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FOLIA CARDIOLOGICA

ISSN: 2353-7752

e-ISSN: 2353-7760

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DOI: 10.5603/FC.a2022.0040

Article type: Original paper

Submitted: 2022-05-16

Accepted: 2022-06-12

Published online: 2022-06-15

ORIGINAL ARTICLE / PRACA ORYGINALNA

Comparative analysis of the quantitative assessment of left ventricular systolic function using echocardiographic methods

Analiza porównawcza ilościowej oceny funkcji skurczowej lewej komory z zastosowaniem metod echokardiograficznych

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Abstract

Introduction. The aim of the study is to compare echocardiographic methods in the assessment of left ventricular systolic function.

Material and methods. In a group of 84 patients (45 men; mean age 59 ± 11 years), left ventricular ejection fraction (LVEF) was quantified using the biplane Simpson method; triplane method, 2D speckle tracking echocardiography (2D STE) and semiautomatic 4D Auto LVQ algorithm in 3D echocardiography.

Results. The highest correlation was demonstrated for the parameters of longitudinal strain in 2D speckle tracking with the LVEF (regardless of the echocardiographic method of its measurement). The strongest correlation was between systolic longitudinal strain in 2D STE and left ventricular ejection fraction in 4D Auto LVQ. There was no satisfactory correlation between global systolic deformation parameters in 4D Auto LVQ and LVEF values calculated using the Simpson two-plane method in 2D and 3D echocardiography.

Conclusions. Modern echocardiographic methods are becoming helpful in assessing the systolic function of the left ventricular, and the semiautomatic algorithms of 3-dimensional echocardiography allow to improve the diagnostic value.

Key words: ejection fraction, strain, left ventricular, echocardiography

Introduction

Standard 2-dimensional echocardiography (2DE) is a commonly used method of the left ventricular (LV) function evaluation based on visual analysis, the limitation of which is subjectivity [1, 2]. However, more and more often, the technique of speckle tracking echocardiography (STE) is used, which is free from this limitation, providing quantitative data regarding LV function [3]. Furthermore, when using matrix probes, it is possible to record 3-dimensional data sets, including the accurate measurement of volume, left ventricular ejection fraction (LVEF), and the assessment of wall motion abnormalities. Importantly, 3-dimensional echocardiography (3DE) allows obtaining data for spatial reconstruction, including assessment of global, and regional LV function, regardless of the adopted geometric assumptions [4].

We aimed to compare echocardiographic methods in the quantification of global and regional left ventricular systolic function.

Material and methods

Clinical characteristics of the study population

Eighty-four patients were included in the study (45 men; 39 women; mean age 59 ± 11 years), including 13 after myocardial infarction and 22 after the previous revascularization (coronary angioplasty or coronary artery bypass grafting). The study group consisted of patients with exercise chest pain, patients at moderate risk of coronary artery disease (10% to 20% on the Framingham scale), including patients with inconclusive results of previous exercise tests or contraindications to exercise testing, acute chest pain with no abnormalities detected in ECG and negative results of blood tests for markers of myocardial damage, suspicion of cardiomyopathy or large vessels anomaly. Clinical characteristics of the study population are presented in Table 1.

Table 1. Clinical characteristics of the study group (n = 84)

Data of the study group	Number of patients	Incidence
Men/Women	45/39	54%/46%
Hypertension	77	91%

Hypercholesterolemia	76	90%
Diabetes	14	16%
Obesity	22	26%
Typical angina	39	46%
History of myocardial infarction	13	15%
History of PCI	21	25%
History of CABG	1	1.2%

CABG — coronary artery bypass grafting; CAD — coronary artery disease; PCI — coronary angioplasty

Transthoracic 2D echocardiographic examination

All patients underwent 2D transthoracic echocardiographic examination with a stationary device (VIVID 7, GE Vingmed USG AS, Horten, Norway) equipped with the M4S probe in harmonic mode 2.0/4.3 MHz (framerate 64–112 fps; mean framerate: 73 fps). All measurements were performed following the American Society of Echocardiography and European Association of Cardiovascular Imaging guidelines.

Basic measurements were performed using both the apical 4-chamber and 2-chamber and short-axis parasternal on the mitral valve level, papillary muscles, and apex views. Volumetric parameters such as left ventricular end-diastolic volume (LVEDV), left ventricular end-systolic volume (LVESV), and left ventricular ejection fraction (LVEF) were assessed with the biplane Simpson method. The 16-segment model of the left ventricular was used for regional systolic function assessment. Diagnosed wall motion abnormalities were graded and categorized as: 1 point — normokinesis or hyperkinesis, 2 points — hypokinesis, 3 points — akinesis, 4 points — dyskinesis. Wall motion score index (WMSI) was also calculated [5].

2D speckle–tracking echocardiography

LV function 2D STE assessment was performed using ECHOPAC 6.1.2 (GE Vingmed). The following views were analyzed: apical four-, three- and two-chamber view, short-axis parasternal on the level of the mitral valve (basal segments), papillary muscles (median segments), and apex (apical segments). Endocardial border tracing was manually enhanced to improve the quality of the examination.

Three cardiac cycles were analyzed, and the mean LV strain and strain rate were measured (Figure 1). Based on the apical 2-chamber, 3-chamber, and 4-chamber views, the global and regional systolic longitudinal strain (SLS), peak longitudinal strain (PLS), peak systolic longitudinal strain rate (SLSR), longitudinal displacement (DL), transverse displacement (DT), transverse strain rate (STSR) were assessed.

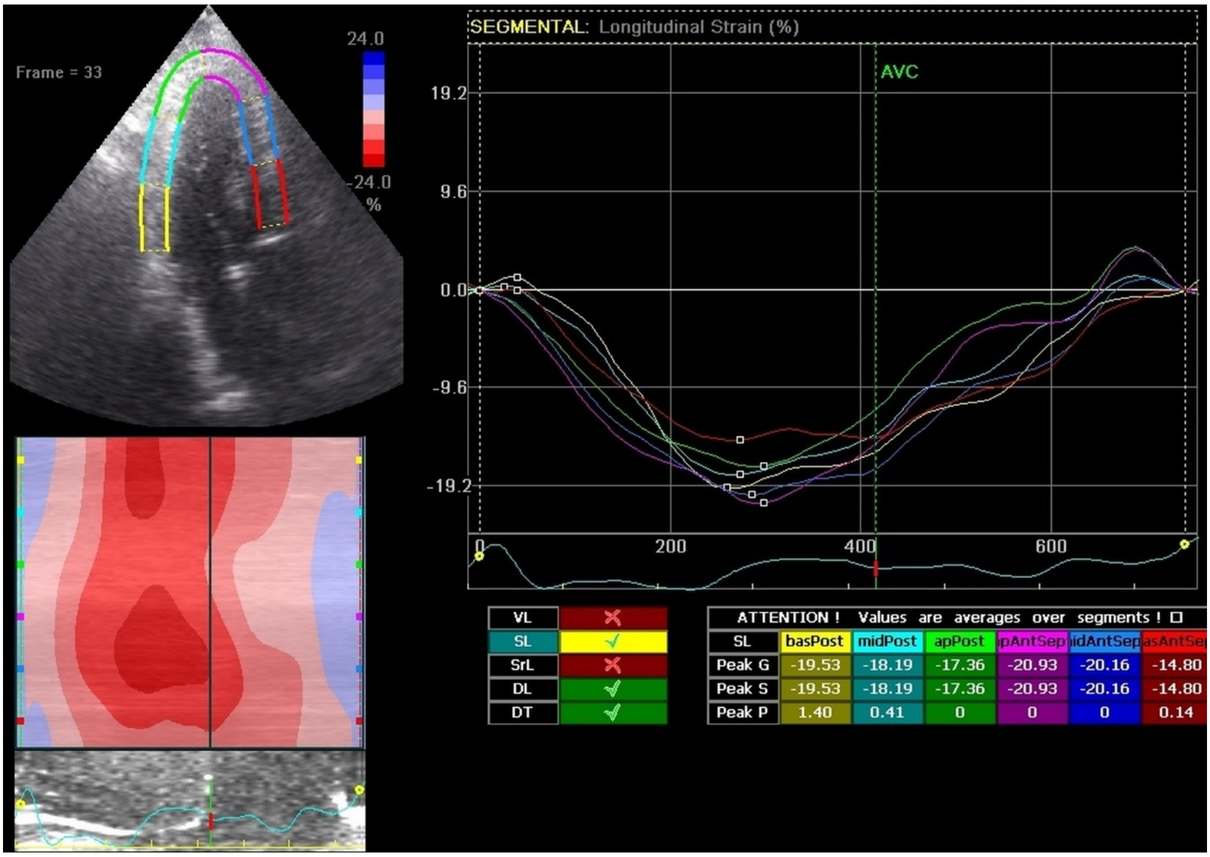

Figure 1. Measurement of the systolic longitudinal strain of the left ventricular using the technique of 2D speckle tracking

Based on the parasternal views in the short axis on the basal, middle, and apical segments level, a circumferential systolic strain (SCS), peak circumferential strain rate (SCSR), systolic radial strain (SRadS), and radial displacement (DR) were measured (Figure 2).

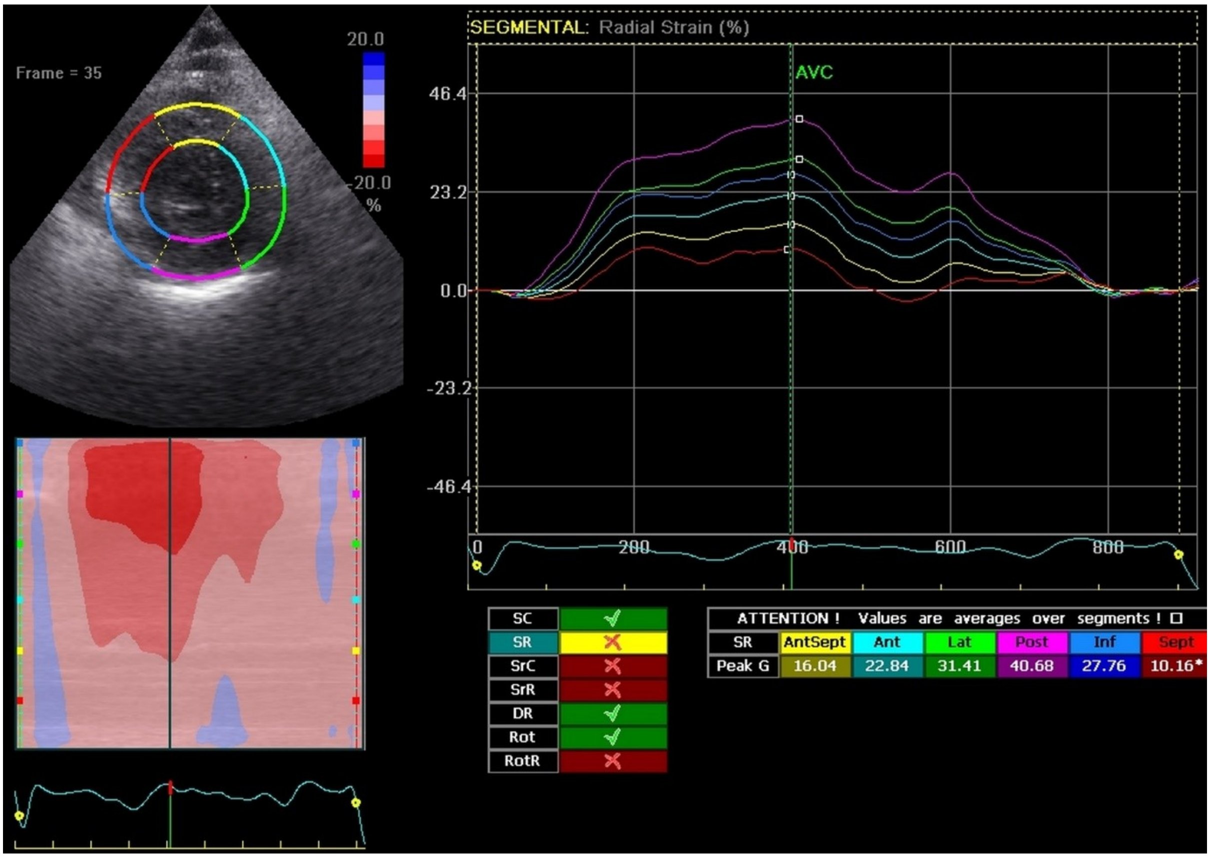

Figure 2. Measurement of the systolic radial strain of the left ventricular using the 2D speckle tracking

3D echocardiography with speckle tracking analysis

Three-dimensional echocardiographic examination was performed with the VIVID 7 (GE Vingmed) stationary echocardiography equipped with a 3V probe (frequency 1.7–3.3 MHz). Three views in triplane mode were registered from the apical window; the 3D dataset of LV was similarly acquired in full-volume mode.

The data was processed with ECHOPAC BT11 (GE Vingmed). LVEF was measured in triplane mode based on the manually traced endocardial borders during the maximum diastole and systole.

Three-dimensional volumetric data was processed with a 4D Auto LVQ software pack which allowed for the semi-quantitative evaluation of the LV systolic function. The following parameters were assessed: LVEDV, LVESV, LVEF, Global Systolic Longitudinal Strain (4D GSL), Global Systolic Circumferential Strain (4D GCS), Global Systolic Radial Strain (4D GRadS) and Global Area Strain (GAS). Regional LVEF was calculated for each of the 16 segments (Figure 3).

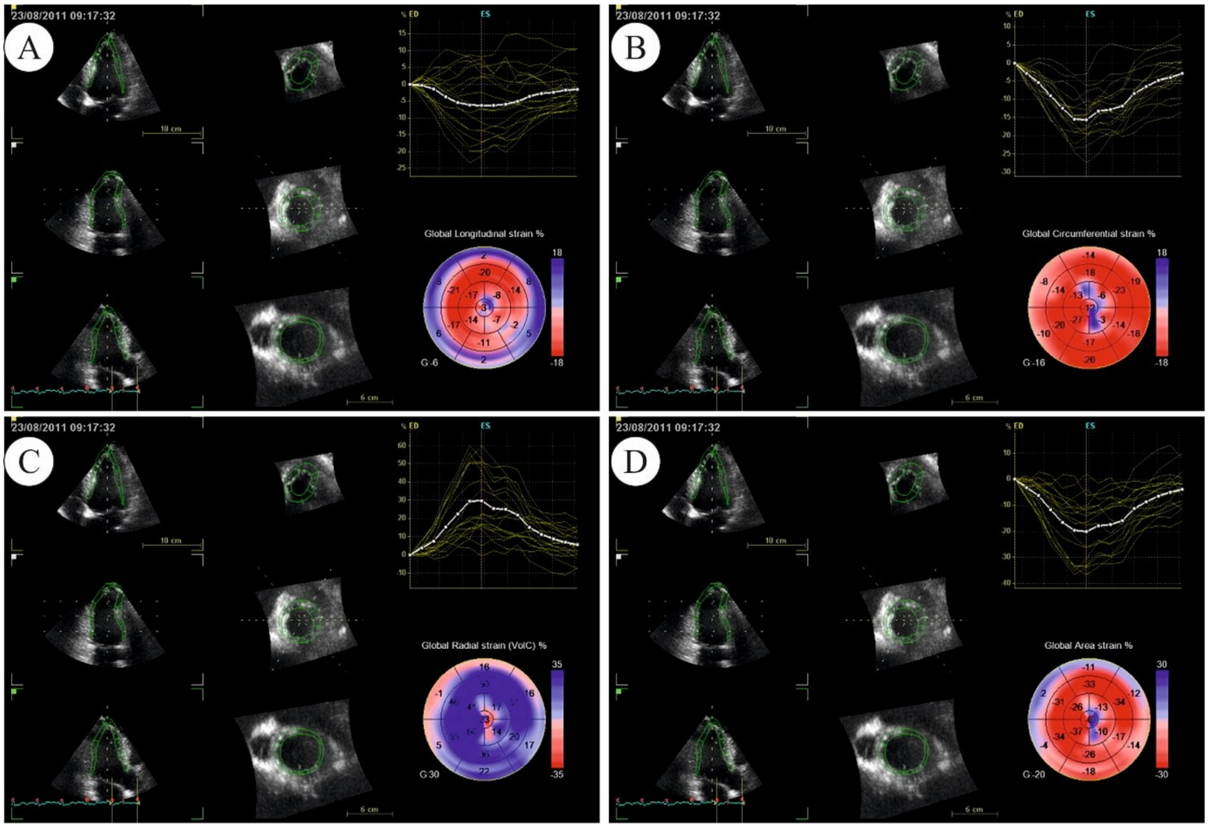

Figure 3. Quantitative analysis using 4D Auto LVQ — measurement of global and regional deformations: longitudinal (**A**), circular (**B**) and radial (**C**) and total left ventricular area (**D**)

Statistical analysis

Statistical analysis was performed using the licensed software suite Statistica (13.1 Dell Inc, Round Rock, TX, US). Obtained data was tested for the normal distribution with the Kolmogorov–Smirnov test. Statistical significance of the differences encountered between the two groups was checked with the Mann–Whitney and t-student tests. To test the linear relation between the parameters, two coefficients were used: Pearson's correlation coefficient in case of normal data distribution and Spearman's when such criterion was not met. To check the agreement between the results of echocardiography and multislice computed tomography Bland–Altman test was used. The threshold of statistical significance was set at $p < 0.05$.

Results

Two-dimensional echocardiography

In the semi-quantitative (visual) assessment of the LV systolic function in 2DE out of 1342 segments, 20 were excluded (1.5%) due to the suboptimal imaging quality. 1172 segments

(88.7%) were qualified as normokinetic, 115 segments (8.7%) as hypokinetic, and 14 segments (1.1%) as akinetic. The mean WMSI was 1.1 ± 0.2 (ranging from 1.0 to 2.3) and the mean LVEF was 58 ± 7.0% (range from 22 to 70%).

The mean results of the biplane Simpson's method measurements were: LVEF 58 ± 9.0% (ranging from 30 to 70%), LVEDV 70 ± 34 mL (ranging from 23 to 194 mL), and LVESV 32 ± 21 mL (ranging from 11 to 135 mL). The mean measurements based on the triplane method were: LVEF 59 ± 10% (ranging from 28 to 79%), LVEDV 85 ± 35 mL (ranging from 33 to 239 mL), LVESV 36 ± 22 mL (ranging from 11 to 129 mL).

2D speckle tracking

Seventy-nine segments (5.9%) were excluded from the analysis with this technique. In the remaining group of 1263 segments, the quality of which allowed for analysis, the mean SLS was –16 ± 5.0% (ranging from –43 to –1.7%), PLS –17 ± 7.0% (ranging from –33 to 3.0%), average SLSR –1.03 ± 0.4 s^{-1} (ranging –3.0 to 0.8 s^{-1}). The mean SCS value was –11 ± 4.0% (ranging –36 to 13%), the SCSR was –1.6 ± 0.9 s^{-1} (ranging –7.0 to 3.0 s^{-1}). The mean value of SRadS was 20 ± 18% (ranging –0.9 to 81%), while RadSR was 2.0 ± 1.2 s^{-1} (ranging –3.0 to 8.0 s^{-1}), DL 8.0 ± 6.0 mm (ranging –1.9 to 26 mm), STS 17 ± 15% (ranging –21 to 86%), STSR 1.7 ± 1.2 s^{-1} (ranging –4.0 to 9.0 s^{-1}), DT 2.8 ± 2.1 mm (ranging –2.4 to 16 mm).

In 3DE using the 4D Auto LVQ method, we obtained the following mean values: 4D GLS — 13.7 ± 9.0% (ranging — 37 to 31%), 4D GCS — 14.4 ± 8.0% (ranging — 40 to 8.0%), 4D GradS 37.5 ± 23% (ranging — 7 to 179%) and 4D GAS — 23 ± 13% (ranging — 60 to 48%).

Comparative analysis

A weak correlation was found between WMSI and the global systolic longitudinal and circumferential deformation in 2D STE.

Wall motion score index correlated poorly with the global systolic deformation parameters in 4D Auto LVQ.

A good correlation was shown for LVEF (regardless of the method of its measurement) with the global SLS and PLS in 2D STE (r_p from –0.40 to –0.52; $p < 0.001$), with the strongest correlation found between the global SLS in 2D STE and LVEF in 4D Auto LVQ.

The maximum systolic longitudinal strain rate (SLSR) correlated well with the LVEF value calculated by the Simpson 2-plane method in 2DE and the triplane (TP) method, (r_p = –0.49 and r_p = –0.43; p <0.001) (Table 2).

Table 2. Correlation analysis of the parameters of the LV systolic function assessed by 2D speckle tracking and the values of the LVEF assessed by the visual method, in 2DE by the Simpson 2-plane method, by the triplane method, and in 3DE using 4D Auto LVQ

		LVEF visual [%]	LVEF Simpson [%]	LVEF triplane [%]	LVEF 4D Auto LVQ [%]
Global SLS [%]	r_p P	–0.44 < 0.001	–0.40 < 0.001	–0.44 < 0.001	–0.52 < 0.001
Global PLS [%]	r_p P	–0.45 < 0.001	–0.45 < 0.001	–0.45 < 0.001	–0.45 < 0.001
Global SLSR [s^{-1}]	r_p P	–0.38 < 0.001	–0.49 < 0.001	–0.43 < 0.001	–0.37 < 0.001
Global SCS [%]	r_p P	–0.24 0.02	–0.20 0.05	–0.25 < 0.02	–0.29 0.007
Global PCS [%]	r_p P	–0.33 0.002	–0.23 0.03	–0.24 0.02	–0.22 0.04
Global SCSR [s^{-1}]	r_p P	NS	–0.29 0.006	NS	NS
Global SRadS [%]	r_p P	0.28 0.009	0.33 0.002	0.22 0.04	0.23 0.03
Global RadSR [s^{-1}]	r_p P	NS	0.24 0.02	NS	NS
Global STS [%]	r_p P	0.35 0.001	0.27 0.01	0.31 0.003	0.34 0.001
Global STSR [s^{-1}]	r_p P	0.20 0.06	0.42 < 0.001	0.27 0.01	0.28 0.008
Global DL [mm]	r_p	0.40	0.27	0.37	0.49

	P	< 0.001	0.01	< 0.001	< 0.001
Global DT [mm]	r_p P	0.23 0.03	NS	0.24 0.008	0.29 < 0.001
Global DR [mm]	r_p P	NS	NS	NS	NS

2DE — 2-dimensional echocardiography; 3DE — 3-dimensional echocardiography; DL — longitudinal displacements; DR — radial displacement; DT — transverse displacement; LV — left ventricular; LVEF — left ventricular ejection fraction; NS — non significant; P — level of statistical significance; PCS — maximum circular strain; PLS — maximum longitudinal strain; RadSR — systolic rate of radial strain; r_p — Pearson linear correlation coefficient; SCS — systolic circular strain; SCSR — rate of circular strain; SLS — systolic longitudinal strain; SLSR — systolic rate of longitudinal strain; SRadS — systolic radial strain; STS — systolic transverse strain; STSR — systolic rate of transverse strain

A weak correlation was demonstrated for LVEF (regardless of the measurement method) with global, SCS, STS, and RadS (r_p from –0.33 to 0.35; $p < 0.05$).

Left ventricular global DL correlated well with the LVEF assessed in 4D Auto LVQ (r_p from 0.40 and 0.49; $p < 0.001$).

A weak correlation was shown between the global lateral displacement (DT) and the LVEF assessed in 2DE, TP, and 4D Auto LVQ (r_p from 0.23 to 0.29; $p < 0.05$).

There was no significant correlation between LVEF (regardless of the method of its measurement) and radial displacement (DR) in 2D STE.

In the 4D Auto LVQ analysis, a strong correlation was obtained between the global LVEF and individual values of the global, systolic strain in 4D Auto LVQ (r_s from –0.53 to 0.52; $p < 0.001$) (Table 3).

Table 3. Correlation analysis of the mean values of the parameters of global longitudinal, circular, radial deformation and the entire surface of the left ventricular assessed in 3DE using the 4D Auto LVQ analysis with the values of the LVEF assessed by the visual method, the Simpson 2-plane method, the triplane method and in 3DE using the 4D Auto LVQ analysis

	LVEF visual	LVEF Simpson	LVEF triplane	LVEF 4D Auto LVQ

		[%]	[%]	[%]	[%]
4D GLS [%]	r_s P	–0.30 0.004	 NS	–0.36 < 0.001	–0.52 < 0.001
4D GCS [%]	r_s P	–0.38 < 0.001	–0.29 0.006	–0.37 < 0.001	–0.53 < 0.001
4D GRadS [%]	r_s P	0.38 < 0.001	NS	0.37 < 0.001	0.52 < 0.001
4D GAS [%]	r_s P	–0.34 0.001	NS	–0.34 0.001	–0.52 < 0.001

3DE — 3-dimensional echocardiography; GAS — global systolic strain of the entire surface of the left ventricular; GCS — global systolic circular strain; GLS — global systolic longitudinal strain; GRadS — global systolic radial strain; LVEF — left ventricular ejection fraction; NS — non significant; P — level of statistical significance; r_S — Spearman correlation coefficient

There was a weak correlation between the LVEF assessed by the TP method and the global values of LV deformation in 4D Auto LVQ (r_s from –0.36 to 0.37; $p \leq 0.001$).

There was no evidence of a correlation between LVEF using the Simpson method and the magnitude of the global systolic strain in 4D Auto LVQ.

Discussion

Transthoracic echocardiography is recommended for risk stratification in patients with angina [6]. The LVEF is a parameter for the assessment of the systolic function LV, with the 2-plane Simpson technique as the most commonly used one [7]. Resting ejection fraction remains the best prognostic parameter in patients with a history of myocardial infarction as it is an independent factor of heart insufficiency development [8].

In cases of myocardial ischemia, the decreased SLS and SRadS values are earlier detected than changes in the SCS. SLS has a proven prognostic value as a predictor of the post-infarction LV function recovery [12].

More and more often, global and regional LV deformation parameters are used in the clinical evaluation of the patient, and they contribute additional diagnostic and prognostic value compared to LVEF [13].

Research confirms that GLS has a positive predictive value for post-infarction heart failure and death [14]. It is worth noting that a full-thickness myocardial infarction and an infarction involving only the subendocardium significantly reduce the value of longitudinal deformation [15]. It has been shown that GLS best correlates with LVEF assessed by magnetic resonance ($r = -0.95$; $p < 0.001$) [16]. SLS, SLSR, and SRadS remain the most important quantitative parameters aiding in the ischemia identification [18].

Apart from the SLS, SCSR is also a sensitive indicator of ischemia in microvascular decompression patients. Reduction of the SCSR values also precedes changes in myocardial ischemia [19].

Due to the multidimensional assessment, the 3DE allows more accurate assessment of the mechanics of LV muscle contraction than a single longitudinal or circular deformation. The 3DE deformation assessment technique allows the measurement of myocardial displacement in any direction, and the global deformation of the ventricular surface integrates the displacement of longitudinal, circular, and endocardial fibers [20].

Casas-Rojo et al. [21] using 3DE, analyzed the systolic function of the LV in patients with severe, asymptomatic mitral valve insufficiency using 3DE. An independent prognostic factor for the development of heart failure over 23 months was a reduction in 4D GAS (−48.6 ± 4.6% vs. −43.7 ± 6.2%; $p = 0.006$), which enabled the prediction of adverse cardiovascular events including the severity of dyspnea, a reduction in LVEF < 60%, hospitalization for symptoms of heart failure. The cut-off for GAS less than –41.6% reached a hazard ratio of 4.41 ($p = 0.004$) for adverse events. This was to a lesser extent reducing 4D GLS, 4D GSC, and 4D LVEF ($p = 0.034$ and 0.036). These conclusions may help recruit asymptomatic patients with severe asymptomatic mitral regurgitation and become one of the criteria for qualifying for early valve repair or replacement surgery.

The discussed study confirms the reliability of 3DE in the clinical assessment of the LVEF, regardless of the ventricular shape, diameter, and wall thickness [22].

Volumes measured using the 3D echo modality show slight underestimation compared to the magnetic resonance imaging and multislice computed tomography [23].

According to Shahgaldi et al. [24] LVEF assessed with the visual method in 2DE, and triplane method were comparable and correlated well with the measurements from the 3DE (treated as a reference), with the visible trend of the underestimation of ejection fraction in 2DE without the statistical significance.

The results correlated well with measurements obtained in real-time 3DE as a standard of measurement with a visible underestimation of LVEF in 2DE, but without a significant statistical value.

Conclusions

The analysis showed a good correlation between longitudinal deformation (SLS, PLS) in 2D STE and the global LVEF, regardless of the echocardiographic method of its measurement.

The strongest correlation occurred between global SLS in 2D STE with LVEF in 3DE.

There was no satisfactory correlation between global systolic parameters of LV deformation in 3DE with the LVEF calculated by the Simpson biplanar method in 2DE and the 3-plane method.

In the analysis of 3DE, a good correlation relationship was obtained between 4D LVEF with global longitudinal, circular, radial deformation and the entire surface of the chamber.

In conclusion, modern echocardiographic methods provide several parameters characterizing the systolic function of the left ventricular, which do not always show a close correlation. The clinical suitability of individual parameters needs to be verified in further studies.

Conflict of interest

None declared.

Funding

None.

Streszczenie

Wstęp. Celem niniejszej pracy jest analiza porównawcza zgodności metod echokardiograficznych w ocenie funkcji skurczowej lewej komory.

Materiał i metody. W grupie 84 pacjentów (45 mężczyzn i 39 kobiet; średnia wieku 59 ± 11 lat) oceniono ilościowo funkcję skurczową lewej komory za pomocą przezklatkowego badania echokardiograficznego metodą dwupłaszczyznową Simpsona, metodą trójpłaszczyznową, techniką śledzenia markerów akustycznych (2D STE) i za pomocą echokardiografii trójwymiarowej, posługując się algorytmem „4D Auto LVQ”. Dokonano pomiarów globalnego skurczowego odkształcenia oraz tempa odkształcenia podłużnego, okrężnego i radialnego oraz całej powierzchni komory. Wyniki porównano za pomocą korelacji Pearsona i analizy Blanda–Altmana.

Wyniki. Wykazano najsilniejszy związek korelacyjny dla parametrów odkształcenia podłużnego (SLS, PLS) w 2D STE z wielkością frakcji wyrzutowej lewej komory (niezależnie od echokardiograficznej metody jej pomiaru). Najsilniejszy związek korelacyjny wystąpił pomiędzy SLS w 2D STE i frakcją wyrzutową lewej komory w „4D Auto LVQ". Nie wykazano dobrej korelacji pomiędzy globalnymi, skurczowymi parametrami odkształcenia w echokardiografii trójwymiarowej w „4D Auto LVQ" a wielkościami EF LV obliczonymi metodą dwupłaszczyznową Simpsona w 2DE i metodą trójpłaszczyznową.

Wnioski. Nowoczesne metody echokardiograficzne stają się przydatne w ocenie funkcji skurczowej lewej komory, a półautomatyczne algorytmy echokardiografii trójwymiarowej pozwalają na poprawę wartości diagnostycznej.

Słowa kluczowe: frakcja wyrzutowa, odkształcenie, lewa komora, echokardiografia

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