New Indicators of Myocardial Work in Healthy Individuals

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Aim. To study in healthy individuals the gender and age characteristics of left ventricular (LV) myocardial work indicators, their correlations with global LV deformity indicators and echocardiographic parameters characterizing LV systolic and diastolic functions.

Materials and methods. 70 Healthy individuals (n=70; 34 men and 36 women; aged 39.3±8.9 years) were included in the study. The echocardiographic examination determined the standard parameters and indicators of myocardial work: global work efficiency (GWE), global constructive work (GCW), global wasted work (GWW), global myocardial work index (GWI); as well as the myocardium deformation characteristics: global longitudinal deformation (GLS), global radial deformation (GRS) and global circular deformation (GCS). Spearman's correlation coefficient was used to investigate the relationship between parameters. A correlation was considered weak at $r \leqslant 0.3$, moderate at $0.3 < r < 0.7$, and strong at $r \geqslant 0.7$.

Results. The average value of global work efficiency (GWE) in men was 97% (96; 98), in women – 98% (97; 98). Global constructive work (GCW) in men was 2343.8±350.4 mm Hg%, in women – 2362.2±343.8 mm Hg%. The average value of global wasted work (GWW) in men was 46 mm Hg% (27; 75), in women – 44 mm Hg% (33; 55.5). The global myocardial work index (GWI) in men was 2069.9±356.4 mm Hg%, in women – 2055.7±339.9 mm Hg%. No significant differences were found in the comparative analysis of performance indicators. The analysis of correlations found that the myocardial work indicators didn't have significant correlations with age. Ejection fraction was moderately correlated with GWI (r=0.45) and GCW (r=0.49). Global longitudinal strain was strongly correlated with GWI (r=0.77) and GCW (r=0.77). Global radial strain correlated moderately directly with GWI (r=0.4) and GCW (r=0.4). Global circular strain was moderately correlated with GCW (r=0.35). A strong negative correlation was found between the GWE indicator and the post systolic contraction index (PSI) (r=-0.85). At the same time, PSI and GWW had a strong positive correlation (r=0.85).

Conclusion. Indicators of LV myocardial work in healthy individuals do not have gender differences. The efficiency of the work of the myocardium depends primarily on the deformation of the LV, while the constructive work is determined by the volume characteristics. The wasted work indicator depends on the number of segments that peak in the post-systolic period.

Key words: global myocardial work, speckle tracking echocardiography, postsystolic contraction, pressure-strain loop.

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Introduction

Advances in the treatment and prevention of cardiovascular diseases are also due to the improvement of instrumental diagnostics.

The relevance of the cardiovascular pathology study motivates the development of new indicators to assess the risk of life-threatening complications, heart failure and a decrease in the quality of life. The successfully developing echocardiographic techniques allow today a more detailed and informative assessment of the heart pumping function.

The recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging indicate that the left ventricle (LV) global longitudinal deformity (GLS) is reproducible and useful in assessing LV myocardium systolic function [1,2]. But the speckle tracking echocardiography method has its limitations, one of which is depending on the heart afterload during the study. Deformation indices decrease with increasing afterload and do not reflect the true contractile function of the myocardium [3].

A new approach is proposed to overcome this dependence. This approach makes it possible to assess the heart pumping function by calculating the indicators of the LV myocardium global work. Smiseth O.A. et al proposed to evaluate the global myocardial work using the pressure-strain curve using the speckle tracking echocardiography method [4], and K. Russell et al. showed a close correlation between global wasted work ratio and noninvasive LV pressure [5].

According to the authors of this concept, the indicators characterizing the myocardium work are more informative and sensitive in comparison with the LV ejection fraction (EF) and GLS [6]. Obviously, the new indicators will not find wide application in clinical practice until there is enough data on their diagnostic and prognostic value in diseases of the cardiovascular system.

The study aim was to study the LV myocardial work indicators in healthy individuals, their gender characteristics and correlation with global LV deformation indicators and echocardiographic parameters characterizing LV systolic and diastolic functions.

Materials and methods

The study included 70 healthy volunteers: 34 men and 36 women, aged 21 to 61 years (average age was 39.3±8.9 years).

Inclusion criteria for the study: absence of complaints, anamnestic and physical data indicating the presence of cardiovascular diseases and/or damage to other organs and systems; no abnormalities in resting electrocardiography; lack of regular intake of any medications.

Exclusion criteria: plasma glucose ⩾6.1 mmol/l; dyslipidemia, total cholesterol ⩾5.0 mmol/l; chest trauma; body mass index >30 kg/m^2; poor visualization of the echocardiogram.

The study was approved by the local ethics committee of Penza State University. All subjects included in the study signed an informed consent.

All subjects included in the study were determined by lipid profile and glucose level.

Transthoracic echocardiography was performed on a Vivid 95 ultrasound scanner (GE Healthcare, USA) with synchronized limb electrocardiography according to the standard protocol [7]. Image analysis was performed using EchoPAC software version 202 (GE Healthcare, USA). Standard echocardiographic parameters were assessed [7].

Tissue Doppler sonography determined the total speed of early diastolic movement (E' total, cm/s), and the speed ratio of early diastolic filling and the total speed of early diastolic movement (E/E' total, cm/s).

The parameters of global longitudinal (GLS, %), radial (GRS, %) and circular (GCS, %) deformities were also determined using speckle tracking echocardiography.

Work indices were calculated in automatic mode: GWI (Global Work Index, mm Hg%) is the global work index, defined as the volume of myocardial work performed by the left ventricle during systole and equal to the area under the pressure-strain curve; GCW (Global Constructive Work, mm Hg%) is a global constructive work that directly provides the heart pumping function and is the sum of positive work done in systole and negative work in diastole; GWW (Global Wasted Work, mmHg%) is a global indicator of wasted work which is the sum of negative work during systole and positive work during diastole; GWE (Global Work Efficiency,%) is the global work efficiency which is determined by the following formula – GCW/(GCW+GWW) [5, 8].

The peak contraction of one or another myocardium segment can occur both in the period of systole and in the post systolic period. Segments, the maximum contraction of which occurs during systole, make the maximum contribution to the effective myocardium work. But there are always single segments, the maximum deformation of which occurs in the post systolic period, due to which they fall out of the effective myocardium work. The post systolic index (PSI) was determined automatically for each subject. Segments with PSI>1 were allocated to count the number of segments whose peak contraction occurred in the post-systolic period.

Statistica 13.0 software package (StatSoft Inc., USA) was used for statistical processing. Data are presented as M±SD with correct distribution. The parametric Student's t-test was used to analyze them. Data were presented as Me (Q 25%; Q 75%) with incorrect distribution. A comparison was performed using the Mann-Whitney's rank test. Differences were considered statistically significant at $p<0.05$. Spearman's correlation coefficient was used to study the relationship between quantitative traits. The correlation was considered weak at $r\leqslant0.3$, moderate at $0.3<r<0.7$, and strong at $r\geqslant0.7$. When determining the correlation between GLS and GCS with performance indicators, the modules of these values were taken into account for the convenience of data perception.

Results

The patients were divided into 2 groups based on gender. The first group included 34 men aged 36.0±8.2 years, the second group included 36 women aged 42.5±8.5 years. Comparison of systolic (SBP) and diastolic (DBP) blood pressure indicators found that these indicators were lower in women, and indexed values of the LV end-diastolic and end-systolic volumetric parameters had higher values in men. LVEF and LV diastolic function parameters didn't have significant gender differences. Such parameters of myocardial deformity as GCS and GRS didn't differ significantly by gender, and GLS was higher in women (Table 1). There were no gender differences in the myocardial work indicators considered in this article (Table 2).

The analysis of correlations found that the myocardial

Table 1. Some parameters and ECHO-parameters in healthy individuals

Parameter	Total (n=70)	Male (n=34)	Female (n= 36)	p
Age, years	39.3±8.9	36±8.2	42.5±8.5	0.002
Height, cm	172.5 (165; 180)	180 (178; 183)	165 (163.5; 168)	<0.001
Weight, kg	72.3±13.4	83 (75; 88)	63 (58; 68)	<0.001
BNI, kg/m^2	24.0±2.8	25.1±2.5	23.1±2.8	0.003
SBP, mmHg	120 (115; 130)	123 (120; 130)	118.8±11.1	0.030
DBP, mmHg	80 (72; 80)	80 (78; 80)	77 (70; 80)	0.130
Glucose, mmol/l	4.8±0.4	4.8±0.6	4.8±0.4	0.840
TC, mmol/l	4.7±0.5	4.8±0.7	4.6±0.4	0.600
iEDV, ml/m^2	55.6 (51.5; 63.8)	60 (51.9; 64.8)	54.1 (49.8; 58.8)	0.046
iESV, ml/m^2	21.1 (16.8; 25.7)	24.1±6.1	19.7±4.7	0.0012
EF, %	60.8±4.6	61.1±5.2	60.6±4.1	0.630
Ve/Va	1.49±0.34	1.47±0.28	1.5±0.4	0.830
DTE, msec	124.2±37.3	125.4±37.5	123±38.5	0.870
IVRT, msec	56 (48; 67.5)	58.5±14.2	51.5 (48; 65)	0.730
E' total, cm/sec	0.12 (0.1; 0.14)	0.11 (0.08; 0.14)	0.12±0.02	0.030
E/E' total	5.6±1.3	5.9±1.4	5.1 (4.7; 6.1)	0.180
GLS, %	-20.9±1.8	-20.4±1.7	-21.3±1.9	0.043
GCS, %	-15.8 (-17.8; -13.4)	-15.5±3.1	-16.3 (20.6; 13.5)	0.240
GRS, %	29.8 (26.7; 36.2)	30.3±9.1	30 (27; 37.1)	0.260
PSI, RU	1.1 (0.65; 1.7)	0.94 (0.65; 1.53)	1.4±1.0	0.430
Number of segments with PSI>1	4 (3; 6)	4 (3;6)	4.1±2.5	0.700

p – differences between Male and Female groups

BMI – body mass index, SBP – systolic blood pressure, DBP – diastolic blood pressure, TC – total cholesterol, iEDV – index of final diastolic volume, iESV – index of final systolic volume, EF – ejection fraction, Ve/Va – ratio of the rates of early and late ventricular filling, DTE – time of slowing down of early diastolic ventricular filling, IVRT – time of isovolumetric relaxation ventricle, E'total – the rate of early diastolic movement, GLS – global longitudinal deformation, GCS – global circular strain, GRS – global radial strain, PSI – Index of postsystolic contraction.

Table 2. Gender differences of Indicators of myocardial work in healthy individuals

Parameter	Total (n=70)	Male (n=34)	Female (n= 36)	p
GWE, %	97.5 (97; 98)	97 (96; 98)	98 (97; 98)	0.48
GWI, mmHg%	2062.6±345.5	2069.9±356.4	2055.7±339.9	0.86
GCW, mmHg%	2353.3±344.6	2343.8±350.4	2362.2±343.8	0.83
GWW, mmHg%	45 (32; 68)	46 (27; 75)	44 (33; 55.5)	0.65

p – differences between Male and Female groups

GWE – global work efficiency, GWI – global work index, GCW – global constructive work, GWW – global wasted work.

Table 3. Correlations of myocardial work indicators

Parameter	GWE, %	GWI, mmHg%	GCW, mmHg%	GWW, mmHg%
GLS, %	r=0.3; p=0.0059	r=0.77; p<0.00006	r=0.77; p=0.00003	r=-0.15; p=0.19
GCS, %	r=0.12; p=0.3	r=0.2; p=0.068	r=0.35; p=0.033	r=-0.075; p=0.53
GRS, %	r=0.09; p=0.45	r=0.4; p=0.0002	r=0.4; p=0.0001	r=-0.023; p=0.84
EF, %	r=0.25; p=0.032	r=0.45; p=0.00007	r=0.49; p=0.00001	r=-0.19; p=0.1
iEDV, ml/m^2	r=0.095; p=0.42	r=-0.017; p=0.89	r=-0.0074; p=0.95	r=-0.09; p=0.45
iESV, ml/m^2	r=-0.088; p=0.46	r=0.24; p=0.043	r=-0.26; p=0.023	r=0.09; p=0.45
BMI, kg/m^2	r=0.15; p=0.19	r=0.13; p=0.26	r=0.15; p=0.2	r=-0.2; p=0.067
BSA, m^2	r=-0.06; p=0.6	r=0.12; p=0.3	r=0.1; p=0.36	r=0.06; p=0.62
Age, years	r=0.05; p=0.68	r=0.008; p=0.94	r=0.06; p=0.6	r=-0.06; p=0.6
SBP, mmHg	r=-0.18; p=0.13	r=0.37; p=0.0014	r=0.39; p=0.0007	r=0.2; p=0.066
DBP, mmHg	r=-0.13; p=0.27	r=0.26; p=0.026	r=0.3; p=0.0074	r=0.13; p=0.29
Ve/Va	r=0.13; p=0.3	r=0.06; p=0.6	r=0.04; p=0.7	r=-0.1; p=0.37
DTE, msec	r=0.18; p=0.34	r=-0.07; p=0.7	r=-0.02; p=0.9	r=-0.17; p=0.38
IVRT, msec	r=-0.05; p=0.8	r=0.1; p=0.6	r=0.08; p=0.67	r=0.08; p=0.7
PSI, RU	r=-0.85; p=0.0007	r=0.07; p=0.5	r=-0.05; p=0.68	r=0.85; p=0.00004
Number of segments with PSI>1	r=-0.46; p=0.0002	r=0.26; p=0.03	r=0.12; p=0.3	r=0.57; p=0.0003

BMI – body mass index, SBP – systolic blood pressure, DBP – diastolic blood pressure, TC – total cholesterol, iEDV – index of final diastolic volume, iESV – index of final systolic volume, EF – ejection fraction, Ve/Va – ratio of the rates of early and late ventricular filling, DTE – time of slowing down of early diastolic ventricular filling, IVRT – time of isovolumetric relaxation ventricle, E'total – the rate of early diastolic movement, GLS – global longitudinal deformation, GCS – global circular strain, GRS – global radial strain, PSI – Index of postsystolic contraction.

work indicators had no significant relationship with age. The study of the relationship between EF and global performance parameters revealed a direct moderate correlation with GWI and GCW (r=0.45 and r=0.49, respectively) and a weak correlation with GWE (r=0.25).

A similar trend was observed when analyzing the relationship between deformation indices and myocardial work parameters. GLS had a moderate direct correlation with GWE (r=0.3), a strong correlation with GWI and GCW (r=0.77, r=0.77, respectively), and had no statistically significant associations with GWW. GRS was moderately directly correlated with GWI and GCW indicators (r=0.4 and r=0.4, respectively). A significant direct moderate correlation was found between GCS and GCW (r=0.35). A moderate correlation was found between SBP and GWI with GCW, and between DBP and GCW.

A strong negative correlation was noted between PSI and GWE (r=-0.85). In contrast, a strong positive correlation was observed between PSI and GWW (r=0.85). Determination of the relationship between the number of segments contracting in diastole and the myocardial work parameters showed that GWE and GWW had a negative and positive correlation with the number of segments (r=-0.46 and r=0.57, respectively) (Table 3).

Discussion

The study of myocardial work indicators to assess LV systolic function has long attracted the attention of cardiologists. The first studies of the myocardium work were carried out back in the 60s of the last century by E. Braunvald et al., who described the dependence of the myocardium work on the myocardial fiber length, and active tension [9]. However, it was not possible to conduct a clinical non-invasive study of myocardial work due to the imperfection of the equipment of that time.

In 2011 O.A. Smiseth, K. Russell, H. Skulstad proposed using the pressure-strain curve construction as a means to quantify the effect of dyssynchrony on the distribution of myocardial work in patients who received cardiac resynchronization therapy [10].

The myocardial work indicator, based on the pressure-strain relationship analysis, characterizes the relationship between the LV contractile and pumping functions. The heart work involves the work of moving a certain blood volume against the resistance that is created by the pressure and the work of imparting acceleration to this blood volume. The ultrasound scanner software used in the present study incorporates a work calculation algorithm based on pressure-strain area analysis proposed by K. Russell et al. using the pressure indicator obtained by the non-invasive method [5].

A prospective multicenter NORRE study conducted in 2018 with the participation of 226 healthy individuals, whose average age was 45±13 years, determined the reference values of the main performance indicators [11]. Men had significantly lower GWE values and higher GWW values. GWI and GCW increased significantly in women with age.

In 2020, the results of myocardial function assessment were published in 779 healthy volunteers (mean age was 49±10 years, 59% of women) included in the STAAB study [12]. It was found that the GCW, GWW and GWE values in healthy people from the general population obtained by echocardiography didn't depend on gender and body mass index, but had a different relationship with age. Women had significantly higher GWI values (+66 mm Hg%) compared to men. GWE didn't differ between men and women and averaged 96.4% (96.3; 96.5).

The study by S.I. Ivanov et al. of healthy volunteers (n=40) found that the global work index, the LV constructive and waste works significantly increased in response to the load [13].

The data presented in this study on the assessment of global performance indicators in healthy individuals didn't reveal gender differences.

An important task was to determine the correlations between the myocardial work indicators and echocardiographic parameters characterizing the LV systolic and diastolic functions.

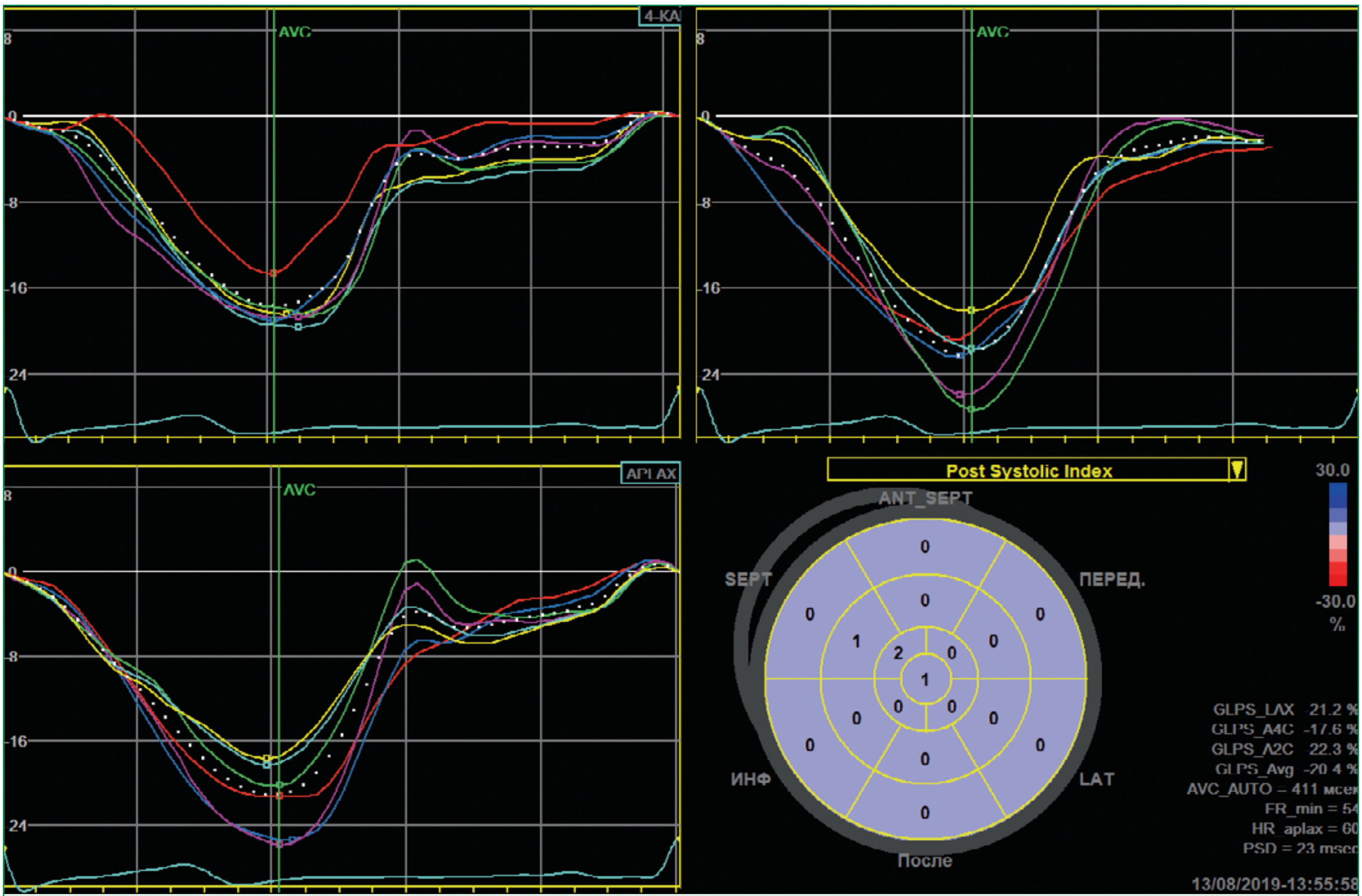
It was found that myocardial work doesn't have a significant correlation with age, which is consistent with the data of other researchers [14]. Myocardial work indicators didn't correlate with LV diastolic function parameters but at the same time, they had a clear connection with LV systolic function. Analysis of the relationship between the myocardial work parameters and LVEF showed a moderate correlation with GCW and GWI and no connection with GWW (r=-0.19), which is explained by the minimum amount of waste work in healthy individuals. Thus, myocardial work in systole in healthy individuals is determined by its constructive component.

The high correlation of myocardial work indices with longitudinal, circular and radial deformities reflected the role of each type of strain in LV systolic function. Global constructive work, reflecting the shortening of myocardial fibers during systole and their lengthening in diastole, contributes to the blood expulsion from the LV. Significant correlations of this indicator with the indexed end-diastolic volume, SBP and DBP make it one of the important integral parameters of LV pumping function.

Obviously, LV systolic dysfunction can be caused by both a decrease in the absolute value of the peak deformity indicators and asynchronous contraction of individual segments [15]. The reduction in the absolute majority of segments in healthy individuals occurs during systole, which determines the maximum possible LV efficiency. However, there are single segments, the deformation peak of which occurs in the post systolic period (Fig. 1). The highest negative correlation of the mean PSI value was observed with the GWE indicator (r=-0.85), which characterizes the high information content of this parameter in terms of LV segments synchronous contraction.

The GWE indicator is calculated, its value in healthy individuals tends to unity due to the minimum amount of waste LV work. The correlations obtained in this study indicate that this indicator is mainly determined by the deformation characteristics of the myocardium and doesn't depend on the LV volumetric parameters. Probably, GWE may have an important diagnostic value in people with heart failure and LV dyssynchrony, which deserves further study.

The global work index, which characterizes all work performed by the LV over the period from closure to opening of the mitral valve in healthy individuals, is determined mainly by constructive work, which is confirmed



The curves reflect the shortening of the longitudinal fibers in each LV segment during one cardiac cycle (AVC – aortic valve closing) and characterize the longitudinal strain. The circular diagram "bull's eye" shows LV segments in a cross-section at three levels: external - basal, middle, internal - apical.

Figure 1. Global longitudinal strain curves recorded in four- (A), two- (B), and five (C) - chamber positions and the "bull's eye" diagram with PSI values in 18 LV segments (D).

by strong correlations with the main echocardiographic parameters. This indicator is mainly determined by the longitudinal myocardium deformation (r=0.77), and to a lesser extent, it's determined by the LV volumetric parameters (r=0.37).

The waste work index, reflecting the lengthening of cardiomyocytes during systole and their shortening in the isovolumetric relaxation phase in healthy individuals, had low values. Therefore, GWW is primarily determined by segments with post systolic contraction, the number of which can vary depending on the myocardial damage degree. In the present study, the GWW indicator had a lower value than in other studies, probably because the number of segments whose peak contraction occurs in the post systolic period increases with age [16,17]. Obviously, the younger age of the included persons was responsible for this difference.

Conclusion

Myocardial work indicators, which are derivatives of deformation characteristics and blood pressure, don't have gender differences in healthy individuals. The myocardium efficiency depends mainly on the LV deformation, and the myocardium constructive work is determined by its volumetric characteristics, which is confirmed by the presence of reliable correlations with EF and indexed values of the end-systolic volume.

The waste work indicator depends on the number of segments that become ineffective in the myocardium work, and, probably, their number increases with age.

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