M-mode speckle tracking – a novel echocardiographic approach to assess left ventricular torsional deformation

Łukasz Chrzanowski, Barbara Uznańska, Michał Plewka, Maria Krzemińska-Pakuła, Jarosław Kasprzak

2nd Department of Cardiology, Medical University, Lodz, Poland

Abstract

Background: Speckle tracking echocardiography (STE) requires special image processing for complex assessment of left ventricular (LV) function, including strain and rotation.

Aim: To evaluate a novel M-mode STE technique as a readily applicable approach, providing potential insights into LV deformation.

Methods: Fifty one patients (mean age 52 ± 14 years, 24 women) with normal or impaired LV function (mean LVEF 51 ± 16%, range between 14% and 66%) were studied. Left ventricular rotation at mitral valve and apical level was measured using dedicated conventional STE software. Grey-scale short axis digital loops at mitral valve level were also used to obtain M-mode STE images, presenting the movement of LV wall speckles along the cursor, with the LV cavity left out. Then, the distance of peak systolic shift (PSS) was measured for one selected speckle.

Results: Mean rotation at mitral valve level was 7.4 ± 3.1°, apical rotation was 7.6 ± 6.4° and LV torsion was 14.9 ± 7.1°. Measurement of PSS with a novel M-mode STE approach was feasible in all patients, producing a mean value of 7 ± 2 mm. Subsequently, two subsets with PSS of less than 7 mm and PSS equal to or above 7 mm showed a significant difference between mean LV torsion of 10.7° and 17.0°, respectively ($p = 0.002$). In the ROC analysis, PSS cut-off value of less than or equal to 7 mm yielded a sensitivity of 92% and a specificity of 61% to predict LV torsion < 10.7° ($p < 0.0001$).

Conclusions: M-mode STE appears to be a feasible approach to detect movement of speckles and to measure PSS within the LV inferior and septal wall in short axis view images. PSS cut-off value of less than 7 mm indicates significantly lower LV torsion. Further studies are required to assess the potential role of M-mode STE in cardiac imaging.

Key words: speckle tracking echocardiography, left ventricular rotation, M-mode imaging

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Introduction

Tissue echocardiography is currently a component of non-invasive assessment of myocardial function. It has an established position in some selected clinical applications such as estimating left ventricular (LV) filling pressure, differentiation between myocardial restriction and pericardial constriction and evaluation of mechanical asynchrony. The method is based mainly on the velocity parameter derived with the use of tissue Doppler echocardiography (TDE) [1, 2]. More sophisticated quantitative parameters, which characterize changes in heart muscle geometry, and which include strain and strain rate, are an area of great interest, however, they remain mainly experimental techniques.

The newer generation of tissue echocardiography is represented by speckle tracking echocardiography (STE), which completely eliminates the use of Doppler technique [3]. In this technique, the basis for further evaluation is two-dimensional cine-loop images, which are recorded with high enough temporal resolution. This means that the number of frames per second (FPS) is optimised. Currently, STE analysis in possible only in the off-line mode and it is based on manual contouring of the region of interest including the studied segments. Further steps include an automated post-processing mechanism using dedicated software [4]. It enables analysis of the smallest level of the sum of differences between numerous digital parameters, which characterise the observed acoustic markers (speckles, groups of pixels), i.e. image granulations caused by dispersed reflection of the ultrasound wave within the myocardial wall. By indicating, on the consecutive image frames, change in location of the pre-specified myocardial regions, characterised by the unique parametric configuration of the granulations, the software calculates

Address for correspondence:

Łukasz Chrzanowski MD, PhD, II Katedra Kardiologii, Uniwersytet Medyczny, ul. K. Kniaziewicza 1/5, 91-347 Łódź, tel.: +48 42 251 60 15, fax: +48 42 653 99 09, e-mail: chrzanowski@ptkardio.pl

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their displacement vector representing spatial (distance) and temporal (velocity) data. On the basis of these data it is possible to derive, in the further steps of the analysis, multiple above-mentioned parameters of myocardial deformation and movement.

Owing to the use of the two dimensional view, STE enables elimination of one of the most important limitations of Doppler analysis, associated with the influence of ultrasound beam angle [1]. Moreover, when compared to TDE, STE is characterised by wider possibilities of parametric analysis, including radial strain of all LV segments or angular deformation parameters (LV rotation and torsion). According to the above-mentioned data, the speckle tracking algorithm enables automatic collection of many quantitative tissue parameters simultaneously in several LV segments. It requires simple basic steps and is not time consuming. However, suitable software for STE analysis is available as an advanced option, which is independent of parameters used in the standard echocardiographic assessment and which is available only in the highest class of ultrasound systems and compatible work stations. Considering general aspects, there are conditions associated with significant limitations of the advanced analysis of strain parameters, which – as mentioned above – has not found wide acceptance in echocardiographic practice.

Because myocardial granulations are an inherent characteristic of cardiac ultrasound studies, visualisation of changes in their location should be potentially available with the use of a simpler technique, at least in a limited range. Older M-mode imaging gives advantages associated with visualisation of structures along a single line of imaging and high baseline resolution [5]. Therefore, the aim of our study was to assess the utility of a new echocardiographic method, using speckle tracing in M-mode imaging, as a technique potentially enabling characterisation of changes in LV geometry with simultaneous simplification and higher availability when compared to the conventional STE algorithm.

Methods

Patients

The study included 51 patients, with a mean age of 52 ± 14 years (24 females). The echocardiographic study was performed as a part of assessment of patients with hypertension, coronary artery disease, heart failure, valvular pathologies or arrhythmias. The studied population had normal or impaired LV function. Mean LV ejection fraction (EF) was 51 ± 16% (range 14-66%).

Echocardiographic study

Echocardiographic analysis was performed in standard parasternal and apical views using the VIVID 7 Dimension ultrasound system (GE Healthcare). For speckle tracking, according to technical requirements, high temporal resolution of the recorded cine-loop two-dimensional images (in grey scale) was set in order to achieve at least 50 frames per second (FPS) or more. The achieved range was 50 to 89 FPS. The rest of the parameters were set automatically by using pre-specified settings of the ultrasound system. Left ventricular rotation was evaluated after termination of image acquisition (off-line) using a dedicated workstation with conventional STE software

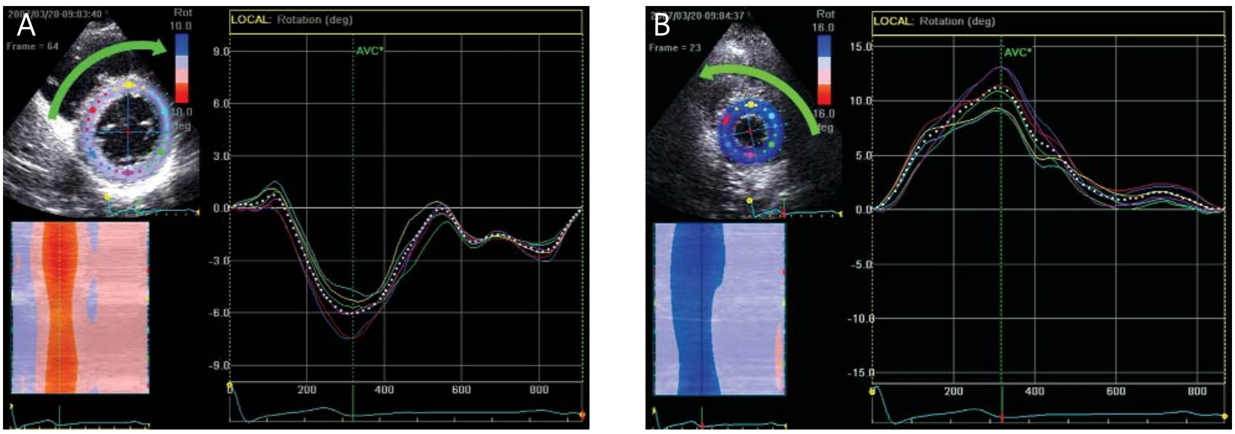

Figure 1. Left ventricular rotation assessment using STE in the short axis views as seen from the apex. At the level of the mitral valve **A** rotation of left ventricular walls is clockwise, marked with a green arrow. The degree of the angle of rotation for each segment is seen on the graph. The dotted line represents mean value. At the level of the apex **B** rotation has counter-clockwise direction marked with a green arrow. Left ventricular torsion represents the absolute difference between opposite rotation in both presented planes (in the example 17.4°)

AVC – aortic valve closing

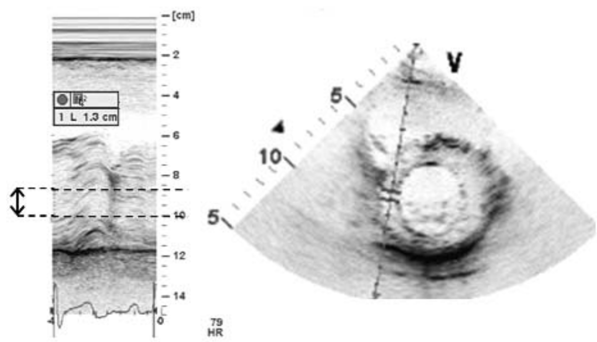

Figure 2. The method of speckle tracking in M-mode imaging. Short axis parasternal view at the level of the mitral valve demonstrating intramyocardial localisation of the cursor line within the interventricular septum and inferior wall, with exclusion of the left and right ventricular chamber. Movement of each group of hyperechogenic pixels during the heart cycle is also seen (on the left). For the selected intramyocardial acoustic marker it is possible to measure peak systolic shift (PSS) characterizing change in its localisation along the cursor line with reference to the beginning of the QRS complex (double arrow, the value of PSS in the presented example is 13 mm)

enabling speckle tracking (EchoPac version 6.1.0, GE Healthcare). For this analysis two separate LV short axis views in the parasternal transducer position were obtained: at the level of the mitral valve and at the level of the apex. The latter was defined as LV region most distally located from the heart base and possible to visualise, with no visible papillary muscles. Acquisition of images was optimised in order to achieve maximal regularity (circularity) of cross-sectional views of the LV. The STE analysis included manual contouring of LV endocardium, approval of the proper level of quality of imaging of the analysed area including possible corrections and manually performed further analysis. For further analysis the rotation parameter (which was the mean of the values for all 6 visible segments) round the central LV axis at two levels was used (Figure 1). Left ventricular torsion was calculated at the time of aortic valve closure as the absolute difference of the opposite rotation (expressed in degrees) at the level of the mitral valve and the apex. A detailed description of the method has been previously reported [6]. Moreover, digitally recorded cineloops in grey scale at the level of the mitral valve were analysed with the new acoustic marker tracking technique in M-mode, by placing the cursor within the heart wall with exclusion of the left and right ventricle cavity. This enabled visualisation of the movement of each pixel group during the heart cycle. Then, for a selected intramyocardial speckle, measurement of peak systolic shift (PSS) was performed for characterising change in its location along the cursor line with reference to the beginning of the QRS complex (Figure 2). The only modification of the M-mode cursor line positioning was its parallel movement with a stable initial point in the apex of the region of interest; the line was not curved, nor was its location modified in the anatomical option.

Statistical analysis

Statistical analysis was performed using MedCalc software (version 8.2.0.2, 2006). Results are presented as mean ± SD. Correlation between studied parameters were examined using a Pearson correlation coefficient. The receiver operator characteristic (ROC) curves were computed to asses optimal values of sensitivity and specificity of PSS. A p value < 0.05 was considered significant.

Results

Mean LV rotation at the level of the mitral valve was –7.4 ± 3.1° and demonstrated clockwise movement typical for this region, in the configuration when the cross-sectional area was visualised from the apical side. On the other hand, mean rotation at the level of the apex was 7.6 ± 6.4°, which reflects physiological for this part of the heart counter-clockwise movement by the above-mentioned spatial localisation conditions. The calculated mean value of LV torsion was then 14.9 ± 7.1°. The study did not include regional parameters of rotation (the value of angular displacement for each of 6 segments visualised in the region of interest) obtained by STE analysis. Measurement of peak systolic shift (PSS) using the new M-mode method of speckle tracking was feasible in all patients (100% feasibility), and had a mean value of 7 ± 2 mm. A moderate correlation between PSS and LV torsion and a less pronounced correlation between PSS and LVEF were demonstrated (Figures 3 and 4).

As the next step, the following subgroups were defined from the total population:

- 17 patients with PSS below 7 mm (mean 4.4 mm, range 2-6 mm)
- 34 patients, with PSS equal to or higher than 7 mm (mean 8.7 mm, range 7-14 mm).

There was a significant difference between the subgroups in relation to the mean LV torsion (10.7 vs. 17.0°, p = 0.002), and LVEF (43 vs. 55%, p = 0.007). The ROC curves revealed that in all patients included in the study, the cut-off value ≤ 7 mm for PSS demonstrated sensitivity of 92% and specificity of 61% for LV torsion below 10.7° (p < 0.0001, area under the curve 0.8, 95% CI 0.66-0.9) (Figure 5).

Discussion

The results of this preliminary study indicate that by using the new M-mode echocardiography method of

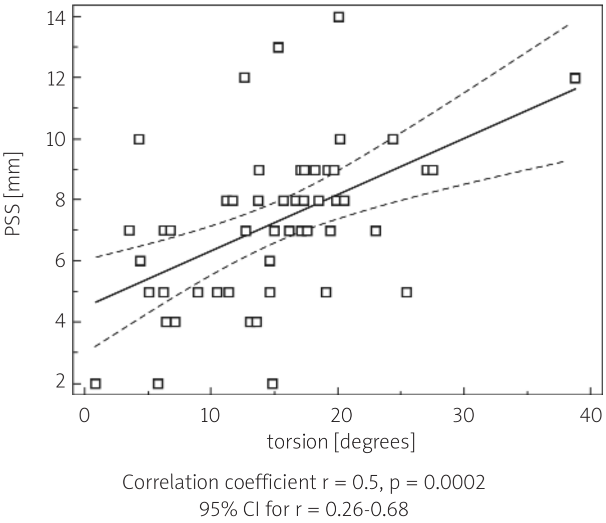

Figure 3. Linear regression graph demonstrating a moderate correlation between the value of LV torsion expressed in degrees and PSS of acoustic marker expressed in millimetres

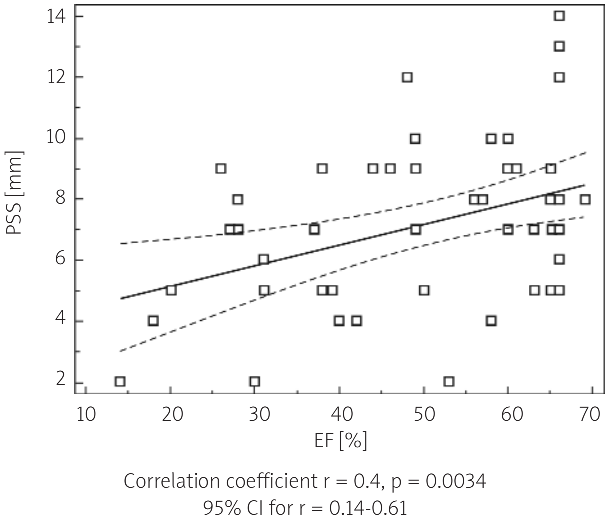

Figure 4. Linear regression graph demonstrating a poor correlation between LVEF and PSS of acoustic marker expressed in millimetres

speckle tracking it is possible to visualise changes in pixel position within the left ventricular inferior wall and within the intraventricular septum at the level of the mitral valve in the short axis view. Intramyocardial placement of the cursor line, excluding left and right ventricle chambers, enables one to obtain images of wall granulations as parallel lines which achieve maximal amplitude of deflection during systole and thereafter their location returns to the baseline one. The presented image is similar to the view of the posterior wall movement in conventional M-mode imaging in the parasternal view. The only difference is lack of echo at the border of the endocardium and LV chamber. After obtaining the M-mode view it is also possible to perform quantitative analysis of PSS for a selected intramyocardial marker. The presented results might be useful for comprehensive analysis of LV myocardial deformation.

Previous observations demonstrated that myocardial fibres are characterised by parallel, transverse or oblique location and form a complex spiral spatial configuration, which determines the advanced shape of mechanical deformation [7]. This issue, owing to development of imaging modalities which eliminate the previous imaging difficulties, is currently achieving an important role in the assessment of heart morphology and function [7, 8].

Taking into consideration the mechanism of systole, PSS is a result of several elements. The following factors should be included: regional inferior wall and interventricular septum rotation in the short axis, which at the level of the heart base has clockwise direction, reflecting with appropriate simplification the change in location of the vector directed upwards and to the right. This region changes its shape simultaneously in three planes: its circumference decreases and represents circumferential strain, its thickness increases, which is responsible for radial strain, and its shortening represents longitudinal strain. It is obvious that such complicated spatial mechanical activity cannot be evaluated by any of the simple imaging methods. Even with the use of the currently available advanced STE method it is not possible to simultaneously assess strain parameters in more than two directions during a single

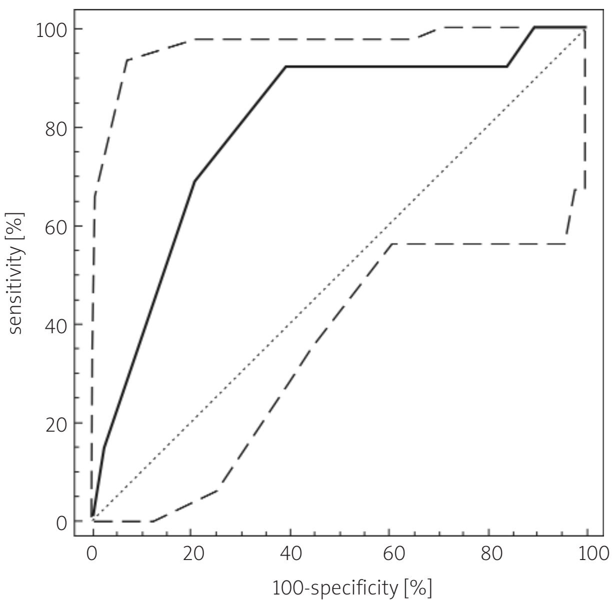

Figure 5. ROC curves indicating the optimal sensitivity and specificity of PSS value of ≤ 7 mm, associated with coexisting LV torsion below 10.7°

heart systole. Moreover, previous attempts of three dimensional imaging of changes in myocardial geometry had only limited range, although they are possible with the use of commercially available echocardiography systems. Further clinical studies and further development of the technique are needed [9-11].

Nevertheless, the results of the current study confirm only a moderate correlation between an advanced parameter of global LV deformation represented by torsion and a simple M-mode parameter – PSS. Additionally, PSS value < 7 mm indicated, with acceptable precision, the presence of a lower value of LV torsion. Although the parameters obtained in other studies in healthy individuals demonstrate wide variety, depending among other things on age, torsion lower than 10° may represent a pathologically decreased value [12, 13].

In our analysis we have not evaluated the controversy concerning different definitions of LV torsion. Some authors restrict the term torsion (as opposite to twist) only to a gradient between rotation at the base and at the apex. This approach requires, apart from calculation of the absolute difference, normalisation for the LV long axis dimension and expression of the result in degrees per centimetre (°/cm) [14]. More precise localisation of planes and determination of their true distance in the echocardiographic study represent bias, and because of that, this measurement is omitted in the majority of papers. It should be underlined that in our study no regional parameter or tissue deformation was assessed with the use of STE. Nevertheless, the use of the simple parameter such as PSS in the limited region of the heart was initially deemed as useful for representation of global parameters of LV torsion deformation. The choice of region of interest and placing the M-mode line cursor within basal segments of the interventricular septum and within the inferior wall were determined by optimal spatial orientation and the quality of visualisation acquired speckles shift. The presented results should be regarded as preliminary in the context of the above-mentioned difficulties with advanced methods of tissue imaging on the way to propagation in echocardiographic practice.

Study limitations

Limitations of the presented study include using the off-line analysis, which causes, apart from longer duration of the acquisition, lower image resolution – the number of frames per second is determined by the two-dimensional mode (in grey scale). However, the use of M-mode imaging in real time seems to be more difficult for stabilisation of the cursor within LV wall and is associated with a larger number of artefacts. Moreover, high resolution can paradoxically lead to more difficult visualisation of intramyocardial image granulations by increasing noise of the available ultrasound signal. It should also be kept in mind that the results of the current study, especially quantitative parameters, can be applied only to the population with mild global LV dysfunction and with high values of torsion. As limitations of the current study, it is also necessary to consider the spatial character of LV strain, which causes through-plane motion during the heart cycle. It can lead to undesirable changes of pixels within the analysed region, especially in cross-sectional area at the level of the mitral valve. At the current level of development of tissue echocardiography and methodology of real time three-dimensional strain this phenomenon is an unavoidable limitation of all previous studies evaluating LV torsion (torsion function) [15, 16].

Conclusions

The new echocardiographic method of M-mode speckle tracking makes it possible to visualise changes in pixel localisation. Additionally, it enables measurement of PSS within the LV inferior wall and interventricular septum in cross-sectional views. The value of PSS below 7 mm represents significantly reduced LV torsion. Our study is a preliminary report and demonstration of the potential clinical utility of the presented method with the use of M-mode echocardiography in wider applications of cardiac diagnostic imaging requires further studies.

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Śledzenie markerów akustycznych przy zastosowaniu trybu jednowymiarowego (M-mode) – nowa metoda echokardiograficznej oceny odkształcenia skrętnego lewej komory

Łukasz Chrzanowski, Barbara Uznańska, Michał Plewka, Maria Krzemińska-Pakuła, Jarosław Kasprzak

II Katedra Kardiologii, Uniwersytet Medyczny, Łódź

Streszczenie

Wstęp: Echokardiograficzna technika śledzenia markerów akustycznych (lub śledzenia pikseli) (ang. *speckle tracking echocardiograph*y, STE) umożliwia zaawansowaną ocenę czynności lewej komory, z uwzględnieniem parametrów tkankowych reprezentowanych przez odkształcenie i rotację. W procesie diagnostycznym z zastosowaniem omawianej metodyki konieczna jest jednak osobna rejestracja obrazów dwuwymiarowych i ich dalsze przetworzenie przy użyciu specjalnego oprogramowania.

Cel: Ocena przydatności nowej metody echokardiograficznej wykorzystującej STE w trybie jednowymiarowym (M-mode) jako procedury pozwalającej scharakteryzować zmiany geometrii mięśnia sercowego lewej komory z jednoczesnym uproszczeniem i zwiększoną dostępnością obrazowania w stosunku do konwencjonalnego STE.

Metody: Badanie przeprowadzono w grupie 51 chorych (w tym 24 kobiety), których średni wiek wynosił 52 ± 14 lat. Obrazowanie echokardiograficzne stanowiło element diagnostyki nadciśnienia tętniczego, choroby niedokrwiennej serca, niewydolności serca, wad zastawkowych i zaburzeń rytmu. Pacjenci charakteryzowali się prawidłową lub upośledzoną czynnością skurczową lewej komory, ze średnią wartością frakcji wyrzutowej 51 ± 16% i jej zakresem pomiędzy 14 i 66%. Rotację lewej komory w osi krótkiej na poziomie zastawki mitralnej i koniuszka oceniano z zastosowaniem konwencjonalnego oprogramowania wykorzystującego technikę STE. Poza tym ruchome echokardiograficzne obrazy w skali szarości na poziomie zastawki mitralnej zarejestrowane cyfrowo poddano analizie nową metodą STE w trybie jednowymiarowym (M-mode), przedstawiającą ruchomość poszczególnych zbiorów pikseli w obrębie ściany mięśnia sercowego wzdłuż kursora, z wyłączeniem jam lewej i prawej komory. Następnie dla wybranego śródmięśniowego markera akustycznego dokonano pomiaru maksymalnego przemieszczenia w skurczu (ang. *peak systolic shift*, PSS).

Wyniki: Średnia rotacja lewej komory na poziomie zastawki mitralnej wynosiła 7,4 ± 3,1°, a na poziomie koniuszka 7,6 ± 6,4°, co odpowiada średniej wartości skręcenia (ang. *torsion*) lewej komory 14,9 ± 7,1°. Przeprowadzenie pomiaru maksymalnego przemieszczenia markera w skurczu z zastosowaniem nowej metody jednowymiarowej STE było możliwe u wszystkich pacjentów, średnia wartość wyniosła 7 ± 2 mm. Następnie spośród badanych wyodrębniono dwie podgrupy, wykazujące PSS < 7 mm oraz PSS ≥ 7 mm, i stwierdzono znamienną statystycznie różnicę pomiędzy średnimi wartościami skręcenia lewej komory – odpowiednio 10,7° oraz 17,0° (p = 0,002). W analizie krzywej ROC (ang. *receiver operating characteristic*) wartość odcięcia PSS ≤ 7 mm wykazywała 92-procentową czułość i 61-procentową swoistość w wykrywaniu skręcenia lewej komory o wartości mniejszej od 10,7° (p < 0,0001).

Wnioski: Nowa echokardiograficzna metoda STE w trybie jednowymiarowym daje możliwość uwidocznienia zmiany pozycji pikseli, a także pomiaru maksymalnego skurczowego przesunięcia markera w obrębie ściany dolnej lewej komory i przegrody międzykomorowej na przekrojach poprzecznych w osi krótkiej. Wartość PSS < 7 mm odpowiada istotnie zmniejszonemu skręceniu lewej komory. Ustalenie przydatności przedstawionego trybu wykorzystującego echokardiografię jednowymiarową w szerszym zakresie diagnostyki obrazowej serca wymaga dalszych badań.

Słowa kluczowe: echokardiograficzne śledzenie markerów akustycznych, rotacja lewej komory, obrazowanie jednowymiarowe

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Adres do korespondencji:

dr n. med. Łukasz Chrzanowski, II Katedra Kardiologii, Uniwersytet Medyczny, ul. K. Kniaziewicza 1/5, 91-347 Łódź, tel.: +48 42 251 60 15, faks: +48 42 653 99 09, e-mail: chrzanowski@ptkardio.pl

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