VVI TECHNIQUE POSSIBILITIES IN THE ASSESSMENT OF THE INDICES OF LEFT VENTRICULAR SYSTOLIC FUNCTION AND ALL ITS SEGMENTS

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The aim of the investigation was to estimate Velocity Vector Imaging (VVI) feasibility in the study of left ventricular (LV) and all its segments of systolic function in healthy volunteers when developing standards.

Materials and Methods. 26 healthy volunteers without cardiovascular pathology were recruited and participated in the survey, their mean age being 21.7±3.0 years. LV systolic function using VVI was studied in apical 4-, 5- and 2-chamber views and in parasternal view along a short axis at the level of the mitral valve (LV basal segments), papillary muscles (LV middle segments), and the apex (LV apical segments). We analyzed the following indices: myocardial movement rate, strain (deformation), strain rate (rate of deformation), LV ejection fraction and volume.

Results. The comparison of LV systolic function indices using standard echocardiography and VVI technique showed VVI value in the assessment of the parameters to be rather high and able to acquire objective data on a large number of parameters. VVI enables to record even minimal LV dysfunctions, and the analysis of longitudinal, radial and circular fibers enables to assess transmural damage and reveal LV dysfunction mechanism. The indices of longitudinal, circular and radial deformation averaged –19.9±2.6, –21.6±5.5 and 32.3±7.6%, respectively. Strain rate of longitudinal, circular and radial fibers were –1.17±0.26, –1.32±0.44 and 1.58±0.32 s^{-1}, respectively. LV systolic function indices obtained using VVI can serve as a norm in the assessment of the functioning of LV and all its segments.

Key words: left ventricular systolic function; strain; myocardial deformation; strain rate; myocardial deformation rate; Velocity Vector Imaging; VVI.

Myocardial contractile function assessment is based echocardiographically on visual estimation of cardiac wall motion. Left ventricular (LV) systolic function, as a rule, is determined by ejection fraction (EF) calculated by volume indices of LV cavity in systole and diastole using a modified Simpson method or other techniques. The assessment of segmental contractility presents greater difficulties. Wall motion and their thickness can be visually estimated using 2D echocardiography. However, this approach has a number of limitations related to a researcher's experience, and in some cases, to the quality of ultrasonic equipment. Moreover, imaging technique does not enable to detect minor myocardial contractile dysfunctions [1]. Tissue Doppler imaging enables to reveal the features of myocardial contractility, detect invisible zones of impaired contractility.

Doppler technique to study myocardial motion was first suggested in the 60s of the XX c. [2]. J.B. Kostis et al. [3] and E.N. Sonnenblick et al. [4] elaborated an idea of using impulse wave Doppler to study local contractility, and I. Mirsky and W.W. Parmley [5] set forth the principles of myocardial strain (deformation) application to determine myocardial "stiffness". There was developed a radically new concept of quantitative analysis of normal and pathological myocardial motion [6], and in the middle 90s of the XX c. there were developed ultrasonic and Doppler techniques, which enabled to realize quantitative method to

analyze myocardial motion [2]. Color flow mapping (CFM) underlay a future technique of tissue Doppler imaging in echocardiography [7–9]. Almost alongside with that there was described the principle of determining myocardial velocity gradient to assess myocardial motion [10]. To study the characteristics of myocardial motion at rest and in exercise testing, there were described in detail tissue techniques in the form of the methods to study myocardial deformation [7, 11].

Currently, echocardiography uses mainly the following modes of tissue velocity imaging.

1. Pulse-wave spectrum mode — enables to record maximum movement rate of myocardial parts, which fall within control volume during the whole cardiac cycle.

2. Color-mode — reflects an average velocity. Brighter colors correspond to higher rates. The advantage of the method is the possibility to measure the movement rate of different myocardial segments simultaneously.

3. The assessment of strain (deformation) and strain rate (rate of deformation). These parameters characterize the capability of an impaired segment to spontaneous contractility, and enable to obtain information on systolic and diastolic function of the impaired segments.

4. Tissue tracking enables to diagnose quickly delayed contractility of any myocardial segment under study.

5. Tissue synchronization imaging is color coded

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myocardial staining according to delay time of contraction peak of myocardial segments in relation to QRS complex.

Tissue Doppler echocardiography is characterized by high sensitivity in detection of myocardial motion with low velocities. Its usage promotes early diagnosis of minimal functional changes, which are not managed to be revealed by the parameters traditionally used in echocardiography. Tissue Doppler echocardiography helps to study successfully regional LV function, analyze systolic and diastolic function of the right ventricle, perform differentiated diagnosis of constrictive pericarditis and restrictive cardiomyopathy, calculate pressure in cardiac cavities and the pulmonary artery, and determine the indications for cardiac resynchronization therapy [1, 12].

However, the measurement results in tissue velocity imaging are limited by scan angular dependence. The source of measurement error is also compound parallel and rotation motion, which the heart has in the chest throughout a cardiac cycle.

When there appeared a method based on determination of myocardial movement rate by tracking the movement of the so called speckle structures on standard B-mode echocardiography imaging, it enabled to obtain information on myocardial movement rate, deformation and deformation rate of the surrounding myocardial parts. This technique — STE (speckle tracking echocardiography) — is much easier than the usage of tissue velocity imaging, since it has no limitations related to parallel movement of an object and a ultrasound beam.

One of the new methods for myocardial deformation assessment according to two-dimensional echocardiography is Velocity Vector Imaging (VVI).

The technology of myocardial movement velocity vector imaging enables to obtain data on the direction and value of myocardial movement velocity vector throughout a cardiac cycle. This technique enables to estimate deformation, the rate of deformation, indices of systolic and diastolic functions of cardiac ventricles along a long axis and a short axis without considering angular limitations, as well as analyze myocardial dyssynchrony.

The study is started with outlining the endocardium on a monitor (Fig. 1). For outline one should have high-res images, though VVI technique enables to perform analysis in technically difficult patients [1]. The only condition is the presence of the whole ventricle or the area of interest in the field of vision throughout a cardiac cycle.

ECG recording is required in parallel with echocardiography. If an image was recorded without ECG support, a user can assign heart rate or enter the number of cardiac cycles manually. After outlining the endocardium, there appear yellow-color vectors superimposed on a two-dimensional image. Vectors enable to estimate visually tissue direction and rate of motion. Longer vectors correspond to higher rates (Fig. 2).

VVI program enables to construct a velocity-time diagram, with the data on velocity in relation to the point chosen by a researcher (Fig. 3).

Along the contour we calculated the parameters of deformation and the rate of deformation, and their values are also represented on corresponding diagrams. Using VVI one can analyze LV function by a long axis and a short axis (Fig. 4).

In Russian literature only a few researches devoted to VVI system and its application are reported [3]. Foreign literature has a greater part of such studies [13, 14]. The standards developed by foreign researchers are certainly to give a clear-cut idea of VVI operation. We analyzed in detail apical 4-, 5- and 2-chamber views of LV, estimated LV cross-section at the level of the mitral valve, papillary muscles and LV apex, and determined the standards for basal, middle and apical LV segments. Based on Sh. Carasso [13] recommendations we used the same views to study LV systolic function, but the indices of rate, strain and strain rate were calculated for each LV segment. We
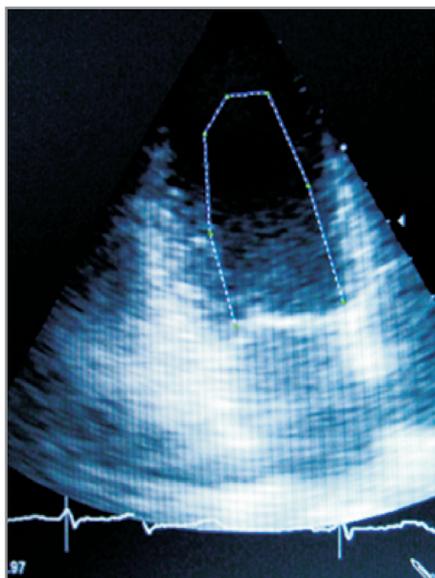

Fig. 1. Apical 4-chamber view. Outline of the left ventricular endocardium
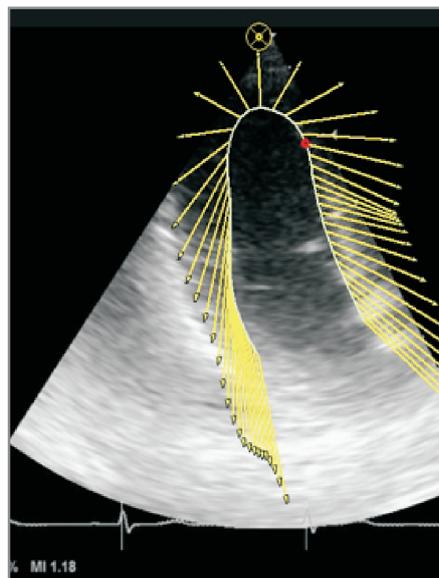

Fig. 2. Apical 4-chamber view. Vector analysis of the left ventricular wall motion
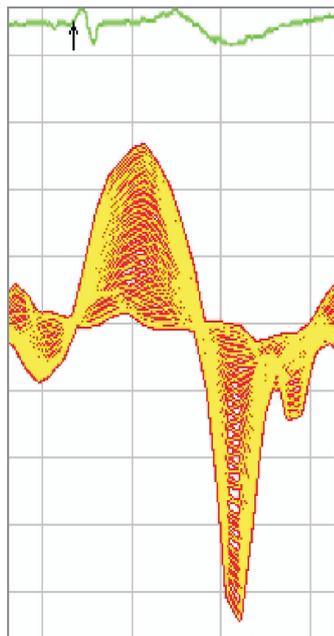
Fig. 3. Resulting curve of the motion of segments in apical 4-chamber view (time — horizontal axis, velocity — vertical axis)
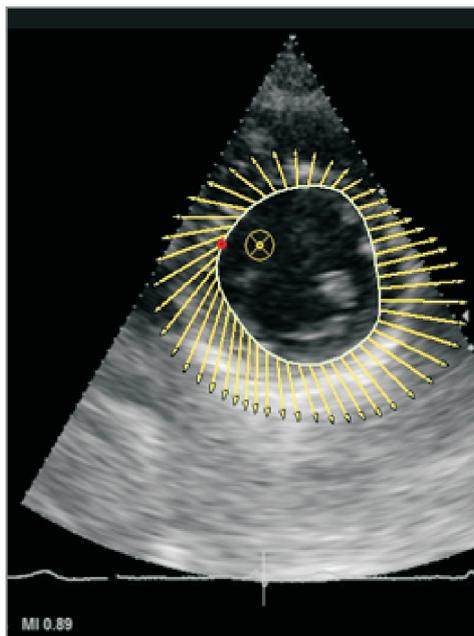

Fig. 4. Analysis of left ventricular function by a short axis. Left ventricular cross-section at the level of papillary muscles

have not encountered similar studies in available literature. The development of standards of systolic function indices of each LV segment will make it possible to assess more reliably the intensity of systolic disturbances in patients with coronary heart disease, as well as make more detailed prognoses regarding coronary bed lesion.

The aim of the investigation was to estimate Velocity Vector Imaging feasibility in the study of systolic function of the left ventricle and all its segments in healthy volunteers to develop standards.

Materials and Methods. 26 healthy volunteers without cardiovascular pathology were recruited and participated in the survey, their mean age being 21.7±3.0 years.

The study complies with the Declaration of Helsinki (the Declaration was passed in Helsinki, Finland, June, 1964, and revised in October, 2000, Edinburg, Scotland) and was performed following approval by the ethic committee of Nizhny Novgorod State Medical Academy (Russia). Written informed consent was obtained from every patient.

Echocardiography was performed on ultrasonic imaging system Siemens Acuson X300 (Germany) using a sector transducer with frequency 1–5 MHz in B-, M-, D-modes and CFM. We used the following views: parasternal — along a long LV axis; parasternal — along a short LV axis at the level of the cusps mitral and aortal valves, papillary muscles, apex; apical — in the position of 2-, 4-, 5-chamber imaging.

The analysis of echocardiograms at rest enabled to estimate LV end-diastolic volume (EDV), LV end-systolic volume (ESV), LV ejection fraction (EF) and stroke volume (SV). LV cavity volumes were calculated according to a modified Simpson equation (1989).

LV contractile function was determined in 16 segments

according to the recommendations of American Society of Echocardiography (ASE).

LV indices using VVI were studied in apical 2-, 4- and 5-chamber view and in parasternal view along a short axis at the level of the mitral valve, papillary muscles, and the apex [13, 14] (Fig. 5). We analyzed the following indices: myocardial movement rate, strain (deformation), strain rate (rate of deformation), LV ejection fraction and volume.

Results and Discussion. Traditionally, LV systolic function indices in standard B-mode echocardiography in most cases are estimated based on Simpson method (1989), which includes LV volumes in systole (ESV) and diastole (EDV), calculation of EF and SV indices. The use of VVI technique enables to assess not only volume indices, but also segmental contribution in the change of volumes [1].

The comparison of LV systolic function indices in standard echocardiography (Simpson method) and VVI showed similar values (Table 1). It permits to use VVI to estimate the previous images.

Since VVI technique enables to assess volumes and EF of every segment under study, it offers the opportunity to identify the segments with impaired contractility [1].

Table 1

The comparison of left ventricular systolic function indices using Simpson method and VVI in healthy volunteers (n=26)

Index	Simpson method	VVI	p
EDV, ml	69.02±18.86	65.24±20.47	<0.49
ESV, ml	26.42±7.27	28.60±8.70	<0.37
EF, %	60.34±0.04	56.84±0.03	<0.002

Fig. 5. Left ventricular segmental structure (ASE recommendations; Garasso Sh. et al., 2012): *a* — apical 4-chamber view; *b* — apical 5-chamber view; *c* — apical 2-chamber view; *d* — LV cross section at mitral valve level (basal segments); *e* — LV cross section at the level of papillary muscles (middle segments); *f* — LV cross section at apical level (apical segments); *1* — anterior septal segment; *2* — anterior segment; *3* — anteriolateral segment; *4* — posteriolateral segment; *5* — lower segment; *6* — lower septal segment
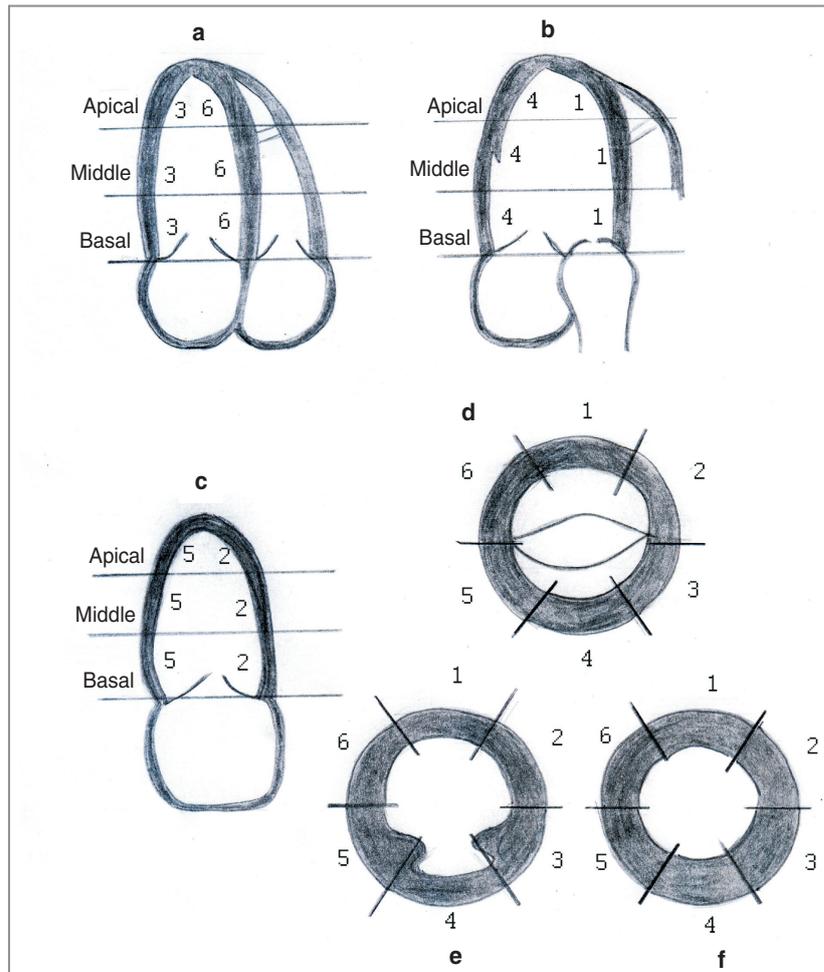
All 26 subjects were found to have no abnormalities in segmental volumes and EF. The value of the option is demonstrated by EF comparison in a patient with dilated cardiomyopathy and in a healthy volunteer (Fig. 6).

The analysis of segmental EF in a healthy volunteer (Fig. 6, *a*) showed its value in all six segments to stay within standards (green and blue colors on a color scale), but a detailed study demonstrated EF indices of segments 4, 5 and 6 to be higher than those of segments 1, 2 and 3. For this reason, it can be expected that this healthy volunteer has the more expressed contractile function of the interventricular septum.

EF indices of all segments in a patient with dilated cardiomyopathy (Fig. 6, *b*) were lower than normal values (red and yellow color on the scale). Total EF value obtained by VVI technique in this patient was 12%. The analysis of EF of each segment showed its values to be significantly higher in segments 1 and 2 (23 and 19%, respectively), therefore, one might assume that LV anteriolateral wall contractility in basal and middle segments are more active compared to the rest segments.

LV myocardial contractile function was quantitatively estimated using the assessment of myocardial movement and myocardial deformation rate.

Myocardial movement rates in apical section are decreasing from the base to the apex [1, 2, 4]. In their
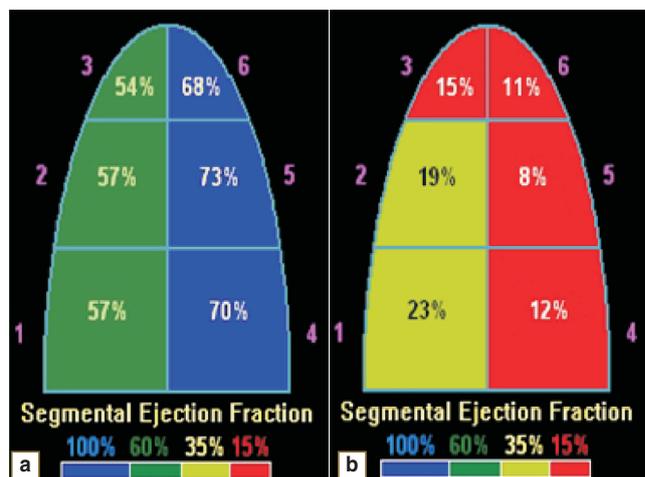
Fig. 6. Apical 4-chamber view. Segmental ejection fraction in a healthy volunteer (*a*) and a patient with dilated cardiomyopathy (*b*): *1* — basal anteriolateral segment; *2* — middle anteriolateral segment; *3* — apical anteriolateral segment; *4* — basal lower septal segment; *5* — middle lower septal segment; *6* — apical lower septal segment

assessment one should take into consideration spatial orientation of longitudinal and radial LV myocardial fibers. VVI program enables to estimate longitudinal and

radial velocities from apical 4-, 5- and 2-chamber views (Table 2).

The analysis of longitudinal and radial velocities of LV endocardial movement showed greater movement rates of

Longitudinal and radial velocities of left ventricular segments of healthy volunteers (apical approach)

Segments	Myocardial movement rate, cm/s, in different views		
	4-chamber	5-chamber	2-chamber
Longitudinal velocities			
1	4.1±1.2	3.9±1.5	4.4±1.4
2	3.1±1.0	3.1±1.0	3.0±0.9
3	1.6±0.5	1.4±0.7	1.2±0.5
4	4.7±1.2	4.5±2.0	4.0±1.0
5	2.7±0.6	2.4±1.3	2.2±0.9
6	1.1±0.4	0.9±0.5	0.8±0.5
Mean velocity	2.9±0.5	2.7±0.8	2.6±0.5
Radial velocities			
1	3.1±1.0	2.6±0.8	3.3±1.2
2	2.2±1.0	2.3±0.9	3.0±1.5
3	1.3±0.6	1.3±0.8	1.7±1.2
4	3.0±0.6	2.1±1.2	3.0±1.0
5	2.3±0.6	1.6±0.9	1.9±0.7
6	1.4±0.4	0.9±0.5	0.9±0.4
Mean velocity	2.2±0.4	1.8±0.5	2.3±0.6

Fig. 7. Radial (positive) (*a*) and longitudinal (negative) (*b*) myocardial deformation

basal segments compared to apical ones, and revealed the tendency for rate decrease from LV base to apex.

Modern complex echocardiography using modern technologies includes not only the estimation of LV wall movement rates but also strain assessment. Deformation is defined as the change of segment length related to its initial length. It is a dimensionless value, which presents the percentage of myocardial fiber dimensional change over the period from rest state to post-exercise state. Deformation is a differentiated movement. In myocardium motion is longitudinal, radial and circular. In systole there occur longitudinal shortening, radial thickening and circular shortening of fibers. Using ultrasonic technologies it is possible to study only one direction of movement at once [2], while using VVI method — all movements simultaneously.

Critical distinction of velocity indices from deformation indices is the following fact: myocardial rate values in apical section decrease from the base to the apex, while systolic deformation is distributed uniformly all over the myocardium. Its assessment in standard segments enables to estimate their contractility [2, 15, 16]. Longitudinal deformation is estimated from apical approach, circular — by a short LV axis. Radial deformation can be estimated from apical approach and by a short axis.

When interpreting VVI findings, one should take into consideration that longitudinal and circular fibers are shortened in systole (negative deformation), and radial — are thickened (lengthened) (positive deformation) (Fig. 7). In the norm, mean systolic strain of myocardial fiber is about 20% [2, 13, 17]. The analysis of all LV segments in our study showed mean value of longitudinal deformation in all subjects was –19.9±2.6% (Table 3).

Circular and radial deformations were estimated using LV cross section at the level of the mitral valve (basal LV segments), papillary muscles (middle LV segments) and the apex (apical LV segments) (Table 4). Mean value of circular strain is –21.6±5.5% [13].

As Tables 3 and 4 show, longitudinal and circular deformation values fall within the limits from –18 to –22%. According to some authors [2, 17, 18], accepted values of normal strain values in lateral and posterior wall are 15±5%. So, Sh. Carasso et al. [13] in their LV function study in

Left ventricular longitudinal deformation of healthy volunteers (apical approach) according to VVI findings

Segments	LV longitudinal deformation, %, in different views		
	4-chamber	5-chamber	2-chamber
1	–21.1±4.1	–19.5±3.4	–20.1±4.8
2	–20.7±4.8	–18.3±2.4	–19.9±4.6
3	–20.0±4.0	–18.4±4.8	–20.3±3.6
4	–21.0±5.0	–20.5±4.6	–20.7±1.4
5	–20.2±3.8	–19.4±5.0	–18.8±3.6
6	–20.2±4.6	–18.5±4.1	–20.2±4.2
Segmental mean value	–20.5±2.7	–19.3±2.9	–20.0±1.9
Overall mean		–19.9±2.6	

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Table 4

Left ventricular circular and radial deformation in healthy volunteers (a short axis of the left ventricle), %, according to VVI findings

Segments	Basal segments	Middle segments	Apical segments
Circular deformation			
1	−21.6±6.8	−22.2±6.1	−20.7±5.5
2	−19.7±5.7	−22.7±5.1	−20.1±5.2
3	−19.4±6.4	−19.8±5.3	−19.9±5.0
4	−21.7±7.1	−18.5±8.4	−18.9±3.6
5	−20.5±7.6	−21.2±4.7	−19.8±4.0
6	−21.4±8.0	−20.5±1.1	−22.1±5.1
Segmental mean value	−20.7±5.5	−21.9±2.6	−19.5±2.8
Overall mean	−21.6±5.5		
Radial deformation			
1	27.2±10.3	34.7±8.1	30.9±2.6
2	26.1±9.7	33.4±11.1	35.3±5.2
3	28.7±11.0	28.8±8.1	27.4±7.4
4	27.0±10.1	28.1±10.0	26.2±10.6
5	29.4±7.6	31.5±4.7	30.2±4.0
6	28.2±8.0	34.3±5.1	37.1±5.1
Segmental mean value	29.3±9.4	33.96±7.80	32.4±5.8
Overall mean	32.3±7.6		

Table 5

Longitudinal strain rate of the left ventricle in healthy volunteers (apical approach) according to VVI findings

Segments	Longitudinal strain rate, s^{-1}, in different views		
	4-chamber	5-chamber	2-chamber
1	−1.31±0.43	−1.50±0.79	−1.10±0.33
2	−1.21±0.32	−1.05±0.51	−1.07±0.37
3	−1.29±0.35	−1.09±0.44	−1.14±0.37
4	−1.31±0.63	−1.41±0.73	−1.11±0.40
5	−1.24±0.34	−1.09±0.60	−1.03±0.20
6	−1.27±0.38	−1.12±0.44	−1.04±0.44
Segmental mean value	−1.22±0.22	−1.18±0.36	−1.08±0.17
Overall mean	−1.17±0.26		

Table 6

Circular and radial left ventricular strain rates of healthy volunteers (LV short axis), s^{-1}

Segments	Basal segments	Middle segments	Apical segments
Circular deformation			
1	−1.47±0.70	−1.51±0.47	−1.42±0.60
2	−1.18±0.59	−1.47±0.49	−1.37±0.49
3	−1.32±0.52	−1.38±0.47	−1.26±0.47
4	−1.37±0.70	−1.33±0.56	−1.16±0.40
5	−1.25±0.60	−1.53±0.50	−1.23±0.50
6	−1.37±0.67	−1.59±0.49	−1.60±0.68
Segmental mean value	−1.30±0.39	−1.40±0.31	−1.25±0.57
Overall mean	−1.32±0.44		
Radial deformation			
1	1.57±0.57	1.51±0.38	1.52±0.47
2	1.59±0.59	1.64±0.42	1.52±0.50
3	1.76±0.78	1.68±0.36	1.51±0.52
4	1.47±0.56	1.52±0.47	1.39±0.41
5	1.45±0.62	1.36±0.43	1.57±0.42
6	1.40±0.51	1.53±0.53	1.77±0.31
Segmental mean value	1.61±0.44	1.57±0.23	1.55±0.24
Overall mean	1.58±0.32		

healthy volunteers received longitudinal deformation values within the range from −17 to −21%.

Radial deformation values compared to longitudinal and circular ones are somewhat higher (See Table 4). A mean value — 32.3±7.6% — is comparable with data reported in literature (30.1±7.5% [13]).

Deformation value was found to enable to assess quantitatively the degree of impaired myocardial contractility [1, 2, 19]. In segments, which are akinetic, according to echocardiography, deformation value is statistically significantly lower in modulus than in hypokinetic. A criterion lower than −13% has a high sensitivity (86%) and specificity (85%) in terms of impaired contractility in myocardial ischemia and acute myocardial infarction [1, 2, 19].

In addition to deformation value, VVI technique enables to calculate the so called deformation rate (strain rate). It is spatial velocity gradient between two nearby myocardial points moving at a definite velocity in point A and point B [2]. Longitudinal rate values are calculated using apical approach (4-, 5-, 2-chamber views), circular and radial rate values — using a short LV axis (basal, middle and apical segments). In systole there occurs systolic shortening of longitudinal and circular LV myocardial fibers (negative strain rate) and thickening (lengthening) of radial fibers (positive rate). The findings are diagnostically significant in LV myocardial ischemia detection. So, according to data reported in literature [2, 19], the values of systolic strain rate less than −0.8 s^{-1} can be criteria of acute myocardial infarction.

The analysis of longitudinal strain rate values in healthy volunteers showed mean value to be −1.17±0.26 s^{-1} (Table 5). In the study reported in literature [13] it amounted to −1.02±0.12 s^{-1}.

Mean circular strain rate was −1.32±0.44 s^{-1}, and according to other authors [13] −1.66±0.33 s^{-1} (Table 6).

Radial rate value in our study is higher than circular and longitudinal. Its mean value was 1.58±0.32 s^{-1}, while that reported in literature [13] — 1.33±0.28 s^{-1}.

Besides the considered indices, VVI technique enables to estimate rotational LV movements (rotational mechanics) resulting in reduction of longitudinal and radial lengths of LV cavity. In systole basal LV segments rotate clockwise (negative views), middle and apical segments — rotate counterclockwise (positive views) [13, 20]. Rotation is angular displacement of a myocardial segment. The measurements

are performed along a short LV axis at the level of basal, middle and apical segments. The analysis of LV rotation meets difficulties in optimal choice of an echocardiographic view. According to the data reported by M.N. Alekhin [20], the existing landmarks for choosing views in rotation analysis are rather conventional. For LV segments there should be recorded the tips of mitral valve cusps; for apical segments — round shape of LV cavity with no visible papillary muscles. It should be noted that basal and middle LV segments are characterized by a significant range of rotation in different segments in contrast to apical, which are characterized by minimal rotation difference [20, 21]. In our study (using VVI) rotation indices in healthy subjects averaged in basal segments: –4.6±2.69°, in middle segments — 3.83±1.87°, in apical segments — 4.52±1.69°, in the study of other authors [13] rotation index in basal segments averaged to –3.4±2.1°, in middle segments — 2.2±2.0°, and in apical — 7.01±3.3°. Such a difference in values can be due to the fact that the age of subjects in foreign researchers ranged within 19–84 years, while in our study healthy volunteers aged from 21 to 23 years, and in literature it is indicated that the indices of LV rotation significantly depend on age [20].

Thus, the value of VVI technique in the assessment of LV systolic function indices is high and enables to obtain objective data on a greater number of parameters compared to standard echocardiography. With the help of VVI it is possible to record even minimal LV function disturbances, and the analysis of longitudinal, radial and circular fibers enables to assess transmural damage and reveal LV dysfunction mechanism.

Conclusion. Velocity Vector Imaging technique enables to estimate the left ventricular volumes in systole and diastole, as well as calculate overall and segmental ejection fraction. The comparison of these findings with standard echocardiographic ones (Simpson method) showed them to be similar. Using this technique one can estimate longitudinal, radial and circular LV velocities, as well as strain (deformation) and strain rate (rate of deformation), which compared to standard echocardiography enable to estimate left ventricular contractile function, and in patients with chronic heart disease — reveal hidden zones of impaired contractility, which are not found in visual echocardiography.

The standards of the basic indices of systolic functions for each LV segments, developed by means of VVI, enable to assess more objectively the damage degree and record even minimal disturbances.

Conflict of Interest. The author has no conflict of interests to disclose.

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