New views into the structural and functional state of the heart muscle and modern technologies for their assessment

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Abstract

Background: One of the most frequently used diagnostic methods for non-invasive assessment of morpho-functional changes in the heart is two-dimensional routine echocardiography, which enables visual and semi-quantitative assessment of global and regional cardiac contractility by observing the movement of myocardial segments. However, this method is somewhat dependent on the quality of technical performance and the qualifications of the doctor, which significantly determines the reliability of the results obtained. That is why new technologies are emerging in cardiac diagnostics, including tissue Dopplerography a type of Doppler study that studies the movement of the myocardium, valvular apparatus, and other tissues using low- frequency and high-amplitude waves. Attempts to quantitatively assess the contractile function of the myocardium with tissue Doppler was not widely adopted because of technical problems - low sensitivity and dependence on the scanning angle, which contributed to the emergence of a new modification of two-dimensional echocardiography - Speckle Tracking - 2D Strain (STE) in the field of diagnostics in contemporary practice.

The present work presents a literature review of modern views on the structural- functional organization of the heart based on the concept of the spiral structure of the heart muscle and the use of a new method of their assessment, Speckle Tracking - 2D Strain Echocardiography, which enables the elucidation of the pathophysiological mechanisms of left ventricular (LV) dysfunction by assessing myocardial deformation and the early detection of asymptomatic stages of systolic and diastolic cardiac dysfunction in the preclinical stage. **(TCM-GMJ May 2026; 11 (1): P17-P21)**

Keywords: Strain, Speckle tracking echocardiography, Cardiac mechanics, Cardiac remodeling, Myocardial fiber, EF .

Introduction

In the 21st century, cardiovascular diseases still remain one of the main causes of disability and mortality in most countries of the world. To solve this problem, early diagnosis of morpho- functional changes in the heart, the use of informative criteria and objective assessment of the results obtained are necessary, which enables effective treatment of cardiovascular diseases.

One of the most frequently used non-invasive diagnostic methods for studying the cardiovascular system is echocardiography, which is traditionally used for non-invasive assessment of the systolic and diastolic function of the left ventricular myocardium, although its findings are limited because of the subjectivity of technical performance, dependence on the qualification of the doctor and the relatively low sensitivity of detecting segmental disorders, It should also be noted here that early assessment of heart damage is crucial for determining the treatment strategy in various clinical situations.

It is well established that different points (spaces) of the myocardium move in different directions and at different speeds. Moreover, they move not only spatially, but also relative to each other. This phenomenon is known as myocardial deformation (strain). The magnitude of the strain is an indicator that characterizes the degree of elongation and shortening of myocardial segments during systole compared to the final diastolic size, and the deformation rate reflects the time-dependent rate of change in deformation.

For the first time, myocardial deformation was studied using tissue Dopplerography in the 1960s by Kost and coworkers [1, 3], which was not widely adopted because of

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technical problems of low sensitivity and dependence on the scanning angle. Subsequent scientific and technological progress and in parallel, fundamental changes in traditional views on the macro- and microstructures of the heart contributed to the development of new technologies and the appearance of a new modification of two-dimensional speckle tracking - 2D strain echocardiography in the diagnostic field.

Speckle tracking - 2D strain was first introduced in 2004 (M. Leitman, P. Lakshman et al) [2], which was based on the concept of the spiral structure of the heart, according to which the myocardium is a combination of two spirally coiled fibers, where the fibers of the inner (subendocardial) layer form a right-handed helix, and the fibers of the outer (subepicardial) layer form a left-handed helix (Figure 1).

The fundamental principle of the method is to observe the movement of acoustic markers (speckles) formed as a result of the natural refraction of ultrasound rays at the boundary of two media with different densities.

Any tissue of the body is characterized by a unique structure of speckles (acoustic markers). Each acoustic marker is an ultrasound imprint (spot), which is being observed during the cardial cycle (Figure 3). They are evenly distributed throughout the myocardium and their size is from 20 to 40 pixels (dots). Along with the movement of the tissue, there is a speckle displacement - a change in the location of the acoustic markers (Figure 2) at different speeds and in different directions, and deformation - the movement of the acoustic markers relative to each other at different speeds, which causes a change in shape. By analyzing this movement in two- dimensional mode on a gray-scale image using ultrasound system software, without using a Doppler signal, 2D strain technology makes it possible to determine the displacement of the studied myocardial segments, the frequency (velocity), deformation, deformation rate and rotation [4]. This research method makes it possible to detect functional changes in the heart with greater sensitivity than traditional systolic and diastolic functional measurements, including cardiac ejection fraction (EF). Using speckle-tracking 2D strain echocardiography, myocardial deformation can be assessed based on the strain (the percentage change in the length of myocardial segments compared to their initial length) and the strain rate (the strain per unit time). As is known, myocardial fibers have three different spatial orientations (Figure 4): longitudinal, radial, and circular. Such an arrangement leads to effective myocardial contraction, which is characterized by shortening, thickening, and rotation. Such an arrangement leads to effective myocardial contraction, which can be compared to wringing a wet towel (5, 6). The fibers of the subendocardial layer of the heart muscle experience longitudinal strain, while the fibers of the subepicardial and medial layers experience transverse and circular strain and twisting.

Electromechanical activation of the heart begins in the left ventricle with subendocardial fibers oriented in a right-handed helix, causing the basal segments to rotate counterclockwise and the apex to rotate clockwise, while the subepicardial fibers oriented in a left-handed helix cause the basal segments to rotate clockwise and the apex to rotate counterclockwise (Figure 5).

During systole, the base of the left ventricle rotates clockwise, and the apex rotates counterclockwise, while during diastole, the movements of the base and apex are opposite to the systolic movement. Such rotational movements of the apex and base cause myocardial torsion (rotation) and are measured in degrees, conventionally, counterclockwise rotation is taken as a positive value, and clockwise rotation is taken as a negative value. The rotation of the base and apex in systole causes the heart to twist and it is a normal component of systolic contraction.

Speckle Tracking Echocardiography is a quantitative assessment of left ventricular torsion – twist (twisting) is based on the analysis of the mutual rotation of the apex and base during systole and is determined by the absolute difference between the apex and base rotations.

Twisting (in systole) = apex rotation-base rotation Untwisting – antitwisting is the process that opposes twisting. It is a normal component of diastolic relaxation and is mainly used to assess isovolumic relaxation. Untwisting (in diastole) = apex rotation-base rotation. The relationship of the twist to the longitudinal axis is called torsion, this quantity represents the relationship of the twist to the longitudinal axis of the ventricle, and is defined by the formula:

Torsion = Twisting/LV Longitudinal D (Figure 6), where LV Longitudinal D is the longitudinal diameter of the left ventricle.

Figure 6. Temporal sequence of left ventricular torsion (LVT). A. Velocity rotation of LV base (red curved arrows), and apex (blue curved arrows) during isovolumetric contraction, ejection, and isovolumetric relaxation and early diastole. B. LV rotational curves for the LV base (red line) and apex (blue line) from a normal Healthy subject. LVT (black line and arrow) is the peak stroke difference between basal and apical rotation (arrows). In the figure, LV rotational rate curves for LV base (red line) and apex (blue line) are derived from the same healthy subject in (B). LVT rate (black line, arrow 1) is measured as the peak stroke difference of basal and apical rotational rates, and LV untwist rate (black line, arrow 2) is the peak end diastolic difference between apical and basal. Reverse Rotation (From AHA/ASA Journal Published 19 March 2015).

Global assessments of left ventricular mechanics, information on cardiac strain in three, spatial dimensions (4), and the relative ease of performing the method have generated great interest in Speckle Tracking - 2D Strain Echo technology in the medical community, and numerous studies on the importance of myocardial deformation analysis have appeared in the medical literature.

Left ventricular global longitudinal strain (LVGLS) is an independent predictor of the manifestation of coronary artery disease (CAD).

In 2012, Studies conducted by Hoffmann S, Bjerin-Shorensen T, et al. [7], in which 296 patients with stable angina were included and who underwent 2D strain echocardiography, exercise testing, and coronary angiography, showed that in patients with 70% stenosis of a single coronary artery, global longitudinal strain (GLS) was significantly reduced (-17.1±2.5% versus -18.2±2.6%, $p<0.0001$). According to the studies by M. Leitman et al. [8], in patients with local damage to the left ventricle, the

GLS in normokinetic segments of the myocardium was significantly reduced (-13.4±4.9%, p<0.00001). Better GLS was obtained in hypokinetic segments than in akinetic segments (-6.2±± 3.6, p< 0.00001).

The results of this review showed that 2D strain echocardiography GLS Indicators for detecting local contractility are a highly sensitive and specific marker that can be considered an independent predictor of CAD manifestations.

Assessment of post-infarction cardiac remodeling. In 2010, a study was conducted within the framework of the "VALIANT" project (on the efficacy and safety of valsartan in patients with acute myocardial infarction), in which 639 people participated, longitudinal strain was assessed in -380, and circular - in 420 patients. The initial study was performed on day 5.00±2.5, and the assessment of dilatation (15% increase in end- diastolic volume) was performed 20 months after treatment. The initial values of the longitudinal strain of the left ventricle had a prognostic value and were associated with heart failure, and the circular strain velocity was an independent predictor of the occurrence of ventricular dilatation at 20 months.

According to the studies by A.D Andrea et al. [9], in which patients with acute myocardial infarction without ST segment elevation underwent myocardial revascularization, the assessment of longitudinal strain was performed on the 3rd and 14th days after the development of the infarction, and the assessment of post-infarction dilatation after 6 months. A longitudinal strain rate of ≥12% was an independent risk factor for adverse ventricular remodeling (with a sensitivity of 84.8% and a specificity of 87.8%). Assessment of the cardiotoxic effect of chemotherapy.

Myocardial strain and strain rate are early predictors of the development of cytostatic- induced cardiomyopathy. In oncological diseases, a premature decrease in longitudinal strain of 10 -15% during treatment with anthracyclines and antibiotics was an indicator of cardiotoxicity and indicated a high risk of developing heart failure (Thavendiranathan PP. et al.,2014) (10).

According to the studies by Shatsaka and co-authors [11], after 3, 6, 9, 15 months of chemotherapy with anthracyclines, taxanes and trastuzumab, a decrease in the longitudinal and radial strain of the myocardium was observed in 26 (32%) patients, and heart failure in 5 (6%) patients. In these patients, the indicator of cardiotoxicity was a decrease in longitudinal strain and an increase in troponin I. Longitudinal strain <-19% was observed in all patients who subsequently developed heart failure. In addition, ejection fraction, diastolic function and natriuretic peptide were within the normal range in these patients.

The aim of the study by Yang Anqi, Zhang Yu, and co-authors [12] was to detect early cardiac toxicity after chemotherapy in breast cancer patients using 2D strain echocardiography. The study included 40 patients who were undergoing 4-6 cycles of anthracycline chemotherapy. Patients were examined by echocardiography before chemotherapy (T0) and after the second (T2), fourth (T4), and sixth (T6) cycle. LVEF, LVGLS, and endocardium (GL-Endo), mid-myocardium (GL-Mid), and epicardium (GL-Epi) global longitudinal strain were assessed. Global circumferential strain (GCS), global longitudinal strain of the right ventricle (RV) (GLS), and global longitudinal strain of the left atrium (LA) (LAGLS) were also assessed. According to the results, LVEF was significantly reduced at T4 (P < 0.05). Compared with T0, GLS, GLS-Endo, GLS-Mid and GLS-Epi values were significantly reduced at T2, T4 and T6 (P < 0.05 for all), the apical septum wall was also significantly reduced at T2 (P < 0.05), and the apical and basal segments of the anterior wall were significantly reduced at T4 (P < 0.05). GCS, RVGLS, and LAGS did not change significantly after treatment (P > 0.05). The results showed that changes in global longitudinal strain indices before the decrease in ejection fraction were an indicator of the cardiotoxicity of anthracyclines and indicated a high risk of developing pathological changes in the coronary basin.

Assessment of the prognosis of revascularization. According to the studies by M. Betzker et al. [13], the quantitative assessment of radial deformation indices allows the detection of hyperinflation of the myocardium. According to the results of the studies, a radial strain index -≤17.2% allows the prediction of improvement in myocardial contractility after revascularization (with 71% sensitivity and 92.1% specificity), which did not differ from the results of contrast magnetic resonance imaging (with 71% sensitivity and 92.1% specificity). In addition, the combination of radial and longitudinal strain data also allows the determination of the depth of myocardial damage ("transmurality"). In subendocardial injury, the radial damage of the myocardium remains normal, while the longitudinal strain parameter decreases, which is associated with a decrease in myocardial contractility. In transmural injury, the decrease in both indices indicated a deterioration in the kinetics of the heart muscle.

Thus, the assessment of left ventricular deformation allows for a multifaceted study of myocardial kinetics in different spatial directions, which brings echocardiography closer to other myocardial imaging technologies, such as magnetic resonance imaging. Rapid determination of longitudinal deformation of the left ventricular Speckle tracking ECG allows for clinical use in the diagnosis and assessment of the prognosis of the disease. The high informativeness of the method, unlike other diagnostic methods, accessibility, ease of performance, and the possibility of repeated use determine its popularity and widespread use in daily clinical practice.

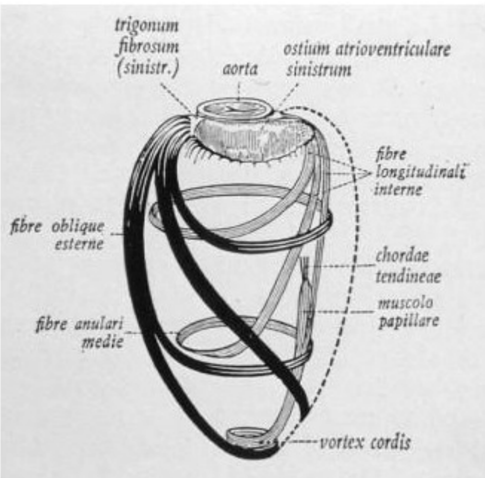

Figure 1. Myocardial fiber orientation and direction of rotation.

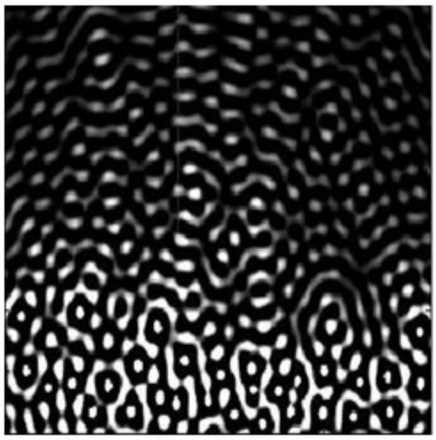

Figure 2. Acoustic markers are presented, which are ultrasound fingerprints.

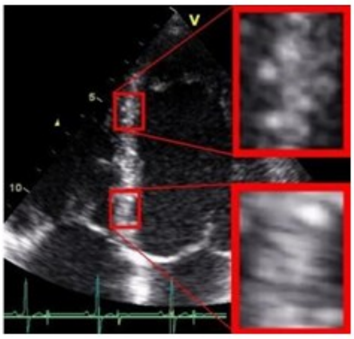

Figure 3. The location of each spot is presented by observing successive frames, on which the spot moves from frame to frame; the speed of the spot movement is the frequency of changing the frames.

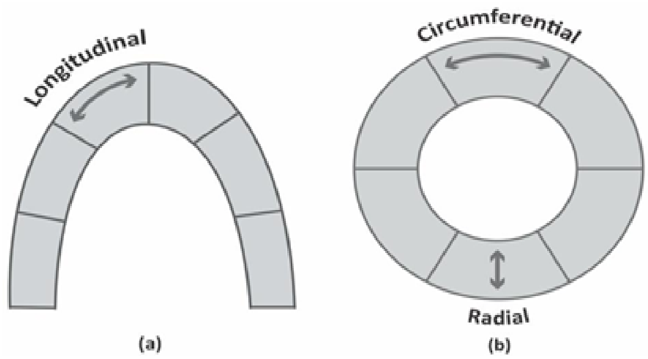

Figure 4. Schematic representation of LV deformation (strain) in three spatial orientations (a) longitudinal and (b) radial and circumferential.

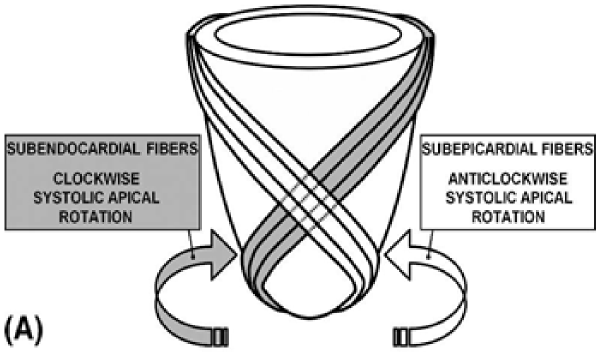

Figure 5. (A) Schematic representation of subepicardial (white) and subendocardial (gray) fiber layout in the left ventricle and the effect of contraction of these fibers on systolic apical rotation.

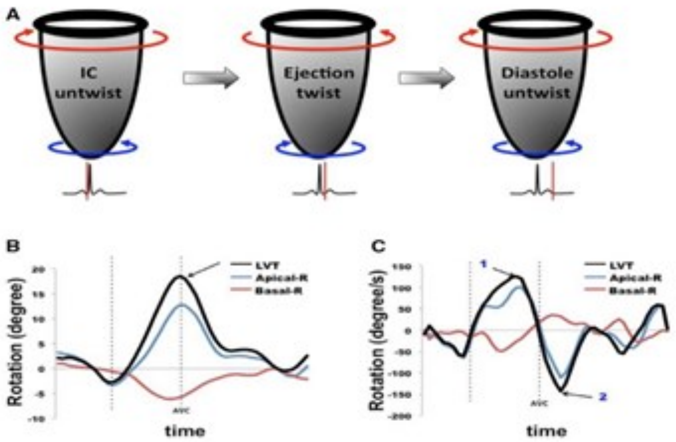

Figure 6. Temporal sequence of left ventricular torsion (LVT).

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