

Relationship between the Deformation Properties of the Left Ventricle and the Severity of Coronary Atherosclerosis in Patients with Coronary Artery Disease

F. M. Bekmetova* ; Kh. G. Fozilov; Sh. N. Doniyorov; R. B. Alieva;
M. G. Mukhamedova; L. T. I'lkhomova; Sh. U. Khoshimov; S. I. Bekmetova

*Republican Specialized Centre of Cardiology
Tashkent, Uzbekistan*

Abstract

The purpose of this study was to assess the properties of left ventricular myocardial deformation in patients with coronary artery disease (CAD) with various degrees of coronary lesions.

Methods and Results: The study included 74 patients with stable angina pectoris Class II-IV aged between 40 and 70 years. All patients underwent the following examinations: assessment of traditional risk factors, physical examination, general clinical and laboratory blood tests, 12-lead ECG, 24-hour ABPM, transthoracic echocardiography, two-dimensional speckle tracking echocardiography (STE), and coronary angiography (CAG). The SYNTAX score was calculated retrospectively according to the SYNTAX score algorithm. All patients were divided into 3 groups: Group 1 included 21 patients with a low SYNTAX score (0–22), for whom standard drug therapy was recommended; Group 2 included 28 patients with an intermediate SYNTAX score (23–32), to whom PCI was recommended; Group 3 included 25 patients with a high SYNTAX score (≥ 33), to whom CABG was recommended.

Left ventricular ejection fraction (LVEF) obtained using the modified biplane Simpson's method was significantly lower in Group 3 than in Groups 1 and 2 ($P=0.001$); it should be noted that this indicator was within the normative values in Groups 1 and 2, and belonged to the gradation "mild dysfunction." A more objective quantitative assessment of the contractile function of the LV myocardium was obtained by assessing the GLS and SR. The comparative analysis of the LV myocardial deformation properties in the three studied groups showed that in Group 3 the GLS and SR indicators were significantly lower than in Group 1 ($P=0.000$ and $P=0.0020$). Moreover, GLS (global longitudinal strain) and SR (strain rate) were significantly higher in Group 1 than in Group 2 ($P=0.0001$ and $P=0.0133$, respectively). GLS significantly correlated with LVEF ($r=0.57$; $P<0.05$), E/A ($r=0.22$; $P<0.05$), and SYNTAX score ($r=-0.63$; $P<0.05$). SR significantly correlated with LVEF ($r=0.49$; $P<0.05$) and SYNTAX score ($r=-0.37$; $P<0.05$).

Conclusion: The results obtained indicate the diagnostic value of STE with the determination of GLS and SR in a comprehensive assessment of the severity of CAD. GLS and SR significantly correlate with the clinical course of the disease, as well as indicators of LV remodeling and LV diastolic dysfunction. STE analysis of GLS and SR has incremental diagnostic value over transthoracic echocardiography in predicting significant CAD. (*International Journal of Biomedicine. 2021;11(2):131-136.*)

Key Words: coronary artery disease • speckle tracking echocardiography • global longitudinal strain

For citation: Bekmetova FM, Fozilov KhG, Doniyorov ShN, Alieva RB, Mukhamedova MG, I'lkhomova LT, Khoshimov ShU, Bekmetova SI, Relationship between the Deformation Properties of the Left Ventricle and the Severity of Coronary Atherosclerosis in Patients with Coronary Artery Disease. International Journal of Biomedicine. 2021;11(2):131-136. doi:10.21103/Article11(2)_OA1

Abbreviations

CAD, coronary artery disease; CABG, coronary artery bypass grafting; CAG, coronary angiography; GLS, global longitudinal strain; IVST, interventricular septal thickness; LV, left ventricle; LVEF, left ventricular ejection fraction; LVDD, left ventricular diastolic dysfunction; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; LVPWT, left ventricular posterior wall thickness; PCI, percutaneous coronary intervention; STE, speckle tracking echocardiography; SR, strain rate.

Introduction

Coronary artery disease (CAD), being the main clinical manifestation of atherosclerosis, for many years has remained one of the main causes of death in economically developed countries. According to the WHO, about 17 million people die from heart disease every year, 7.2 million of them from CAD.

The study of the functional capacity of the myocardium in CAD is an important task from a prognostic point of view, and echocardiography has become the leading method of its study. Conventional echocardiography is a reliable method for analyzing regional contractility and global heart function. However, it has a number of limitations. The most common measure of LV systolic function, the left ventricular ejection fraction (LVEF), evaluates changes in LV chamber volume during the cardiac cycle without directly measuring myocardial muscle contraction, and thus cannot detect early contractile dysfunction. In addition, the reliability of LVEF depends on image quality and in particular the ability to visualize the endocardial border. In contrast, speckle tracking echocardiography (STE) is a promising modern technique for assessing structural and functional changes in the myocardium.

A common standard for STE is provided by a consensus document of the EACVI/ASE/Industry Task Force.⁽¹⁾ LV peak global longitudinal strain (GLS), a measure of myocardial deformation, directly measures the amount of myocardial longitudinal shortening and can detect subclinical myocardial dysfunction.⁽²⁾ LV peak global longitudinal strain rate (SR), which assesses rate of change in strain, is another robust measure of LV systolic function.^(2,3)

The reported normal mean values of GLS among the studies varied from -15.80% to -23.40% (mean -19.05%; 95% CI: -18.18% to -19.93%; $r^2 = 99.0\%$)⁽⁴⁾; normal mean values of SR varied from -1.30 to -2.40 sec(-1) (mean, -1.88 sec(-1); 95% CI: -2.10 to -1.59 sec(-1))⁽⁵⁾. Recent studies have reported that LV GLS is a more sensitive measure of myocardial dysfunction and is more reproducible than LVEF. Additionally, it is a more powerful predictor of outcomes in patients with heart failure with a reduced LVEF.^(6,7) Previous studies have shown that GLS may both diagnose and exclude acute CAD better than LVEF. In addition, GLS has better intra- and inter-observer reproducibility in post hoc analysis than LVEF.^(8,11-13)

Lacalzada et al.⁽¹⁴⁾ found that GLS measured immediately after primary percutaneous coronary intervention is an excellent predictor of adverse LV remodeling and cardiac events in patients with acute myocardial infarction. Geyer et al.⁽¹⁵⁾ summarized the recent developments in STE, a relatively new technique that can be used in conjunction with two-dimensional or three-dimensional echocardiography for resolving the multidirectional components of LV deformation.

The purpose of this study was to assess the properties of LV myocardial deformation in patients with CAD with various degrees of coronary lesions.

Material and Methods

The study included 74 patients with stable angina pectoris Class II-IV (Canadian Cardiovascular Society

Classification) aged between 40 and 70 years. The study protocol was reviewed and approved by the Ethics Committee of the Republican Specialized Centre of Cardiology. All participants provided the written informed consent.

Diagnosis of stable angina pectoris was performed according to the European Guidelines on the management of stable angina pectoris.⁽¹⁶⁾ Exclusion criteria were history of myocardial infarction within previous 3 months, hypertension Grades 2-3 (ESC/ESH,2018), valvular heart disease, acute coronary syndrome, chronic heart failure (NYHA FC>III), cardiac arrhythmia, renal impairment, severe co-morbidities, orthostatic hypotension.

Pharmacological therapy included aspirin 75 mg daily in all patients without specific contraindications, clopidogrel as an alternative antiplatelet agent in patients who cannot take aspirin, statin therapy, ACE-inhibitor, beta-blockers.

All patients underwent the following examinations: assessment of traditional risk factors, physical examination, general clinical and laboratory blood tests, 12-lead ECG, 24-hour ABPM, echocardiography, and CAG.

Transthoracic echocardiography (TTE)

Conventional 2D echocardiography was carried out according to the recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging⁽¹⁷⁾ in M- and B-modes using an ACUSON X700 ultrasound machine equipped with a 1.0-4.0 MHz transducer (SIEMENS, Germany). The LV volumes and LVEF were measured by 2 methods. LVEDV, LVESV and LVEF were calculated using 1) the area-length method (using the apical 4-chamber and apical 2-chamber views) and 2) the modified Simpson's method (biplane method of disks) by tracing the endocardial border of LV cavity in both the apical four-chamber and two-chamber views in end-systole and end-diastole.

LV diastolic function was analyzed by measuring peak early diastolic filling (*E*) and late diastolic filling (*A*) velocities, *E/A* ratio. All parameters were obtained as the average value of 5 consecutive cardiac cycles.

The values of LVEF (modified Simpson's method) were as follows:

Normal: >55%

Mild dysfunction: 45-54%

Moderate dysfunction: 30%-44%

Severe dysfunction: <30%

Two-dimensional speckle tracking echocardiography (STE)

Two-dimensional images of 4-chamber, 3-chamber and 2-chamber apical views, as well as an LV parasternal short-axis view (at the root of papillary muscle), were recorded with the same ultrasound machine. Three consecutive cardiac cycle loops were recorded at end expiration. To ensure acceptable image quality, the frame rate was between 50 and 80 frames per second. A well-defined cardiac cycle was acquired for each view and stored digitally for offline analysis. All images were stored digitally and analyzed with offline software (Syngo Dynamics 9.0 software, Siemens Medical Solutions). Speckle tracking for myocardial strain was performed using Velocity Vector Imaging (VVI) software (TomTec-Arena TTA2, Germany). GLS and SR were automatically calculated as the

average of 6 myocardial segments from 3 echocardiographic views.

Coronary angiography

CAG was performed via the Judkins technique through the femoral or radial artery access using Phillip Allura CV20 (Phillips Medical Systems, The Netherlands). The angiographical severity of coronary stenosis was assessed in the position with the most luminal narrowing, and the percentage of luminal narrowing was recorded according to the American Heart Association reporting system.⁽¹⁸⁾ The SYNTAX score, an anatomical scoring system to grade the complexity of CAD, was calculated for each patient accordingly. All coronary lesions resulting in luminal narrowing of $\geq 50\%$ in diameter for vessels ≥ 1.5 mm in diameter were considered significant stenosis. The SYNTAX score was calculated retrospectively according to the SYNTAX score algorithm.⁽¹⁹⁾ All patients were divided into 3 groups: low SYNTAX score (0–22), intermediate score (23–32) and high score (≥ 33).

Statistical analysis was performed using the statistical software «Statistica» (v6.0, StatSoft, USA). Baseline characteristics were summarized as frequencies and percentages for categorical variables and as mean \pm standard deviation (SD) for continuous variables. Multiple comparisons were performed with one-way ANOVA with Tukey's *pairwise comparisons*. Group comparisons with respect to categorical variables were performed using chi-square tests. Pearson's correlation coefficient (*r*) was used to determine the strength of the relationship between the two continuous variables. A probability value of $P < 0.05$ was considered statistically significant.

Results

The patients were further divided into 3 groups based on the results of CAG and the SYNTAX score: Group 1 included 21 patients with a low SYNTAX score, for whom standard drug therapy was recommended; Group 2 included 28 patients with an intermediate SYNTAX score, to whom PCI was recommended; Group 3 included 25 patients with a high SYNTAX score, to whom CABG was recommended. The baseline clinical characteristics of the patients included in the study are presented in Table 1.

Table 1.

Clinical characteristics of the CAD patients

Variable	Group 1 (n=21)	Group 2 (n=28)	Group 3 (n=25)	Statistics
Average age, yrs	59.3 \pm 9.4	60.0 \pm 8.1	61.6 \pm 6.2	$P > 0.05$
Gender (M/F)	8/13 (38.1%/61.9%)	18/10 (64.3%/35.7%)	23/2 (92%/8%)	$\chi^2 = 14.9$ $P = 0.000$
Hypertension, n (%)	12 (57.1%)	23 (82.1%)	21 (84%)	$\chi^2 = 5.496$ $P = 0.064$
History of MI, n (%)	1 (4.8%)	11 (39.3%)	23 (92%)	$\chi^2 = 36.05$ $P = 0.000$
T2D, n (%)	1 (4.8%)	7 (25%)	4 (16%)	$\chi^2 = 3.619$ $P = 0.164$

MI - myocardial infarction; T2D - Type 2 diabetes

The average age of the patients in the 3 groups was comparable. Analysis of gender differences showed a significant predominance of men in Group 3, compared to Groups 1 and 2 ($P = 0.000$). In Group 3, there were more patients with a history of myocardial infarction than in Groups 1 and 2 ($P = 0.000$). The number of patients with hypertension and diabetes was slightly predominant in Groups 2 and 3, compared with Group 1.

Comparative analysis of the parameters of central hemodynamics revealed significant differences in contractility of the LV myocardium in the studied groups of patients (Table 2). Thus, LVEF (area-length method) was significantly lower in Group 3 than in Groups 1 and 2 ($P = 0.001$). At the same time, the LV dimensions (LVESD and LVEDD) in Group 3 were significantly larger than in Groups 1 and 2 ($P = 0.000$ and $P = 0.001$, respectively).

Table 2.

Echo-based parameters of central hemodynamics

Variable	Group 1 (n=21)	Group 2 (n=28)	Group 3 (n=25)	Statistics
Aorta, mm	28.5 \pm 6.4	27.3 \pm 6.1	31.7 \pm 7.8	$F = 2.8887$ $P = 0.0622$
Left atrium, mm	34.8 \pm 3.7	33.1 \pm 3.4	35.3 \pm 5.7	$F = 1.8332$ $P = 0.1674$
IVST, mm	11.0 \pm 1.6	11.8 \pm 1.6	11.4 \pm 1.9	$F = 1.3266$ $P = 0.2719$
LVPWT, mm	10.4 \pm 1.5	10.5 \pm 1.3	10.3 \pm 1.2	$F = 0.1499$ $P = 0.8610$
LVEDD, mm	47.0 \pm 4.8	48.1 \pm 5.0	54.0 \pm 9.6	$F = 7.2803$ $P = 0.0013$ $P_{1-2} = 0.8443$ $P_{1-3} = 0.0027$ $P_{2-3} = 0.0072$
LVESD, mm	31.3 \pm 4.5	32.3 \pm 5.2	40.3 \pm 10.6	$F = 11.0067$ $P = 0.0001$ $P_{1-2} = 0.8849$ $P_{1-3} = 0.0003$ $P_{2-3} = 0.0005$
LVEF (area-length), %	61.1 \pm 9.9	56.1 \pm 11.0	48.0 \pm 12.5	$F = 8.0544$ $P = 0.0007$ $P_{1-2} = 0.2785$ $P_{1-3} = 0.0006$ $P_{2-3} = 0.0288$
Biplane Simpson's LVEDV, ml	107.4 \pm 26.3	111.3 \pm 29.6	141.1 \pm 75.1	$F = 3.4049$ $P = 0.0387$ $P_{1-2} = 0.9595$ $P_{1-3} = 0.0612$ $P_{2-3} = 0.0790$
Biplane Simpson's LVESV, ml	42.1 \pm 18.1	50.4 \pm 21.4	78.0 \pm 58.0	$F = 6.0193$ $P = 0.0038$ $P_{1-2} = 0.7241$ $P_{1-3} = 0.0052$ $P_{2-3} = 0.0247$
Biplane Simpson's LVEF, %	61.3 \pm 9.1	55.9 \pm 9.9	48.4 \pm 12.2	$F = 8.7657$ $P = 0.0004$ $P_{1-2} = 0.1849$ $P_{1-3} = 0.0003$ $P_{2-3} = 0.0310$

LVESV obtained by the modified biplane Simpson's method was significantly higher in Group 3 than in Groups 1 and 2 ($P = 0.038$) and exceeded the standard values (> 70 ml). LVEF obtained using the modified biplane Simpson's method

was significantly lower in Group 3 than in Groups 1 and 2 ($P=0.000$); it should be noted that this indicator was within the normative values in Groups 1 and 2, and belonged to the gradation “mild dysfunction.”

A more objective quantitative assessment of the contractile function of the LV myocardium was obtained by assessing the GLS and SR (Table 3). The comparative analysis of the LV myocardial deformation properties in the three studied groups showed that in Group 3 the GLS and SR indicators were significantly lower than in Group 1 ($P=0.000$ and $P=0.002$). Moreover, GLS and SR were significantly higher in Group 1 than in Group 2 ($P=0.0001$ and $P=0.0133$, respectively). GLS significantly correlated with LVESD ($r=-0.38$; $P<0.05$), LVEDD ($r=-0.34$, $P<0.05$), LVEF ($r=0.57$; $P<0.05$), E/A ($r=0.22$; $P<0.05$), and SYNTAX score ($r=-0.63$; $P<0.05$). SR significantly correlated with LVEF ($r=0.49$; $P<0.05$) and SYNTAX score ($r=-0.37$; $P<0.05$).

Table 3.

Quantitative assessment of the contractile function of the LV myocardium obtained by VVI

Variable	Group 1 (n=21)	Group 2 (n=28)	Group 3 (n=25)	Statistics
GLS, %	-18.1±4.4	-11.8±5.9	-10.3±3.6	F=16.6499 P=0.0000 P ₁₋₂ =0.0001 P ₁₋₃ =0.0000 P ₂₋₃ =0.4960
SR, c ⁻¹	-1.5±0.6	-1.1±0.5	-1.0±0.3	F=6.9184 P=0.0018 P ₁₋₂ =0.0133 P ₁₋₃ =0.0020 P ₂₋₃ =0.7268

Table 4.

Relationship between LV deformation properties and structural-functional and clinical parameters in CAD patients

Variable	GLS	SR
IVST	-0.18	-0.33
LVPWT	-0.06	-0.01
LVEDD	-0.34*	-0.24
LVESD	-0.38*	-0.29
E/A	0.22*	0.18
LVEF	0.57*	0.49*
SYNTAX Score	-0.63*	-0.37*

* $P<0.05$

Discussion

The most commonly used strain-based measure of LV global systolic function is GLS. It is usually assessed by STE.^(1,20) According to AES/EACVI, to provide some guidance, a peak GLS in the range of 20% can be expected in a healthy person, and the lower the absolute value of strain is below this value, the more likely it is to be abnormal.⁽¹⁷⁾ There is evidence

that women have slightly higher absolute values of GLS than men and that strain values decrease with age.^(21,22)

The HUNT study in Norway, in which longitudinal strain and SR were determined in 1266 healthy individuals from 3 standard apical views, showed that mean (SD) overall GLS and SR were -17.4% (2.3) and -1.05 s(-1) (0.13) in women, and -15.9% (2.3) and -1.01 s(-1) (0.13) in men. Deformation indices decreased with increasing age.⁽²⁰⁾

A study performed by Smedsrud et al.⁽²³⁾ showed that global systolic strain was significantly lower in patients with significant CAD than in patients without significant coronary artery stenoses ($-17.7 \pm 3.0\%$ vs. $-19.5 \pm 2.6\%$, $P=0.003$).

The results obtained in studies performed by Bochenek et al.⁽²⁴⁾ and Cong et al.⁽²⁵⁾ showed the clinical value of GLS measured by STE in the prediction of LV remodeling after STEMI treated by PCI. D'Andrea et al.⁽²⁶⁾ found that in patients with recent NSTEMI, longitudinal LV global and regional speckle-tracking strain measurements are powerful independent predictors of LV remodeling after reperfusion therapy.

A study performed by Abdelrazek et al.⁽²⁷⁾ showed that GLS decreased incrementally with increasing SYNTAX score, which indicates increasing severity of CAD. Vrettos et al.⁽²⁸⁾ showed similar results when they studied 71 patients and reported that GLS values were inversely correlated to SYNTAX score values.

Abdelrazek et al.⁽²⁷⁾ found a significant correlation between left ventricle EF and GLS ($r=0.25$; $P=0.04$), and Benyounes et al.⁽²⁹⁾ reported similar results when they demonstrated that two-dimensional GLS can predict LVEF ($r=-0.53$; $P<0.001$). Lima et al.⁽³⁰⁾ concluded that LVEF and GLS showed a powerful correlation ($r=0.95$; $r^2=0.89$; $P<0.001$), especially in patients with LV systolic dysfunction, compared to those with normal LVEF.

In conclusion, the results obtained indicate the diagnostic value of STE with the determination of GLS and SR in a comprehensive assessment of the severity of CAD. GLS and SR significantly correlate with the clinical course of the disease, as well as indicators of LV remodeling and LV diastolic dysfunction. STE analysis of GLS and SR has incremental diagnostic value over TTE in predicting significant CAD.

Competing Interests

The authors declare that they have no competing interests.

References

- Voigt JU, Pedrizzetti G, Lysyansky P, Marwick TH, Houle H, Baumann R, Pedri S, Ito Y, Abe Y, Metz S, Song JH, Hamilton J, Sengupta PP, Koliaas TJ, d'Hooge J, Aurigemma GP, Thomas JD, Badano LP. Definitions for a

*Corresponding author: Feruza M. Bekmetova, PhD, ScD. The Republican Specialized Center of Cardiology, Tashkent, Uzbekistan. E-mail: bekmetova@rambler.ru

- common standard for 2D speckle tracking echocardiography: consensus document of the EACVI/ASE/Industry Task Force to standardize deformation imaging. *Eur Heart J Cardiovasc Imaging*. 2015 Jan;16(1):1-11. doi: 10.1093/ehjci/jeu184.
2. Duncan AE, Alfirevic A, Sessler DI, Popovic ZB, Thomas JD. Perioperative assessment of myocardial deformation. *Anesth Analg*. 2014 Mar;118(3):525-44. doi: 10.1213/ANE.000000000000088.
 3. Weidemann F, Jamal F, Sutherland GR, Claus P, Kowalski M, Hatle L, De Scheerder I, Bijmens B, Rademakers FE. Myocardial function defined by strain rate and strain during alterations in inotropic states and heart rate. *Am J Physiol Heart Circ Physiol*. 2002 Aug;283(2):H792-9. doi: 10.1152/ajpheart.00025.2002.
 4. Truong VT, Phan HT, Pham KNP, Duong HNH, Ngo TNM, Palmer C, Nguyen TTH, Truong BH, Vo MA, Tretter JT, Nagueh SF, Chung ES, Mazur W. Normal Ranges of Left Ventricular Strain by Three-Dimensional Speckle-Tracking Echocardiography in Adults: A Systematic Review and Meta-Analysis. *J Am Soc Echocardiogr*. 2019 Dec;32(12):1586-1597.e5. doi: 10.1016/j.echo.2019.07.012.
 5. Levy PT, Sanchez Mejia AA, Machevsky A, Fowler S, Holland MR, Singh GK. Normal ranges of right ventricular systolic and diastolic strain measures in children: a systematic review and meta-analysis. *J Am Soc Echocardiogr*. 2014 May;27(5):549-60, e3. doi: 10.1016/j.echo.2014.01.015.
 6. Smiseth OA, Torp H, Opdahl A, Haugaa KH, Urheim S. Myocardial strain imaging: how useful is it in clinical decision making? *Eur Heart J*. 2016 Apr 14;37(15):1196-207. doi: 10.1093/eurheartj/ehv529.
 7. Adamo L, Perry A, Novak E, Makan M, Lindman BR, Mann DL. Abnormal Global Longitudinal Strain Predicts Future Deterioration of Left Ventricular Function in Heart Failure Patients With a Recovered Left Ventricular Ejection Fraction. *Circ Heart Fail*. 2017 Jun;10(6):e003788. doi: 10.1161/CIRCHEARTFAILURE.116.003788.
 8. Stanton T, Leano R, Marwick TH. Prediction of all-cause mortality from global longitudinal speckle strain: comparison with ejection fraction and wall motion scoring. *Circ Cardiovasc Imaging*. 2009 Sep;2(5):356-64. doi: 10.1161/CIRCIMAGING.109.862334.
 9. Grenne B, Eek C, Sjøli B, Dahlslett T, Uchto M, Hol PK, Skulstad H, Smiseth OA, Edvardsen T, Brunvand H. Acute coronary occlusion in non-ST-elevation acute coronary syndrome: outcome and early identification by strain echocardiography. *Heart*. 2010 Oct;96(19):1550-6. doi: 10.1136/hrt.2009.188391.
 10. Dahlslett T, Karlsen S, Grenne B, Eek C, Sjøli B, Skulstad H, Smiseth OA, Edvardsen T, Brunvand H. Early assessment of strain echocardiography can accurately exclude significant coronary artery stenosis in suspected non-ST-segment elevation acute coronary syndrome. *J Am Soc Echocardiogr*. 2014 May;27(5):512-9. doi: 10.1016/j.echo.2014.01.019.
 11. Kalam K, Otahal P, Marwick TH. Prognostic implications of global LV dysfunction: a systematic review and meta-analysis of global longitudinal strain and ejection fraction. *Heart*. 2014 Nov;100(21):1673-80. doi: 10.1136/heartjnl-2014-305538.
 12. Negishi T, Negishi K, Thavendiranathan P, Cho GY, Popescu BA, Vinereanu D, Kurosawa K, Penicka M, Marwick TH; SUCCOUR Investigators. Effect of Experience and Training on the Concordance and Precision of Strain Measurements. *JACC Cardiovasc Imaging*. 2017 May;10(5):518-522. doi: 10.1016/j.jcmg.2016.06.012.
 13. Karlsen S, Dahlslett T, Grenne B, Sjøli B, Smiseth O, Edvardsen T, Brunvand H. Global longitudinal strain is a more reproducible measure of left ventricular function than ejection fraction regardless of echocardiographic training. *Cardiovasc Ultrasound*. 2019 Sep 2;17(1):18. doi: 10.1186/s12947-019-0168-9.
 14. Laczalada J, de la Rosa A, Izquierdo MM, Jiménez JJ, Iribarren JL, García-González MJ, López BM, Duque MA, Barragán A, Hernández C, Carrillo-Pérez M, Laynez I. Left ventricular global longitudinal systolic strain predicts adverse remodeling and subsequent cardiac events in patients with acute myocardial infarction treated with primary percutaneous coronary intervention. *Int J Cardiovasc Imaging*. 2015 Mar;31(3):575-84. doi: 10.1007/s10554-015-0593-2.
 15. Geyer H, Caracciolo G, Abe H, Wilansky S, Carej S, Gentile F, Nesser HJ, Khandheria B, Narula J, Sengupta PP. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. *J Am Soc Echocardiogr*. 2010 Apr;23(4):351-69; quiz 453-5. doi: 10.1016/j.echo.2010.02.015. Erratum in: *J Am Soc Echocardiogr*. 2010 Jul;23(7):734.
 16. Fox K, Garcia MA, Ardissino D, Buszman P, Camici PG, Crea F, et al.; Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology; ESC Committee for Practice Guidelines (CPG). Guidelines on the management of stable angina pectoris: executive summary: The Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology. *Eur Heart J*. 2006 Jun;27(11):1341-81. doi: 10.1093/eurheartj/ehl001.
 17. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang W, Voigt JU. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*. 2015 Jan;28(1):1-39.e14.
 18. Austen WG, Edwards JE, Frye RL, Gensini GG, Gott VL, Griffith LS, McGoon DC, Murphy ML, Roe BB. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. *Circulation*. 1975 Apr;51(4 Suppl):5-40. doi: 10.1161/01.cir.51.4.5.
 19. Sianos G, Morel MA, Kappetein AP, Morice MC, Colombo A, Dawkins K, van den Brand M, Van Dyck N, Russell ME, Mohr FW, Serruys PW. The SYNTAX Score: an angiographic tool grading the complexity of coronary artery disease. *EuroIntervention*. 2005 Aug;1(2):219-27.
 20. Dalen H, Thorstensen A, Aase SA, Ingul CB, Torp H, Vatten LJ, Stoylen A. Segmental and global longitudinal strain and strain rate based on echocardiography of 1266 healthy individuals: the HUNT study in Norway. *Eur J Echocardiogr*. 2010 Mar;11(2):176-83. doi: 10.1093/ejehocard/jep194.
 21. Kocabay G, Muraru D, Peluso D, Cucchini U, Mihaila S, Padayattil-Jose S, Gentian D, Illiceto S, Vinereanu D, Badano LP. Normal left ventricular mechanics by two-dimensional speckle-tracking echocardiography. Reference values in healthy adults. *Rev Esp Cardiol (Engl Ed)*. 2014 Aug;67(8):651-8. doi: 10.1016/j.rec.2013.12.009.
 22. Kuznetsova T, Herbots L, Richart T, D'hooge J, Thijs L, Fagard RH, Herregods MC, Staessen JA. Left ventricular

- strain and strain rate in a general population. *Eur Heart J*. 2008 Aug;29(16):2014-23. doi: 10.1093/eurheartj/ehn280.
23. Smedsrud MK, Sarvari S, Haugaa KH, Gjesdal O, Ørn S, Aaberge L, Smiseth OA, Edvardsen T. Duration of myocardial early systolic lengthening predicts the presence of significant coronary artery disease. *J Am Coll Cardiol*. 2012 Sep 18;60(12):1086-93. doi: 10.1016/j.jacc.2012.06.022.
24. Bochenek T, Wita K, Tabor Z, Grabka M, Krzych Ł, Wróbel W, Berger-Kuczka A, Elźbieciak M, Doruchowska A, Gluza MT. Value of speckle-tracking echocardiography for prediction of left ventricular remodeling in patients with ST-elevation myocardial infarction treated by primary percutaneous intervention. *J Am Soc Echocardiogr*. 2011 Dec;24(12):1342-8. doi: 10.1016/j.echo.2011.09.003.
25. Cong T, Sun Y, Shang Z, Wang K, Su D, Zhong L, Zhang S, Yang Y. Prognostic Value of Speckle Tracking Echocardiography in Patients with ST-Elevation Myocardial Infarction Treated with Late Percutaneous Intervention. *Echocardiography*. 2015 Sep;32(9):1384-91. doi: 10.1111/echo.12864.
26. D'Andrea A, Cocchia R, Caso P, Riegler L, Scarafilo R, Salerno G, Golia E, Di Salvo G, Calabrò P, Bigazzi MC, Liccardo B, Esposito N, Cuomo S, Bossone E, Russo MG, Calabrò R. Global longitudinal speckle-tracking strain is predictive of left ventricular remodeling after coronary angioplasty in patients with recent non-ST elevation myocardial infarction. *Int J Cardiol*. 2011 Dec 1;153(2):185-91. doi: 10.1016/j.ijcard.2010.08.025.
27. Abdelrazek G, Yassin A, Elkhashab K. Correlation between global longitudinal strain and SYNTAX score in coronary artery disease evaluation. *Egypt Heart J*. 2020 May 15;72(1):22. doi: 10.1186/s43044-020-00064-2.
28. Vrettos A, Dawson D, Grigoratos C, Nihoyannopoulos P. Correlation between global longitudinal peak systolic strain and coronary artery disease severity as assessed by the angiographically derived SYNTAX score. *Echo Res Pract*. 2016 Jun;3(2):29-34. doi: 10.1530/ERP-16-0005.
29. Benyounes N, Lang S, Soulat-Dufour L, Obadia M, Gout O, Chevalier G, Cohen A. Can global longitudinal strain predict reduced left ventricular ejection fraction in daily echocardiographic practice? *Arch Cardiovasc Dis*. 2015 Jan;108(1):50-6. doi: 10.1016/j.acvd.2014.08.003.
30. Lima MSM, Villarraga HR, Abduch MCD, Lima MF, Cruz CBBV, Sbrano JCN, Voos MC, Mathias W Junior, Tsutsui JM. Global Longitudinal Strain or Left Ventricular Twist and Torsion? Which Correlates Best with Ejection Fraction? *Arq Bras Cardiol*. 2017 Jul;109(1):23-29. doi: 10.5935/abc.20170085.
-