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Left ventricular contraction geometry - a new sight at the problem through the myocardium structural organization

Purpose - to establish normative values of global systolic strain and strain rate in the longitudinal, circular and radial directions, as well as the amount of apical and basal rotation, twist and to find out age related features of myocardium strain processes. Object and methods. The study included 33 volunteers - 23 (69.6%) women and 10 (30.4%) men aged an average of 26,7 ± 0,5 years (the 1st group); and 28 volunteers - 12 (43%) women and 16 (57%) men aged on average 55 ± 1,2 years (the 2nd group). Using speckle tracking echocardiography values of global systolic strain of left ventricular (LV) in longitudinal, circular and radial direction were measured, as well as apical and basal rotation and twist. Results. In patients of group 2 there were observed a significant reduction of longitudinal strain by 7%, of the rate of longitudinal strain - 25%, and the rate of circular strain - 17%, compared to the indices of group 1.There were no gender differences in myocardial strain processes in both groups. Average ranks of apical and basal rotation, twist made 5,1 ± 0,3; 4,3 ± 0,3 and 7,8 ± 0,8 °, respectively. Conclusions. With age there is a decrease in retractile subclinical LV myocardial function, with no gender differences in myocardium strain processes in both groups. Normative values of apical and basal rotation, left ventricle twist have been established, which is important prior to their use in daily clinical practice.

Keywords: *speckle tracking echocardiography, left ventricular contraction geometry, strain and strain rate, rotation, twist.*

Preamble

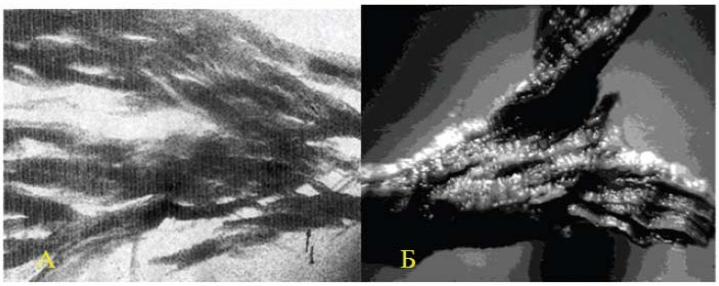
Recently, issues of the left ventricular (LV) remodelling have been studied, including its contraction geometry, and naturally a question on assessment of its functional morphology is raised, taking into account structural orientation of myocardial fibres (Kovalenko V.N., 2004a, b; Notomi Y. et al ., 2006a; b; Sengupta P.P. et al., 2006a; b; Ashikaga H. et al., 2009; Geyer H. et al., 2010). J. Ross et al (1967), considering the structural organization of the LV, said that to build an accurate model, information about succession of change of a cavity form, wall thickness during the cardiac cycle is needed, as well as distribution of stress associated with displacement of fibres. The results of the qualitative and quantitative analysis of heart at macro-and microscopic levels represent a morphological basis for creating a model of the heart, which would allow assessing the functional significance of myocardial fibres orientation (Kovalenko V.N., 2001, Kovalenko V.N., 2004a, b). Myocardium is composed of various thickness and length bundles of muscle fibres (Fig. 1), myocardial fibre bundles are united with layers of connective tissue into structurew of higher order, which in the vertical plane and cross-section have the shape of plates. Myocardial plates are naturally ordered structural elements of myocardium structure (Kovalenko V.N., 2004a, b).

Currently, the most recognized LV model is the concept of spiral myocardium structure. It was proposed at the beginning of the twentieth century by the group of anatomists and ultimately was formed in 1935 (Robb J.S., Robb R.C., 1942). Nowadays, with the development of new technologies of visualization of the heart, this concept is supplemented by new data on morphofunctional organization and biomechanics of the left ventricular contraction (Smiseth O.A., Remme E.W., 2006).

Spiral arrangement of myofibrils is evident at an early stage of the heart embryogenesis (Tobita K. et al., 2005). At this time the primitive tubular heart develops from two layers of epithelial cells. The inner layer multiplies and grows towards the left ventricular cavity to form muscle bundles, chords and trabeculae. The cells of the outer layer proliferate and undergo progressive compaction according to the functional needs of the growing embryo (Sedmera D. et al., 2000).

Myocardium holistic design at the macro- and microscopic level is a complex topographic system of fibres bundles oriented in different directions (Kovalenko V.N., 2004a, b).

Fig.1.



Myocardium structural design. *А - Myocardium fibres bundles (20 times enlargement), Б - Myocardium fibres bundles separation.*

External bundles of fibres as they recess in the wall of the heart are gradually changing the angle, and at mid-wall their course becomes circular with angle 0°. Inner bundles of fibres have a shape of a reverse spiral against external ones - (Fig.2) (Kovalenko V.N., 2004a, b).

Studying orientation of bundles of fibres showed that a layer of "pure" circular fibres is expressed just slightly. Moreover, the change in direction of the bundles of fibres from oblique to circular happens so smoothly that they virtually have no boundary (Kovalenko V.N., 2004a, b).Circular bundles of fibres can be observed only in the middle section of LV and in small quantities. The current view of the predominance of circular fibres in the wall of the left ventricle is obviously due to the fact that the circular fibres are also considered to contain longitudinal fibres with a small angle (Kovalenko V.N., 2004a, b).

Thus, LV is the unity of two spiral fibre layers where the inner (subendocardial) layer of longitudinal fibres forms a twisted right-hand helix, and the external (subepicardial) layer - twisted left-hand helix (Fig.3) (Nielsen P.M.. et al., 1991; Vendelin M. et al., 2002; Chen J. et al., 2005; Sengupta P.P. et al., 2006a; b).

With the same degree of shortening, the left ventricular cavity volume will decrease by 15%, if muscle fibres are placed parallel to the long axis of the chamber, by 30% at transverse fibres arrangement, and almost by 60% - provided that the fibres have a spiral course (Ingels N.B.Jr ., 1997; Buckberg G.D. et al., 2004).

Systole ventricular muscle fibres undergo strain in the longitudinal and circular directions, the wall thickens, and the left ventricle itself is twisted along the long axis (Yip G. et al., 2003). Longitudinal strain of LV means its fibre shortening of right-hand and left-sided spirals in the direction of the heart apex to the basal (Heimdal A. et al., 1998). Fibre shortening corresponds to the circular strain at LV perimeter perpendicular to the longitudinal plane of section (Saito K. et al., 2009).

Naturally, the shortening of the fibres in the longitudinal and circular direction will lead to thickening of the ventricular wall. However, the left ventricular wall thickening is not only the result of a simple shortening of individual myocytes, but also due to the effect of shifting groups of fibres. So, due to the displacement of groups of longitudinal fibres and their shortening by 15%, left ventricular wall thickens in the radial direction > 40%, which in turn leads to an increase in ejection fraction (EF) of LV> 60% (Covell J.W., 2008).

Rotation, twist and torsion are relatively new concepts that are used to explain the phenomenon of left ventricular twist. The term "rotation" means LV rotation in the transverse plane when viewed from its top, and is expressed by the angle between the radial lines connecting the centre of LV conditional to its walls in diastole relative to their displacement in systole (Lorenz C.H. et al. 2000). Units of rotation are degrees. Rotation of the top and basal LV goes in the opposite direction. Twist means left ventricular twist around the longitudinal axis and arithmetically is the sum of angles of rotation between the apical and basal parts of LV. The unit of twist measuring is also degree (Fig.4). Torsion is actually a twist normalized to the distance from the apex to the base of LV and is calculated as the ratio of left ventricular twist angle in degrees (°) to the distance between the scanned planes in centimetres (cm), at which level a recording was performed to calculate video loops to calculate apical and basal rotation of LV expressed in °/cm.

One interesting question: how LV having quite a complex structural organization is able to provide high performance pump function. Changing the LV geometry already takes place at the phase of isovolumic reduction. Mechanical ventricular activity begins with shortening of the subendocardial fibres of middle and apex of LV with subsequent spread to the basal section (Sengupta P. P. Et al., 2006a; b; 2007a; b).

It is important to note that in this phase, subendocardial fibre shortening occurs simultaneously with stretching subepicardial fibres as they are excited the last, due to the direction of excitation spread from endocardium to epicardium (Sengupta P.P. et al., 2005; Ashikaga H. et al., 2007, 2009; Covell J.W., 2008; Remme E.W. et al., 2008).

Shortening subendocardial fibres while stretching subepicardial fibres determines the initial movement of the top clockwise, and basal left ventricular department - in the opposite direction (Fig.4Б, 5A) (Ingels N.B.Jr. Et al., 1989; Sengupta P.P. et al., 2006a; b; 2007a; b).

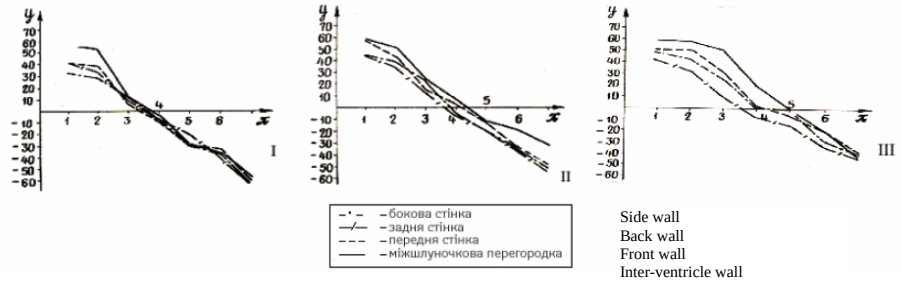
By the early phase of the expulsion of blood from the left ventricle, all myocardium is excited, so this phase features simultaneous shortening of subendocardial and subepicardial fibres (Fig.5Б) (Sengupta P.P. et al., 2005; 2006a; b).

Although the magnitude of shortening of the subendocardial fibres dominates the one of subendocardial, the larger location radius of the latter leads to a more pronounced torque which also results in rotation of the apex of the heart counter clockwise and basal part - clockwise in the blood expulsion phase. As a result, LV twist goes in accordance with the direction of subendocardial fibres (Fig.4Б, 5Б) (Ingels N.B.Jr. Et al., 1989). Importantly, the twist reinforces the shortening of left ventricular in the circular direction (Ingels N.B.Jr. Et al., 1989). In subendocardial part the twist placing entails restructuring of fibres so that they are shifted to the centre of LV, causing wall thickening. Basal part of LV pulls up to the top and the left ventricular longitudinal axis contracts.

Twisting can evenly distribute the tension in the muscle fibres within the walls of the left ventricle (Arts T. et al., 1982). The mathematical model shows that the twist contributes to shortening of the sarcomere by 0.2 microns in subepicardial part of LV, and by 0.48 microns - in subendocardial part (Beyar R., Sideman S., 1986). In case there is no twist, sarcomere shortening in subepicardial part, would decline by 0.10 microns, and in subendocardial part – would increase by 0.55 microns. Thus, if the twist disappears, subendocardial stress and strain will increase, which automatically will increase myocardial oxygen demand and will reduce performance of ventricular pump function (Beyar R., Sideman S., 1986).

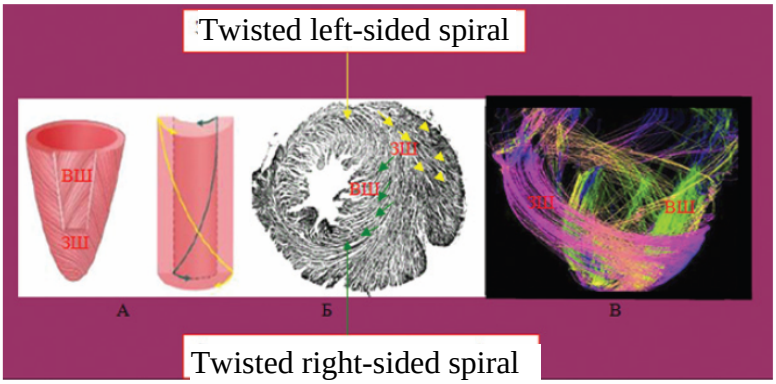
Twisting and shifting of subendocardial fibres deforms the collagen matrix and cytoskeletal proteins (titin), which contributes to the accumulation of elastic potential energy, which is then used for diastolic LV untwisting (Rademakers F.E. et al., 1992; Bell S.P. et al., 2000; Notomi Y. et al., 2006a; b; Wu Y., Kovacs S.J., 2006).

Fig.2



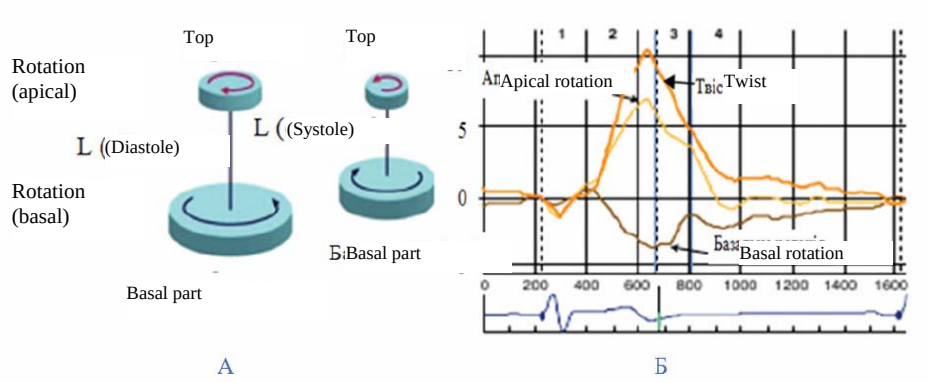
Change of space orientation of LV myocardium fibre bundles in control points by depth and height: x – depth of section from epicardium to endocardium; y – angle of fibre bundles in relation to circular lines of the reference system; I – basal part; II – middle; III – LV top.

Fig.3



Two-spiral model of LV structure. А - schematic view, Б – gross specimen, В – fibres direction according to MRI, ВШ – Internal (subendocardial) layer of longitudinal fibres that form a right-twisted spiral; ЗШ - external (subepicardial) layer of longitudinal fibres that form a left-twisted spiral. Green arrows - direction of subendocardial fibres; yellow arrows - direction of subepicardial longitudinal fibres.

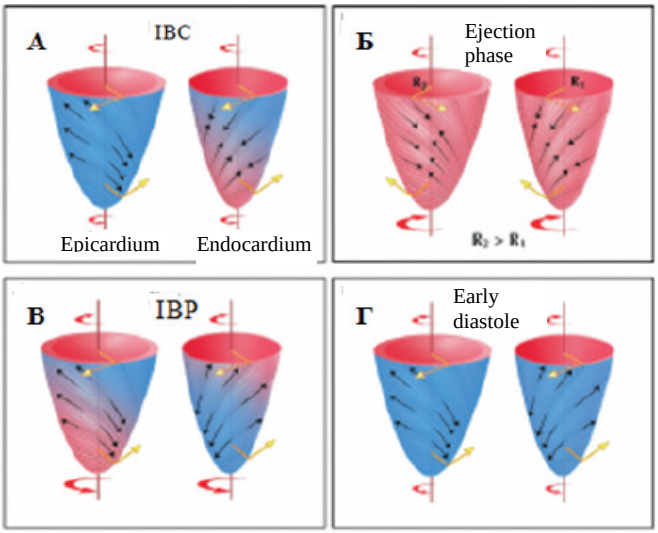
Fig.4



Schematic (А) and graphical (Б) images of left ventricular twist. 1 - isovolumic reduction phase; 2 - expulsion of blood into the aorta phase, 3 - isovolumic relaxation phase; 4 - early diastolic filling phase; L – LV longitudinal axis length.

LV untwisting begins already at the isovolumic relaxation phase (Fig.4Б) and ends at the early diastole. At this time, the strain vectors of subepicardial and subendocardial fibres coincide, causing rotation of the top clockwise, and the left ventricular basal part - in the opposite direction (Fig.4В, 5Г). LV untwisting stops at the opening of mitral valves, causes intraventricular pressure gradient between the LV basal part and the top, that promotes diastolic blood suction and leads to reduced LV filling pressure. One of the studies demonstrated a linear dependence of the LV untwisting rate on the peak of gradient of diastolic suction (Notomi Y. et al., 2006 a; b). It is important to note that the best determinant of maximal oxygen utilization during exercise for both healthy subjects and patients with heart failure is the ability to increase diastolic blood suction (Rovner A. et al., 2005).

Fig.5



The phase structure of the left ventricular rotation during the cardiac cycle. A - isovolumic contraction (IVC) of LV; Б - LV ejection phase; B- isovolumic relaxation (IVR) of LV; Г - early diastole. Red arrows - direction of LV rotation; black - direction of the longitudinal fibres; yellow - direction of the dominant torque; R_1 - radius of torque of subendocardial fibres; R_2 - radius of torque of subepicardial fibres.

In general longitudinal contractility biomechanics is the most vulnerable LV element and can be highly sensitive marker of disease start. At proper functioning of circular fibres and longitudinal fibres of subepicardial layer, circular LV shortening and twisting remain normal, and therefore EF (ejection fraction) is unchanged. However, at this stage of the disease longitudinal biomechanics' early diastolic component can be damaged, which is mainly provided by subendocardial fibres. The result will be decrease or delay of LV untwisting, which will increase LV filling pressure, and hence – the diastolic dysfunction. On the other hand, acute transmural myocardial damage or progression of chronic disease will facilitate involvement of circular fibres and longitudinal fibres of subepicardial layer in the pathological process, so there will be changes in circular shortening and twist that eventually will lead to a decrease in LVEF (Bell S.P. et al. , 2000; Geyer H., et al., 2010).
Thus, understanding the role of different layers of fibre in providing systolic and diastolic functions allows determining the depth of myocardial injury, will reveal a new view on the mechanism of LV dysfunction.
The article's purpose is to establish normative values of global systolic strain and strain rate in the longitudinal, circular and radial directions, values of the apical and basal rotation, twist, and to find out age features of myocardium strain processes.

Research object and methods

The study included 33 volunteers - 23 (70%) women and 10 (30%) men aged in average 26,7 ± 0,5 years, being group 1; and 28 volunteers - 12 (43%) women and 16 (57%) men aged in average 55 ± 1,2 years, which were assigned to group 2. To exclude cardiovascular disease, a detailed clinical examination was conducted, as well as transthoracic echocardiography in a one-dimensional, two-dimensional, colour, pulsed-wave and permanent-wave Doppler modes with tissue Doppler sonography. Echocardiography was performed on the ultrasound scanner «Aplio Artida» («Toshiba Medical System Corporation», Japan). LVEF was determined by method of Discs by Simpson (Lang R. et al., 2006), the index of the end-systolic LV volume (iESV), index of the end-diastolic LV volume (iEDV), index of stroke volume (iSV), the ratio of early (E) to late (L) LV filling (E/ L), time of LV isovolumic ventricular relaxation (IVRT), E deceleration time (Dec Time E), speed of lateral movement of the fibrous ring of the mitral valve in systole (S) and early diastolic velocity of the lateral mitral valve's annulus fibrosus (Ea). LV myocardial mass (LVMM) was determined by linear sizes using formula recommended by the American Society of Echocardiography, followed by the calculation of the LVMM index (iLVMM) (Lang R. et al., 2006).
Speckle-tracking echocardiography (STE) was performed by the method described in our previous publication (V.M. Kovalenko et al., 2012). To analyze the performance of strain and strain rate, software package Wall Motion Tracking has been used. Overall longitudinal systolic strain (OLSS) was determined, as well as overall longitudinal systolic strain rate (OLSSR), circular overall systolic strain (COSS) and circular overall systolic strain rate (COSSR), as well as overall radial systolic strain (ORSS) and overall radial systolic strain rate (ORSSR).
To determine the apical (Arot) and basal (Brot) LV rotation, recording of video clips on the short axis of the left ventricle respectively at the level of LV and mitral valve top was performed. LV twist was calculated as the difference between Arot and Brot, which is mathematically expressed as the sum as for module values of Arot and Brot.
Statistical analysis of the results was performed using Microsoft Excel and SPSS for Windows. Significance of differences was determined using Student's criterion.

Results and their discussion

When comparing the two groups, no significant difference in averages of iEDV, iESV, iSV, EF, Dec Time E were revealed (Table1). In group 2 the average value LVMM was higher by 13% ($p < 0.05$), and iLVMM - by 15% ($p < 0.05$) compared with those of group 1. In addition, the group 2 demonstrated significantly lower average values of S - by 25%, Ea – by 27%, E/A – by 33%, and the average value of IVRT - higher by 14% compared with those in group 1.
Thus, in the elderly there was observed a greater value LVMM and changes of diastolic LV function, indicating a slowing LV relaxation. Our results coincide with the results of scientific papers based on prior research in this area (Klein A.L. et al., 1994; de Simone G. et al., 2005). According to the literature, systolic LV function is preserved and there are no age-related changes in LVEF, SV and cardiac output at rest (Lakatta E.G., 1993, 2000).
Systolic velocity of the mitral valve of annulus fibrosus and the amplitude of its motion is correlated with overall LV contractility (Alekhin M.N., 2002, Nikitin N.P., Clyland J.F., 2002; Belenkov J.N., Agmanova L.T., 2003). The main drawback of study of mitral valve ring excursion is that its motion is due not only to LV function, but also to anatomical and functional state of the left atrium (Nageh M.F. et al., 1999), to hemodynamic factors - the level of pre-and post-load. Therefore, we aimed to examine age-related aspects of LV systolic function using STE, since the impact of these factors on the magnitude of strain and strain rate of left ventricular is minimal.
Thus, in group 2 we observed significantly lower mean values of OLSS – by 7% OLSSR – by 25% and COSSR – by 17% compared with those of group 1 (Table 2). There was no significant difference of averages of COSS, ORSS, ORSSR between groups (see Table 2).

In our investigation we did not observe gender differences in myocardial strain processes in the 1st and the 2nd group (Table 3). Thus, EFLV as the indicator of overall LV contractility does not reflect the full features of age-related changes of systolic LV function. STE has greater potential in this area of research, and special attention should be given to speed and amplitude parameters of longitudinal contractility and COSSR.

Table 1 **Age-related features of systolic and diastolic LV functions**

Indicator	Value (M±m) Group 1 (n=33)	Group 2 (n=28)	p
iEDV, ml/m^2	56,3±1,9	55,3±1,0	>0,05
iESV, ml/m^2	20,9±0,6	19,8±0,6	>0,05
iSV, ml/m^2	34,4±1	35,0±0,8	>0,05
EF, %	63±0,4	64±0,9	>0,05
LVMM, g	145,1±7,2	164,4±6,2	<0,05
iLVMM, g/m^2	76,1±2,7	84,1±2,7	<0,05
E/A	1,6±0,07	1,2±0,05	<0,001
Dec Time E, ms	182,2±3,9	183,4±4,8	>0,05
IVRT, ms	64,1±1,9	73,1±2,8	<0,05
Ea, cm/s	18,8±0,5	13,8±0,4	<0,001
S, cm/s	18,4±0,6	13,8±0,4	<0,001

Table 2 **Age-related features of LV strain and LV strain rate**

Indicator	Value (M±m) Group 1 (n=33)	Group 2 (n=28)	p
OLSS, %	17,0±0,3	15,9±0,28	<0,01
OLSSR, s^{-1}	1,02±0,03	0,81±0,02	<0,001
COSS, %	17,0±0,4	16,5±0,4	>0,05
COSSR, s^{-1}	1,07±0,05	0,91±0,03	<0,01
ORSS, %	33,1±1,5	36,0±1,1	>0,05
ORSSR, s^{-1}	1,88±0,08	1,9±0,05	>0,05

Table 3 **Gender and age-related features of LV myocardium strain and strain rate**

Indicator	Value (M±m) Group 1 (n=33)			Group 2 (n=28)		
	Men	Women	p	Men	Women	p
OLSS, %	16,7±0,8	17,1±0,3	>0,05	15,7±0,4	16,2±0,7	>0,05
OLSSR, s^{-1}	0,9±0,07	1,04±0,04	>0,05	0,8±0,03	0,82±0,02	>0,05
COSS, %	17,4±1,2	16,9±0,4	>0,05	16,8±0,5	16,2±0,7	>0,05
COSSR, s^{-1}	1,2±0,16	1,0±0,03	>0,05	0,88±0,03	0,95±0,05	>0,05
ORSS, %	34,6±2,8	32,5±1,8	>0,05	36,5±1,17	35,3±2,2	>0,05
ORSSR, s^{-1}	1,95±0,18	1,87±0,08	>0,05	1,94±0,07	1,89±0,1	>0,05

Given the importance of LV twist in providing systolic and diastolic LV function and the need to establish reference standards of rotation and twist before use in general clinical practice, we have learned values of LV twist in group 2. Thus, in our investigation Arot value was 5,1 ± 0,3°, Brot - 4,3 ± 0,3°, and the value of LV twist was between 7,8 ± 0,8°, which are comparable with the results of earlier researches (Mor-Avi V. et al., 2011).

Conclusions

Thus, no gender differences discovered in strain processes of LV myocardium both in young adults (average age - 26,7 ± 0,5 years) and in older healthy individuals (average age - 55 ± 1,2 years). In older patients we can see subclinical reduce of retractile LV function. Normative values of Arot, Brot and LV twist have been established, which is important before their widespread use in routine clinical practice.

Literature:

Alekhin M.N. (2002) Possibilities of tissue Doppler practical use. Lection 1. Tissue Doppler, principles of the method and its features. Main modes, methods of registration and analysis. Ultrasound and functional diagnosis, 3: 115-125.

Belenkov J.N., Agmanova N.T. (2003) Diastolic heart function in patients with chronic cardiac insufficiency and diagnosis methods of its impairment with tissue myocardial Doppler echocardiography, 11: 58-65.

Kovalenko V.M., Nesukay O.G. Polenova N.S., et al. (2012) Speckle tracking echo-cardiography: normative values and role of the method in study of LV systolic and diastolic function. Ukr. cardiol. magazine, 6: 103-109.

Kovalenko V.N. (2001) Heart failure and LV remodelling in patients with rheumatic heart defects. Cardiovascular Surgery. Yearbook of scientific publications of the Association of Cardiovascular Surgeons of Ukraine, 9: 168-171.

Kovalenko V.N. (2004a) Structural and functional heart ventricles morphology as the basis of contraction geometry change. Part I. Qualitative analysis. Ukr. cardiol. magazine, 2: 78-82.

Kovalenko V.N. (2004b) Structural and functional heart ventricles morphology as the basis of contraction geometry change. Part II. Qualitative analysis. Ukr. cardiol. magazine, 3: 85-91.

Nikitin N.P., Clyland J.F. (2002) Application of tissue Doppler myocardial echocardiography in cardiology. Cardiology, 3: 66-79.

Arts T., Veenstra P.C., Reneman R.S. (1982) Epicardial deformation and left ventricular wall mechanisms during ejection in the dog. Am. J. Physiol., 243(3): H379-H390.

Ashikaga H., Coppola B.A., Hopenfeld B. et al. (2007) Transmural dispersion of myofiber mechanics: implications for electrical heterogeneity *in vivo.* J. Am. Coll. Cardiol., 49(8): 909-916.

Ashikaga H., van der Spoel T.I., Coppola B.A., Omens J.H. (2009) Transmural myocardial mechanics during isovolumic contraction. JACC Cardiovasc. Imaging, 2(2): 202-211.

Bell S.P., Nyland L., Tischler M.D. et al. (2000) Alterations in the determinants of diastolic suction during pacing tachycardia. Circ. Res., 87(3): 235-240.

Beyar R., Sideman S. (1986) Left ventricular mechanics related to the local distribution of oxygen demand throughout the wall. Circ. Res., 58(5): 664-677.

Buckberg G.D., Weisfeldt M.L., Ballester M. et al. (2004) Left ventricular form and function: scientific priorities and strategic planning for development of new views of disease. Circulation, 110(14): e333-e336.

Chen J., Liu W., Zhang H. et al. (2005) Regional ventricular wall thickening reflects changes in cardiac fiber and sheet structure during contraction: quantification with diffusion tensor MRI. Am. J. Physiol. Heart Circ. Physiol., 289(5): H1898-H1907.
Covell J.W. (2008) Tissue structure and ventricular wall mechanics. Circulation, 118(7): 699-701.
de Simone G., Daniels S.R., Kimball T.R. et al. (2005) Evaluation of concentric left ventricular geometry in humans: evidence for age-related systematic underestimation. Hypertension, 45(1): 64-68.
Geyer H., Caracciolo G., Abe H. et al. (2010) Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. J. Am. Soc. Echocardiogr., 23(4): 351-369.
Heimdal A., Stoylen A., Torp H., Skjaerpe T.
(1998) Real-time strain rate imaging of the left ventricle by ultrasound. J. Am. Soc. Echocardiogr., 11(11): 1013-1019.
Ingels N.B. Jr, Hansen D.E., Daughters G.T. 2nd et al. (1989) Relation between longitudinal, circumferential, and oblique shortening and torsional deformation in the left ventricle of the transplanted human heart. Circ. Res., 64(5): 915927.
Ingels N.B. Jr. (1997) Myocardial fiber architecture and left ventricular function. Technol. Health Care, 5(1-2): 45-52.
Klein A.L., Burstow D.J., Tajik A.J. et al.
(1994) Effects of age on left ventricular dimensions and filling dynamics in 117 normal persons. Mayo Clin. Proc., 69(3): 212-224.
Lakatta E.G. (1993) Cardiovascular regulatory mechanisms in advanced age. Physiol. Rev., 73(2): 413-467.
Lakatta E.G. (2000) Cardiovascular aging in health. Clin. Geriatr. Med., 16(3): 419-444.
Lang R.M., Bierig M., Devereux R.B. et al.; American Society of Echocardiography's Nomenclature and Standards Committee; Task Force on Chamber Quantification; American College of Cardiology Echocardiography Committee; American Heart Association; European Association of Echocardiography, European Society of Cardiology (2006)
Recommendations for chamber quantification. Eur. J. Echocardiogr., 7(2): 79-108.
Lorenz C.H., Pastorek J.S., Bundy J.M. (2000) Delineation of normal human left ventricular twist throughout systole by tagged cine magnetic resonance imaging. J. Cardiovasc. Magn. Reson., 2(2): 97-108.
Mor-Avi V., Lang R.M., Badano L.P. et al. (2011) Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography. J. Am. Soc. Echocar- diogr., 24(3): 277-313.
Nageh M.F., Kopelen H.A., Zoghbi W.A. et al. (1999) Estimation of mean right arterial pressure using tissue Doppler imaging. Am. J. Cardiol., 84(12): 1448-1451, A8.
Nielsen P.M., Le Grice I.J., Smaill B.H., Hunter P.J. (1991) Mathematical model of geometry and fibrous structure of the heart. Am. J. Physiol., 260(4 Pt 2): H1365-H1378.
Notomi Y., Martin-Miklovic M.G., Oryszak S.J. et al. (2006a) Enhanced ventricular untwisting during exercise: a mechanistic manifestation of elastic recoil described by Doppler tissue imaging. Circulation, 113(21): 2524-2533.
Notomi Y., Srinath G., Shiota T. et al. (2006b) Maturational and adaptive modulation of left ventricular torsional biomechanics: Doppler tissue imaging observation from infancy to adulthood. Circulation, 113(21): 2534-2541.
Rademakers F.E., Buchalter M.B., Rogers W.J. et al. (1992) Dissociation between left ventricular untwisting and filling. Accentuation by catecholamines. Circulation, 85(4): 1572-1581.
Remme E.W., Lyseggen E., Helle-Valle T. et al. (2008) Mechanisms of preejection and postejection velocity spikes in left ventricular myocardium: interaction between wall deformation and valve events. Circulation, 118(4): 373-380.
Robb J.S., Robb R.C. (1942) The normal heart. Anatomy and physiology of the structural units. Am. Heart J., 23(4): 455-467.

Ross J. Jr, Sonnenblick E.H., Covell J.W. et al. (1967) The architecture of the heart in systole and diastole. Technique of rapid fixation and analysis of left ventricular geometry. Circ. Res., 21(4): 409421.
Rovner A., Greenberg N.L., Thomas J.D., Garcia M.J. (2005) Relationship of diastolic intra- ventricular pressure gradients and aerobic capacity in patients with diastolic heart failure. Am. J. Physiol. Heart Circ. Physiol., 289(5): H2081-H2088.
Saito K., Okura H., Watanabe N. et al. (2009) Comprehensive evaluation of left ventricular strain using speckle tracking echocardiography in normal adults: comparison of three-dimensional and twodimensional approaches. J. Am. Soc. Echocardiogr., 22(9): 1025-1030.
Sedmera D., Pexieder T., Vuillemin M. et al. (2000) Developmental patterning of the myocardium. Anat. Rec., 258(4): 319-337.
Sengupta P.P., Khandheria B.K., Korinek J. et al. (2005) Biphasic tissue Doppler waveforms during isovolumic phases are associated with asynchronous deformation of subendocardial and sub-epicardial layers. J. Appl. Physiol., 99(3): 1104-1111.
Sengupta P.P., Khandheria B.K., Korinek J.et al. (2006a) Apex-to-base dispersion in regional timing of left ventricular shortening and lengthening. J. Am. Coll. Cardiol., 47(1): 163-172.
Sengupta P.P., Khandheria B.K., Korinek J. et al. (2007a) Left ventricular isovolumic flow sequence during sinus and paced rhythms: new insights from use of high-resolution Doppler and ultrasonic digital particle imaging velocimetry. J. Am. Coll. Cardiol., 49(8): 899-908.
Sengupta P.P., Korinek J., Belohlavek M. et al. (2006b) Left ventricular structure and function: basic science for cardiac imaging. J. Am. Coll. Cardiol., 48(10): 1988-2001.
Sengupta P.P., Krishnamoorthy V.K., Korinek J. et al. (2007b) Left ventricular form and function revisited: applied translational science to cardiovascular ultrasound imaging. J. Am. Soc. Echocardiogr., 20(5): 539-551.
Smiseth O.A., Remme E.W. (2006) Regional left ventricular electric and mechanical activation and relaxation. J. Am. Coll. Cardiol., 47(1): 173-174.
Tobita K., Garrison J.B., Liu L.J. et al. (2005) Three-dimensional myofiber architecture of the embryonic left ventricle during normal development and altered mechanical loads. Anat. Rec. A. Discov. Mol. Cell. Evol. Biol., 283(1): 193-201.

Vendelin M., Bovendeerd P.H., Engelbrecht J., Arts T. (2002) Optimizing ventricular fibers: uniform strain or stress, but not ATP consumption, leads to high efficiency. Am. J. Physiol. Heart Circ. Physiol., 283(3): H1072-H1081.
Wu Y., Kovacs S.J. (2006) Frequency-based analysis of the early rapid filling pressure-flow relation elucidates diastolic efficiency mechanisms. Am. J. Physiol. Heart Circ. Physiol., 291(6): H2942-H2949.
Yip G., Abraham T., Belohlavek M., Khandheria B.K. (2003) Clinical applications of strain rate imaging. J. Am. Soc. Echocardiogr., 16(12): 1334-1342.

Left ventricular contraction geometry - a new sight at the problem through the myocardium structural organization

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Summary. *The aim of the study was to establish normative values of global longitudinal, radial and circumferential strain as well as longitudinal, radial and circumferential strain rate, apical and basal rotation, twist and to study the age-related changes of left ventricle myocardial strain. We observed 33 healthy persons (10 men, 23 women), mean age 26.7±0.5 years (1st group) and 28 volunteers (16 men, 12 women), mean age 55±1.2 years (2nd group).Global longitudinal, radial and circumferential strain as well as longitudinal, radial and circumferential strain rate, apical and basal rotation, and twist values were analyzed by specle tracking echocardiography. It has been estimated that 2nd group persons had significantly lower values of global longitudinal strain, global longitudinal strain rate and global circumferential strain rate compared to those of 1st group. We have not found sex difference of strain and strain rate in both groups. Normative values of apical and basal rotation, twist were established.*

Key words: *speckle tracking echocardiography, geometry of left ventricular contraction, strain, strain rate, rotation, twist.*

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