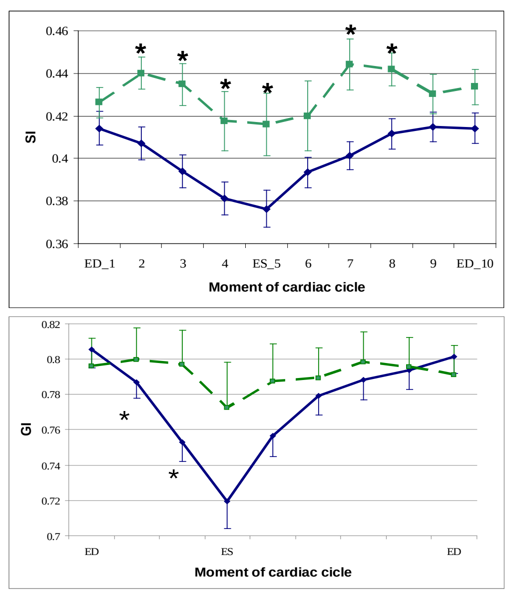

Figure 3. Indexes of circularity.

SI is spherisity index, GI – Gibson index which stand lower from end diastole to end systole. Stars show statistical differences between newborn babes (dotted line) and adults (solid line).

Analysis of the changes in short and long LV axes from diastole to systole allows one to explain the above group distinction. The relative change in length of long and short axis was almost equal in newborn (19.5±1.6% vs 21.2±2.5%). That can mean contraction is more uniform at both longitudinal and circumferential directions in this group. In adults the short axis change was higher than in the long axis during systole (34.2±1.6% vs 26.7±1.5%), suggesting the greater contribution of the circular layers to the LV contraction.

The change in both conicity and Fourier indexes during contraction also suggest an increase in the shape complexity from diastole to systole, which is more prominent in adults that in newborn babes (Figure 4).

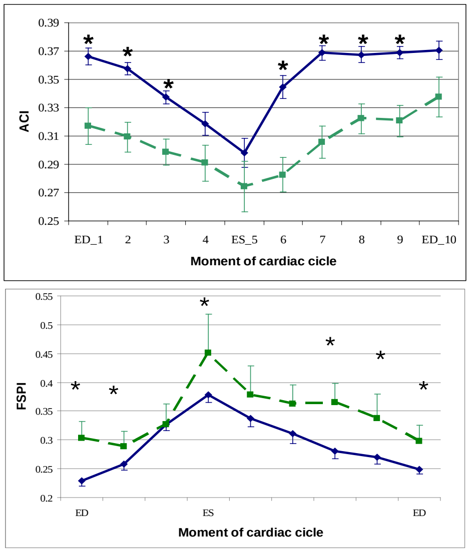

Figure 4. Apical conicity index (ACI) and Fourier shape-power index (FSPI). Stars show statistical differences between newborn babes (dotted line) and adults (solid line).

This result allows us to speculate on the time-ordered development of the functional activity of the circular and longitudinal myocardial layers in the LV wall during ontogenesis.

4. Conclusions

This study aimed at evaluation of the differences in endocardial wall motion at different human ages. We show that (i) the heterogeneity of regional LV wall motion has a regular spatio-temporal pattern which develops during ontogenesis; (ii) in human newborn babes (first 5 days of life) the heterogeneity patterns are not developed yet, segmental movements of LV wall are irregular vs those in adults and demonstrates higher spatio-temporal variability; (iii) the data show the higher contribution of septal segments to LV contraction suggesting its earlier maturation.; (iv) quantitative indexes (CV) of the heterogeneity of individual regional LV wall motion are sensitive and specific to separate investigated groups.

This study shows encouraging results regarding the using quantitative indexes of LV functional geometry. The differences in wall contraction were found both longitudinal and circumferential directions in adults and newborn children. We suggest that this indexes could be clinical significant and help to better evaluate contractile function of heart in routine studies.

Further we plan to study the LV fetuses at different stages of gestation. Also, we continue the study of children including children of different ages (10 days, 1 month and older).

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