Review Article

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Myocardial Strain Imaging Using Two and Three-Dimensional Speckle Tracking Echocardiography: Clinical Applications

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Keywords:
Myocardial strain imaging, Echocardiography.

Abstract:

Cardiac function analysis is the main focus of echocardiography. Myocardial strain & strain rate imaging have emerged as a quantitative technique to accurately estimate myocardial function. In the last decade, two dimensional speckle tracking echocardiography (2DSTE) has gained popularity as a novel technique for strain & strain rate measurement. This technique has been found clinically useful in the assessment of cardiac systolic & diastolic function. 2D strain could potentially be used to differentiate disease from non-disease segments, for identifying early subclinical changes in various pathologies and to learn more about the various strain patterns indicative of specific disease types. A large number of studies have evaluated the role of 2DSTE in predicting the response to cardiac resynchronization therapy in patients with severe heart failure. Emerging areas of applications of 2DSTE include prediction of rejection in heart transplant patients, early detection of cardiotoxicity in patients receiving chemotherapy for cancer and effect of intracoronary injection of bone marrow stem cells on left ventricular function in patients with acute myocardial infarction. However, 2D imag-ing methods have limitations in assessing three dimensional (3D) cardiac motion. Experimental studies and clinical investigations revealed the reliability and feasibility of 3DSTE-derived data. In this review, the meth-odology, validation, and clinical application of both 2D &3DSTE have been discussed.

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Introduction:

Traditionally, the assessment of left ventricular (LV) systolic function has been made from an overall visual impression of LV systolic thickening noted on multiple views on two-dimensional (2D) echocardiograms. Objective measurements such as fractional shortening on M-mode imaging and calculation of the ejection fraction (EF) by modified Simpson's rule, although useful, often provide only a global estimation of LV systolic function and are subject to interobserver and intraobserver variability. Operator experience also influences the visual assessment of LV function. Moreover, all these parameter provide only partial impression of ventricular function regarding its complete mechanics. Strain imaging, also called myocardial deformation imaging, is a technique developed in an attempt to standardize the assessment of regional and global LV mechanics. Myocardial strain /deformation is the change of shape and dimensions of cardiac muscle in relation to original length during systolic & diastolic phases of cardiac cycle. Shortening of the fiber during systole results in a negative value for strain, while lengthening results in a positive value. The extent and the rate of deformation of a myocardial segment during the systolic and diastolic phases of the cardiac cycle gives a better impression of both its mechanical and physiological performance.

Before the advent of Speckle Tracking Echocardiography (STE), tissue Doppler imaging (TDI) was the only echocardiographic modality to measure myocardial velocities and assessing various types of strain and strain rate in the clinical setting.[1] However, TDI has many limitations; it is fairly complex to analyze and interpret, requires high frame rate and, in

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particular, it is angle dependent. Assessment of deformation parameters by TDI is thus only feasible if the echo beam can be aligned to the vector of contraction in the respective myocardial segment. In contrast, STE uses a completely different algorithm to calculate deformation by computing deformation from standard 2D grey scale images & thus, it is possible to overcome many of the limitations of TDI (Table I).

The clinical relevance of deformation parameters with an easy mode of assessment has sparked enormous interest within the echocardiographic community. This is reflected by the increasing number of publications focusing on all aspects of STE and test the potential clinical utility of this new modality. In fact, some have already cited STE as 'the next revolution in echocardiography.[1]This modality is based on 2D echocardiographic technology and not Doppler, thus removing the need for parallel alignment of the ultrasound beam to myocardial wall motion.[1–3] The recent addition of three-dimensional (3D) STE may further expand the scope of this technology. However, it is important to gain an understanding of cardiac muscle layers and the mechanics of cardiac motion before describing this technology.

Cardiac Muscle:

The heart is a double looped helical structure. The myocardial fiber layout makes two loops around a central axis,1 basal and 1 apical loop. The basal loop is oriented transverse and the apical loop is oblique. The oblique fibers which loop at the apex have a descending segment with fibers twisted clockwise and an ascending segment twisted counter clockwise. The transverse fibers forming the basal loop wrap around the ascending and descending segments enclosing the upper two-thirds, but sparing the lower or apical one-third. This intricate arrangement of myocardial fibers results in complex LV mechanics during the cardiac cycle. A close observation of figure 1 will make it easy to understand this complex arrangement. The cardiac muscle mass may be considered to consist of 3 separate layers. The middle layer or the basal loop occupies approximately half of the total muscle mass and has transversely oriented circular fibers which wrap around both ventricles, but spare the cardiac apex and do not involve the ventricular septum. The inner oblique layer (descending segment) and the outer oblique layer (ascending segment) each occupy about a quarter of the total muscle mass and consist of oppositely arranged oblique fibers in the form of a helix (figure of eight), which includes the apex.

Table-I

Comparison between Two-Dimensional Speckle Tracking Echocardiography and Tissue Doppler Imaging.

Tissue Doppler Imaging	Speckle Tracking Echocardiography
Dependent on angle of insonation	Angle independent
Can measure deformation only along one axis (axis of the transducer)	Can measure longitudinal, radial, and circumferential strain. Can also measure left ventricular twist mechanics
Movement assessed in relation to transducer	Movement assessed in relation to adjacent speckles
Higher frame rates and hence good temporal resolution	Lower frame rates and poor temporal resolution. Hence limited utility in tachycardic patients and in those with nonsinus rhythms
Limited spatial resolution	Better spatial resolution
Measures regional strain only	Both regional & global strain can be computed
Measures tissue velocity, strain is derived	Strain & strain rate can be measured directly
Influenced by translational motion	Less influenced by translational motion
Image quality less important	Relies on good image quality
Less reproducibility	Greater concordance among observers

Contraction of the descending segment or inner layer will result in clockwise rotation of the apex and that of the ascending segment or outer layer counterclockwise rotation (as viewed head on from the apex or the feet of an individual lying supine on a bed). It is the interaction between all 3 muscle layers that is responsible for movements of the heart during the cardiac cycle.

Basics of myocardial mechanics

The myocardial fiber arrangement of the LV wall provides an equal distribution of regional stress and strains.[5] In healthy subjects, the LV undergoes a twisting motion which leads to a decrease in the radial and longitudinal length of the LV cavity. During isovolumic contraction the apex initially performs a clockwise rotation. During the ejection phase the apex then rotates counterclockwise while the base rotates clockwise when viewed from the apex.[4] In diastole relaxation of myocardial fibers and subsequent recoiling (clockwise apical rotation) contributes to active suction.[6] Thus, the contraction of the heart is similar to the winding (and unwinding) of a towel (Fig 2).

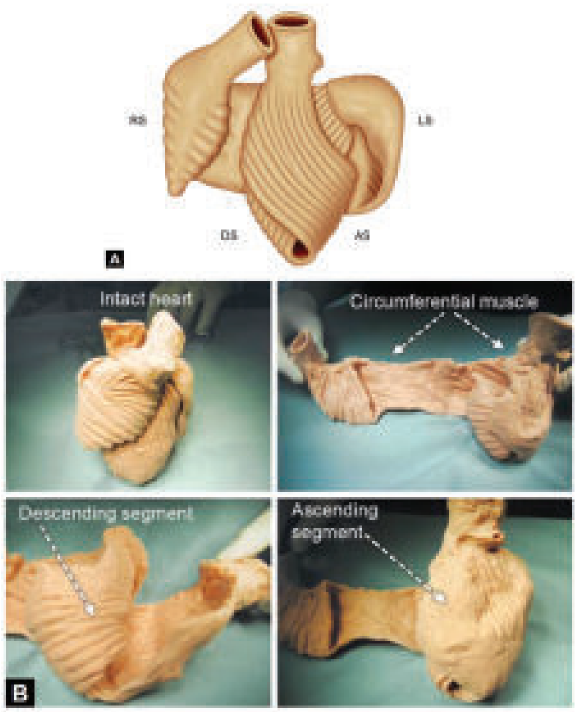

Fig.-1 (A) & (B): *Showing Schematic model and dissected heart model showing myocardial fiber arrangements. (A) Depicts the apical and basal loops. The apical loop consists of an outer ascending segment (AS) with oblique counterclockwise fiber orientation and an inner descending segment (DS) with fibers oriented in an oblique clockwise direction. The basal loop covers the upper two-thirds of the apical loop and its fibers are oriented in a circumferential or transverse direction. It can be considered to have two segments: right (RS) and left (LS). (B) Depicts the way the circumferential fibers of the basal loop wrap around the ascending and descending segments.*[4]

From a mathematical point of view several parameters of myocardial mechanics can be described as follows-

Rotation (degrees) = angular displacement of a myocardial segment in short axis view around the LV longitudinal axis measured in a single plane.

Twist or torsion (degrees)= which is the net difference between apical and basal rotation (calculated from two short axis cross-sectional planes of the LV).[8,9]

Torsional gradient (degrees/cm) which is defined

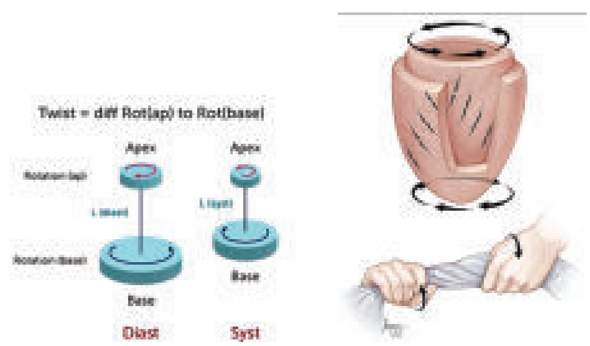

Fig 2: *Rotation of left ventricular apex and base during the heart cycle* [7]*. Rot, rotation; l, length; diast, diastole; syst, systole; ap, apical; diff, difference.*

as twist/torsion normalized to ventricular length from base to apex and accounts for the fact that a longer ventricle has a larger twist angle.[9] LV twist can be quantified in short axis views by measuring both apical and basal rotation with the help of STE (Fig 2). In addition, it is possible to calculate time intervals of contraction/ relaxation with respect to torsion or rotation and therefore measure the speed of ventricular winding and unwinding. In particular, the speed of apical recoil during early diastole seems to reflect diastolic dysfunction.[10,11] Several studies have demonstrated that disturbed rotational mechanics can be found in many cardiac disease states and that specific patterns describe specific pathologies.[10-15] While these parameters are assessed with the help of STE derived deformation parameters and describe the 'mechanics' of the entire heart, deformation parameters can also be calculated for individual segments and specific vectors of direction.

Three different components of contraction have been defined: radial, longitudinal, and circumferential strain (Fig 3).

Longitudinal Strain: Longitudinal contraction represents motion from the base to the apex. The longitudinal strain denotes shortening of the LV along its long-axis.

Radial Strain: Radial contraction in the short axis is perpendicular to both long axis and epicardium. Thus, radial strain represents myocardial thickening and thinning.

Circumferential strain is defined as the change of the radius in the short axis, perpendicular to the radial and long axes.

There are other strain terminologies which are not routinely used in STE, but are briefly described below for a more complete understanding of the concepts used. These are Lagrangian strain, natural strain, and shear strain. Strain measured at any given instance during muscle contraction, not just end-systole, compared to baseline length is termed Lagrangian strain. If, instead of baseline length, any other length at a different previous time is used, it is termed natural strain. In addition to shortening during systole, distortion of the muscle segment may occur in relation to top and bottom borders or left and right borders and this is called shear strain. 2D strain comprises of 4 measurements—2 natural strain and 2 shear strain. If one uses a 3D model, 3 natural strain and 6 shear strain measurements along x, y, and z or azimuthal axes, can be assessed.[2]

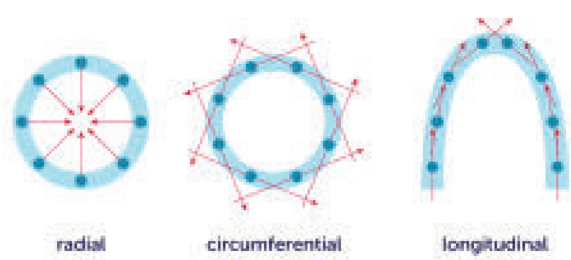

Fig.-3: *Different types of left ventricular myocardial strains*[7]

Speckle Tracking:

'Speckles' are small dots or groups of myocardial pixels that are routinely created by the interaction of ultrasonic beams and the myocardium. They have specific gray scale characteristics or signature. The ability to identify and track the same speckle throughout the cardiac cycle by 2D echocardiography forms the basis for 2D STE (Fig 4). Different parameters of strain, strain rate, and rotational mechanics are measured by 2D STE.

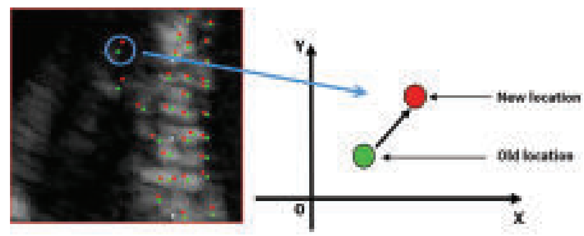

Fig 4: *The fundamental basis of speckle-tracking echocardiography. Myocardial speckles in a gray-scale image are tracked frame-by-frame to resolve myocardial deformation in different directions.*[16]

Measurement of different parameters of strain by 2D STE:

Radial strain and transversal strain refer to thickening of the myocardial wall during inward motion of the ventricle, whereas the former is measured in the short-axis views and the latter in apical views. As the myocardial thickness increases during the inward motion in systole, the value is traditionally denoted by a positive sign. For example, if the myocardium thickens by 40% in the short-axis view from end-diastole to end-systole the radial strain is given as +40%. On the other hand, if the myocardium is thinned by 40%, the radial strain will be expressed as-40% (Figs. 5 and 6).[17]

Longitudinal strain refers to the percentage decrease in the length of the myocardium during systole as the base predominantly moves toward the apex. Because of the decrease in the length in systole, it is expressed as a negative value (Fig. 7).[17]

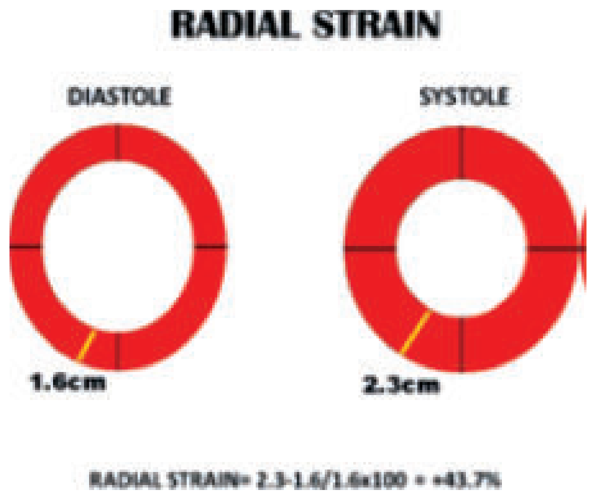

Fig.-5. *Radial strain shows radial thickening of the myocardium during systole. In the end-diastolic frame on the left the myocardial thickness is 1.6 cm and increases to 2.3 cm in end-systole as depicted on the right; hence the radial strain will be +43.7%.*

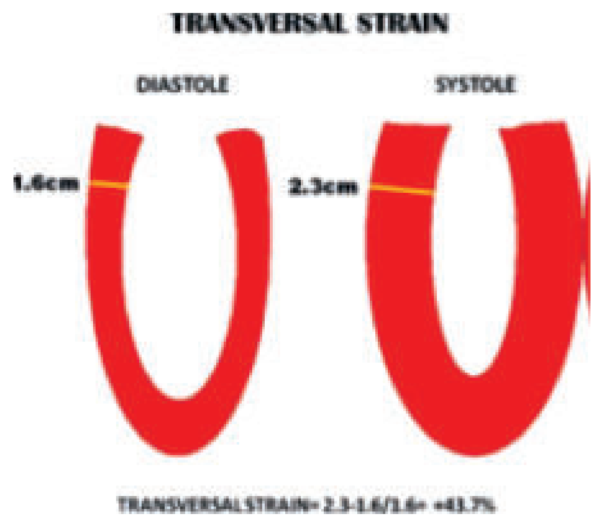

Fig.-6: *Transversal strain. The calculations are similar to radial strain except that the measurements are done using apical views.*

All strain parameters can be individualized for each of the myocardial segments or can be expressed as global strain when all the segmental values are averaged. The rate of change of thickness or deformation is called strain rate. It is important to remember that all these parameter scan be measured not only for the LV but also for the right ventricle (RV) and left and right atria (LA and RA), but these are much less commonly used in the clinical setting and

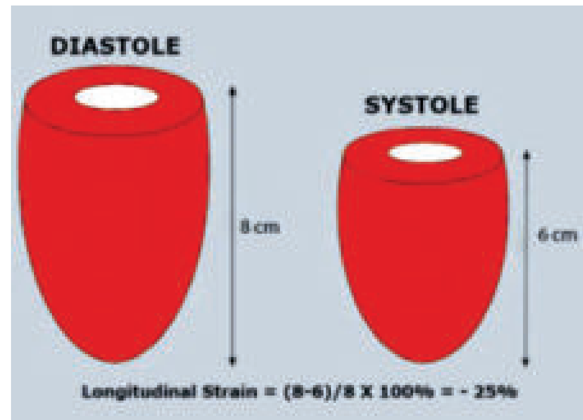

Fig.-7: *Longitudinal strain shows shortening of ventricular length during systole. The figure on the left denotes end diastole and the one on the right depicts end-systole. Note the downward descent of the mitral annulus toward the apex in systole. There is a reduction in length by 2 cm, which is a 25% decrease. As there is a decrease in the longitudinal length, it will be denoted by a negative (-) sign; hence the longitudinal strain will be-25%.*

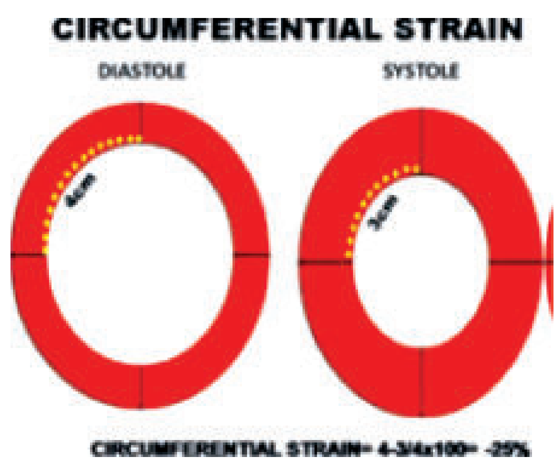

Fig.-8: *Circumferential strain refers to the change in the circumference of each segment as denoted by the dotted yellow line in the figure. As the diameter of the LV perimeter shortens during systole in normal state, the value is negative. There is a 25% reduction in the circumferential length in end-systole from the baseline end-diastole; hence the circumferential strain will be-25%*[17].

some have not been fully validated. The time from the beginning of the QRS complex (end-diastole) to peak strain, which normally would be end-systole coinciding with minimum LV volume, is also often measured for assessment of dyssynchrony which represents the difference in timing of peak contraction between 2 walls or segments of the ventricle. For example, if time to peak strain (peak contraction) is delayed for the LV posterior wall as compared with the ventricular septum, it would mean that the posterior wall does not contract at the same time as the septum and, therefore, its contraction is dyssynchronous and not synchronous (Fig. 9).[18]

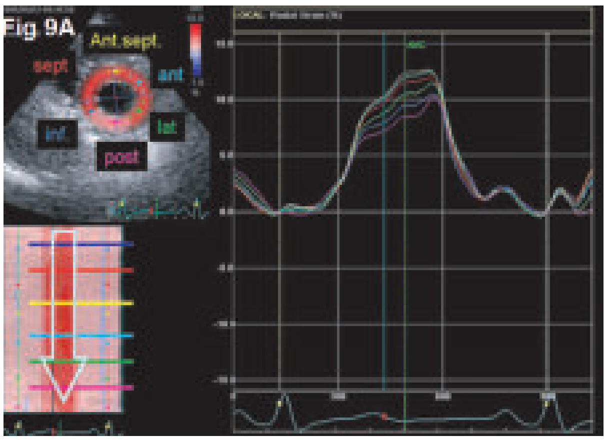

Fig.-9: *A. Normal individual. Left: Color-coded two-dimensional speckle tracking echocardiographic radial strain in a normal individual. Top left: homogeneous color coding during systole without segments of delayed contraction (6 segments-clockwise: Ant. sept = anteroseptal; ant = anterior; lat = lateral; post = posterior; inf = inferior; sept = septal.Bottom left: color-coded map representing strain as relative wall thickening of individual segments in red colors of different brightness related to the cycle time period and demonstrating peak strain in end-systole without delay between each of the segments; arrow = peak strain, segments represented by colored lines. Right: Corresponding radial strain curves are lined up during the cycle indicating no evidence of dyssynchrony. B. Dilated cardiomyopathy. Left: Color-coded speckle tracking echocardiography representing delayed contraction posteriorly. Right: Corresponding segmental radial strain curves. The time delay between the ventricular septum (red curves) and the lateral wall (green curve) is 340 msec, representing distinct dyssynchrony. AVC = aortic valve closure (Reproduced from Nesser HJ, Winter S: Speckle tracking in the evaluation of left ventricular dyssynchrony. Echocardiography 2009;26;324–336).[18]*

Peak strain, that is peak LV contraction, may also occur beyond the end of systole (aortic valve closure) in early diastole in some patients with myocardial ischemia (postsystolic contraction; (Fig. 10).[19]

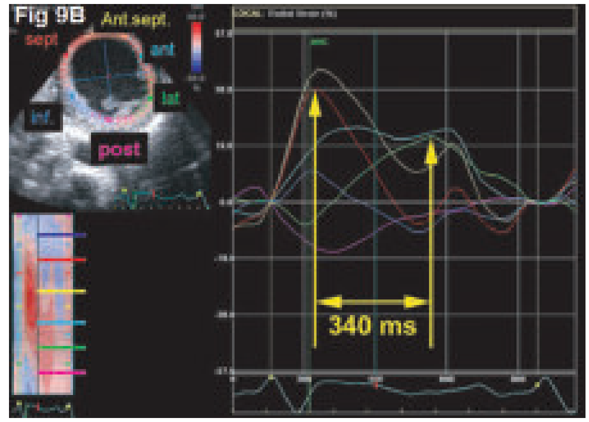

Fig 10: *Longitudinal strain by speckle-tracking echocardiography (two-chamber view) in a patient with acute myocardial infarction the day after percutaneous coronary intervention of an occluded left anterior descending coronary artery. Follow-up late enhancement cardiac magnetic resonance (lower left) showed myocardial scarring represented by the white area in apex and anterior wall. Strain curves display typical features of ischaemic dysfunction, ranging from lengthening throughout systole in a segment with transmural infarction and different degrees of dysfunction in other segments. The color of each trace corresponds to anatomical points on the 2-D color image and the white dotted line shows the average of the six strain curves. The yellow curve shows normal contraction in a non-infarct segment. Post systolic shortening occurred after aortic valve closure & is shown by a long arrow directed upward.*

Measurement of Parameters of Rotational Mechanics using STE:

Rotation is the measure of the rotational movement of the myocardium in relation to an imaginary long axis line from apex to base drawn through the middle of LV cavity. Clockwise rotations are assigned a negative value (e.g., -10°) and counter clockwise rotations a positive value (e.g., 10° or +10°).[17]

Twist measures the algebraic difference in rotation between the apex and the base. For example, if the apex moves 30° counter clockwise and the base moves 15° clockwise, then the twist will be 45° (30-(-15) = 30 +15 = 45°.[17]

Torsion is the same as the twist, except that the value is normalized to the length of the LV cavity, i.e., twist divided by the vertical distance between the apex and base and is expressed as degrees per centimetre. Both twist and torsion can be measured between any 2 segments of the Myocardium.[17]

Procedure to perform speckle-tracking echocardiography:

Now a day number of ultrasound systems are available that offer STE capabilities. Although, all these systems use their own proprietary software for myocardial deformation imaging but the basic steps involved are same. The protocols for acquisition are similar to routine echocardiograms. Gated images are obtained during end expiratory breath-holding spells with stable electrocardiographic traces. Care should be taken to avoid foreshortening of the ventricle or any other chamber of interest. Images acquired should be of high quality as the endocardial border needs to be well delineated and well visualized for reliable radial, transverse, and circumferential tracking. The optimal frame rate should be 60–110 frames per second (FPS). It is preferable to keep the sector width and depth minimal to focus on the structure of interest. Three consecutive cardiac cycles are obtained. The values are averaged for the final value using the software during final processing. A lower FPS than given above compromises the temporal resolution and is more likely to result in poor tracking results with underestimated and inaccurate values. Higher FPS will also undermine tracking results as the speckle patterns do not change enough from frame to frame resulting in algorithm ambiguities.

Apical four-chamber, two-chamber, and three-chamber views are necessary for estimation of LV and RV longitudinal and transversal strains and strain rates by 2D STE. LA and RA strain parameters can also be assessed in these views.

Parasternal short-axis views—one from the basal short-axis view obtained at the tips of the mitral leaflets or papillary muscles, the other at the apex just proximal to the end of LV cavity, are necessary for radial and circumferential strains and strain rates as well as for rotation, twist, and torsion analysis. The ways myocardial segments are divided widely vary among the vendors, but in general, a 16- to 18-segment LV model is used. For the timing determination of cardiac events, mitral inflow and LV outflow velocities are recorded using pulsed-Doppler echocardiography and the aortic and mitral valve closure times are obtained from this.

Image Analysis:

The recordings are analyzed on the same machine or off line using semi automated computer software for estimation of strain and strain rate by 2D STE. The region of interest (ROI) has to be outlined manually. The LV is evaluated in short-axis or apical views by tracing the endocardial border by point and click method. The RV and atria are traced in the apical four-chamber view only when those chambers are studied. The epicardium is automatically traced by the system, but the wall thickness can be manually adjusted and particular care should be given when tracing thinner RV and atrial walls. In 2DSTE, when the image is opened in the software, the software automatically brings up the end-systolic frame of the cardiac cycle. If the automated frame selection seems inaccurate, the same can be adjusted manually.

In the end-systolic frame, endocardial border is traced manually, beginning at one end of the mitral annulus and ending at the other end.

The software then generates a region-of-interest (ROI) to include the entire myocardial thickness (Fig. 11).[16] The width of the ROI can be manually adjusted as required. Care should be taken to avoid bright, echogenic pericardium in the ROI.

The software then tracks the myocardial speckles frame-by frame and generates moving images displaying the tracking. Visual inspection of the moving image allows the operator to determine the adequacy of the tracking. If the tracking does not seem to be accurate, one can go back and readjust the ROI or select an altogether new ROI. Once the satisfactory tracking is achieved, the same is approved by clicking on the approve button (Fig. 11).

The software then divides the LV myocardium into six segments and generates segmental and global longitudinal strain, strain rate, velocity and displacement curves. As the myocardium usually shortens in longitudinal direction during systole, the longitudinal strain and strain rate curves are displayed below the baseline. From these curves, peak systolic longitudinal strain and strain rate can be recorded for each of the myocardial segments. A color-coded parametric image that provides quick, visual impression of the timing and the extent of segmental myocardial deformation is also generated by some systems (Fig. 11).

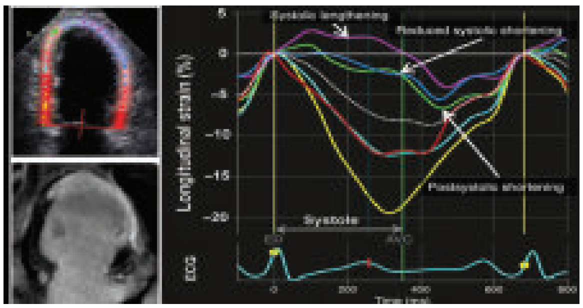

Fig.-11: *Steps involved in speckle-tracking echocardiography.*[16] *A. The endocardial border is manually traced in the end systolic frame. The automated software creates a region-of-interest that includes the entire myocardial thickness. B. The operator is prompted to review and approve the adequacy of tracking for each segment. C. The final strain curves. Color coded curves depict segmental strain whereas the dotted white curve depicts the average strain. The lower left corner shows the parametric image, displaying the timing and the magnitude of segmental longitudinal strain.*

The same process is then repeated with the apical four chamber and two-chamber images.

- The strain values for all the segments are recorded and averaged to obtain the global longitudinal strain (GLS) and strain rate. Some systems also provide Bull's eye display of the regional and global longitudinal strain (Fig. 12).
- The short-axis images are also analyzed in the same manner to derive the segmental and global radial and circumferential strain and strain rate. It is important to recognize that during systole, the LV circumference usually shortens whereas the myocardial thickness increases. Hence, the normal circumferential strain is negative but the normal radial strain is positive (Fig. 13).[16]
- The rotation and rotation rate are automatically measured when the short-axis images are analyzed for strain measurement and no extra step is required. LV rotation has a unit of '°' and the rotation rate '°_/s'. By convention, anticlockwise rotation is displayed above the baseline and is assigned a positive value whereas the opposite is true for the clockwise rotation. Thus, the normal apical rotation is positive and the basal rotation is negative.

For movements such as global twist, the mean value of all the apical segments is compared with the mean value of all the basal segments. The atria are divided into 3 or 6 segments, corresponding to the inter atrial septum, the lateral wall, and the roof. The RV is usually divided into 6 segments (basal RV free wall, mid-RV free wall, apical free wall, basal left septum, mid-left septum, and apical left septum).[17]

Interpretation

There are a number of factors that affect the STE-based measurement of LV strain and rotation. These include physiological factors such as age, gender, loading conditions, as well as technical factors such as the orientation of the imaging planes & quality of the gray-scale images. In addition, there are significant inter-vendor differences in the STE-derived measurements

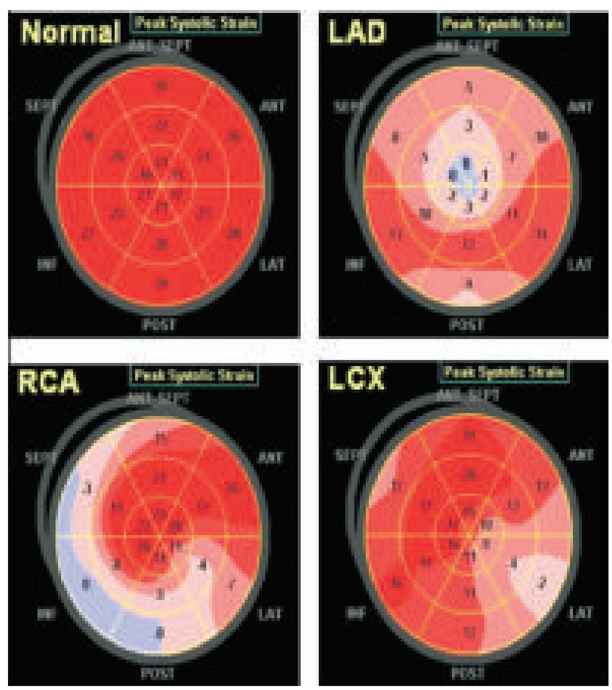

Fig.-12: *Bull's eye map demonstrating segmental peak systolic longitudinal strain in a normal subject and in patients with coronary artery disease showing infarct localization*

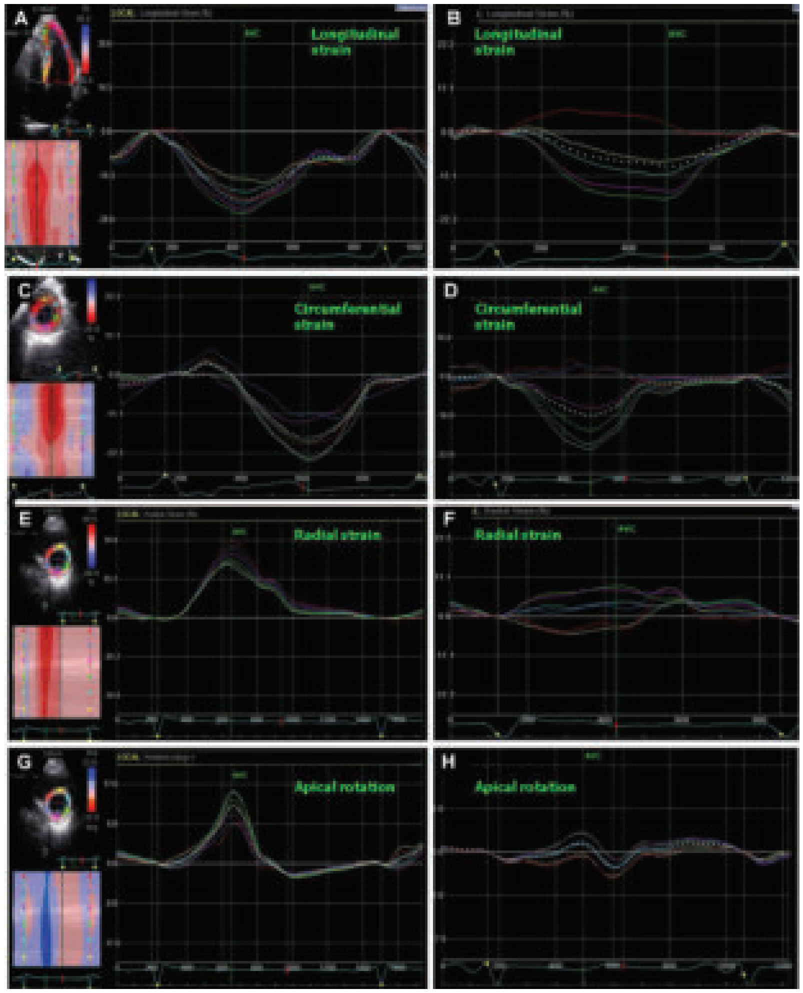

Fig.-13: *Examples of normal and abnormal longitudinal (A, B), circumferential (C, D) and radial (E, F) strain and apical rotation (G, H).*

which mean that the measurements obtained on one ultrasound system are not identical to the measurements obtained on another ultrasound system. For these reasons, no universally accepted normal values are available for the different myocardial deformation parameters, though several investigators have tried to define the age and gender specific reference ranges for the different strain components.[20-24]

Among all the strain parameters, longitudinal strain is more reproducible than the radial and circumferential strain and rotation. Similarly, global strain has much better reproducibility than the segmental strain. The normal GLS is usually in the range of -20± 2%.[25,26] The circumferential strain is usually greater than the longitudinal strain with average values in excess of-20%. The average radial strain is in the range of 40 to 60%. The rotation and torsion have much greater variability which makes it difficult to define the normal ranges for the same. However, it should be noted that the apical rotation is normally much greater than the basal rotation which is limited byte tethering effect of the mitral annulus.Table II shows mean percentage strain values by LV region in normal adults.[15]

Table-III

Normal Rotation & Torsion Values in Young Adults [27]

Peak Apical Rotation (º)	10.1±1.9
Peak Apical Rotation Rate (º/sec)	61.6±25.3
Peak Basal Rotation(º)	4.9±2.0
Peak Basal Rotation Rate(º/sec)	44.2±17.8

Clinical Applications of 2D STE

The most important role of STE is to provide a quantitative, objective measure of LV systolic function that can accurately detect subtle changes in the myocardial function. Among the different myocardial deformation parameters, GLS appears to be the most suited for this purpose. It has better reproducibility and is much more sensitive to the early myocardial damage than any other deformation parameters. The subendocardial fibres determine primarily the longitudinal strain whereas the mid-myocardial and subepicardial fibres determine predominantly the circumferential and radial strain and rotation. Since most of the cardiac pathologies involve the subendocardial layers first, longitudinal strain is usually the earliest to get compromised. The radial and circumferential strain remains preserved or may even be accentuated during the early stages to compensate for the loss of the longitudinal function.[6,20] As the disease becomes more extensive and more transmural, the radial and circumferential strain also get progressively impaired. Thus, the impairment of radial and circumferential strain is a relatively late phenomenon and tends to reflect more extensive myocardial damage. However, in certain pathological conditions that affect the heart from the outside, such as constrictive pericarditis, circumferential strain and rotation may get compromised earlier than the longitudinal strain. The exaggerated rotational movement during systole acts as a compensatory mechanism during the early disease process causing diastolic dysfunction. Untwisting during the post ejection isovolumic interval (isovolumic relaxation period) is impaired early in diastolic dysfunction. As the diseases progress, all the parameters may deteriorate.

There are little data in the literature regarding the clinical usefulness of RV or RA strain and the technique has not been fully validated. As mentioned earlier, another interesting phenomenon detected by STE is "postsystolic thickening or deformation" that is the continued contraction of the myocardium even after aortic valve closure, and is mostly detected by radial strain, but can occur with longitudinal strain also.[28] This has been noticed in myocardial ischemia, stunning, and nonviable myocardium and also in hypertrophic and Tako Tsubo cardiomyopathies and in aortic valve stenosis where it may be due to underlying myocardial ischemia.[29-31] This postsystolic thickening is directly proportional to the severity of ischemia and persists in the experimental setting for up to 2 hours after the ischemic insult has ceased, although it shows time-related reduction in its severity.[32] This ischemic finding is likely to be very helpful during an exercise stress echocardiogram, where there is always significant time pressure to make a judgment on stress-induced wall-motion abnormalities once the patient gets off the treadmill. Asanuma et al.[32] suggested that this phenomenon can be useful even for chest pain evaluation in the emergency room when time-related decline is noted in 2 separate studies done in around a15-minute interval. The mechanism by which postsystolic thickening occurs is still unclear, but has been proposed to be secondary to the regional heterogeneous contractile properties of the myocardium.[27] More likely, it is due to prolonged contraction of the descending segment.[4] Table IV [17]summarizes the clinical usefulness of 2DSTE,[31–58] and Table V [17] describes some parameters that may be helpful in differentiating athlete's heart from hypertrophic cardiomyopathy.

Table IV

Clinical Usefulness of two dimensional Speckle Tracking Echocardiography.

Myocardial ischemia	• Reduction in strain by 2D STE more objective and accurate than the traditional visual method of assessing WMA · Longitudinal, radial, and circumferential strain reduced in ischemic areas in coronary artery disease. · Postsystolic thickening (deformation), detected by radial strain correlates with the severity of ischemia.
Myocardial infarction	• 2D STE successful in differentiating transmural from subendocardial infarction by showing lower circumferential strain in the former. · Reduced subendocardial LV twist also noted in patients with ST-segment elevated myocardial infarction.
	• Decreased LV torsion and segmental longitudinal strain predicts progressive LV dilatation after myocardial infarction.

Myocardial viability	• Strain measurements by 2D STE more objective and accurate than visual WMA for assessment of myocardial viability during low-dose dobutamine stress echocardiography. 2D STE differentiates active contraction from passive motion due to tethering.
Heart failure with normal LVEF.	· Reduced and delayed LV untwisting—at rest and exercise.
Cardiac resynchronization therapy (CRT)	· Combining longitudinal strain from TDI velocity with 2D STE radial strain may help in predicting response to CRT. · Longitudinal strain delay index (calculated from the difference between peak and end-systolic strain) of >25% predicts response to CRT (sensitivity 95%,specificity 83%). · Speckle Tracking and Resynchronization (STAR) study showed radial and transversal strain better than longitudinal and circumferential strain in predicting LVEF response and long term survival after CRT. Lack of dyssynchrony before CRT by 2DSTE radial strain associated with death or hospitalization for heart failure.
Stress cardiomyopathy	• Impaired longitudinal strain noted particularly in apical and mid-ventricular segments.
Restrictive cardiomyopathy	• Impaired longitudinal deformation and twist mechanics are noted.
Constrictive pericarditis	• Impaired LV circumferential deformation and torsion.
Detection of rejection and coronary stenosis in heart transplant patients	• Sudden reduction of -15% in global radial strain associated with acute rejection. Decrease in strain and strain rate at rest and with dobutamine stress echo also useful to detect significant coronary stenosis.
Early detection of chemotherapy induced cardiotoxicity	• Reduction in radial strain may occur before reduction in LVEF and associated with histologic changes.
Detection of subclinical diseases/early myocardial involvement	• Reduction in strain may occur before changes in LVEF in systemic hypertension, diabetes mellitus, systemic sclerosis, amyloidosis, Duchene's muscular dystrophy, and Kawasaki syndrome.
Valvular heart disease	• Decreased radial, circumferential and longitudinal strain in patients with severe aortic stenosis and normal LVEF. Long term follow up after valve replacement showed significant improvement with no change in EF. · Reduced preoperative longitudinal strain in the ventricular septum (apical4-chamber view) predicts a postoperative LVEF decrease of -10% in patients with chronic severe mitral regurgitation.
Congenital heart disease	·• Atrial septal defect—basal clockwise rotation during systole is reduced. · Tetralogy of Fallot—right ventricular global longitudinal strain and strain rate is decreased significantly.

Table-V

Differentiation of Athlete's Heart from Hypertrophic Cardiomyopathy.

Athlete's Heart	Hypertrophic Cardiomyopathy
Normal longitudinal and other types of strain.	Decreased longitudinal strain
Increased LVEDV.	Decreased LVEDV
Decreases after deconditioning for 3 months.	No change with deconditioning.
Increased LV twist.	Delayed LV untwisting.
Increased early LA strain rate.	Reduced LA strain and strain rate.
No postsystolic thickening.	Postsystolic thickening present.

Three-Dimensional Speckle Tracking Echocardiography

The heart is a 3D structure and the walls of the ventricle move in three dimensions. 2D wall motion tracking (WMT) detects motion in one plane. An advantage of 3D WMT is the accurate detection of motion vectors and subsequent assessment of 3D strain. Assessment of all strain & rotation parameters from a single 3D dataset is a time saver. 3D STE Provides more reliable estimation of LV volume and EF. 3D WMT provides new insights for evaluation of LV twist and torsion that cannot be easily detected with other imaging technologies like MRI.

First generation volume imaging system requires at least 4 beats to build pyramidal volume data. Recently upgraded technology enables a single beat full volume acquisition without stitching making it easier to analyze patients with arrhythmias. Planar 2D images 90° to each other are displayed during acquisition and care should be given to make sure the chambers are displayed entirety in width as well as in depth and the pyramidal volume encompasses the entire chamber of interest. The processing of 3DSTE is generally similar to 2DSTE. An advantage of 3D STE over 2D STE is the presence of software in the equipment, which enables the user to identify the longest ventricular diameter in 2 long axis images coronal to each other, thus avoiding foreshortening of the LV. This also ensures that the walls and segments are correctlyidentified.[59,60] Unlike 2D STE, a combined assessment of longitudinal and circumferential strain can be performed by 3D STE, and this is termed area strain. As the values of both longitudinal and circumferential strains are negative in a normal subject, area strain will also be negative (Table VI).

It has also been shown recently that strain parameters are not compromised if they are derived from 18 or 25 FPS datasets, but are underestimated if lower frame rates are used.[61] A major disadvantage of 3D STE is its dependency on the quality of 2D images used for acquisition. Three-dimensional STE is still very new and not yet fully validated. Table VII summarizes the clinical usefulness of 3D STE

Table-VI

Area strain by Three-Dimensional Speckle Tracking Echocardiography in normal adults.[17]

LV basal segment (%)	-38.42±7.58
LV middle segment (%)	-38.74±6.34
LV apical segment (%)	-43.18±12.81

Table-VII

Clinical Usefulness of Three-Dimensional Speckle Tracking Echocardiography [17,62,63]

Ischemic LV dysfunction	· 3D STE longitudinal and area strains correlated with infarct size and scar extent evaluated by magnetic resonance imaging
Acute coronary syndrome	· 3D STE parameters predicts significant coronary artery disease in patients with non ST elevation acute coronary syndrome · Global 3D longitudinal strain is superior to other echo findings in predicting LV function improvement following acute myocardial infarction
LV wall-motion abnormalities (WMA)	· 3D STE is superior to 2D STE for assessing LV WMA · 3D area strain is accurate and reproducible in detecting LV WMA as evaluated by experienced echocardiographers
Early LV systolic dysfunction	· 3D global area strain identified early LV systolic dysfunction in patients with risk factors for heart failure.
LV volume assessment	· LV volume assessment is more accurate and more reproducible by 3D STE as compared with 2D STE using cardiac magnetic resonance as a reference.
Left ventricular dyssynchrony	· Systolic dyssynchrony index of 9.8%, 93% sensitive and 75% specific in predicting response to CRT (meta-analysis of 73 studies). · 3D STE assessment of strain is superior to 2D STE in LV lead positioning.
LV noncompaction	· 3D STE confirmed 2D STE findings that LV twist is nearly absent with both apex and base moving in the same direction (clockwise) in systole.
Differentiation of hypertrophic cardiomyopathy (HCM) from cardiac amyloidosis	· 3D LV basal radial strain is more reduced in amyloidosis (7.5 -19.7%) than HCM(22.3 - 22.7%, P < 0.0001); also, radial strain increased from base to apex in amyloidosis, but decreased in HCM (normal but reduced pattern).

table continued

Stress (Tako Tsubo) cardiomyopathy	· 3D STE provided rapid detection and follow up of LV WMA.
Cardiac sarcoidosis	· Global radial strain is significantly lower in sarcoidosis (18.5 - 8.4%) than dilated cardiomyopathy (28.5- 8.3%, P < 0.01). · Global radial strain -21.1%, 70% sensitive and 88% specific in differentiating sarcoidosis from dilated cardiomyopathy.
Sickle cell disease	· 3D STE detected LV diastolic dysfunction.
Hypertension	· 3D STE global strain reduced in untreated early hypertensives compared with controls.
Transcatheter aortic valvereplacement (TAVR)	· 3D STE similar to 2D STE in showing increased LV global longitudinal strain and twist following TAVR (especially when pre-TAVR LVEF was decreased), but faster image acquisition and data analysis.
Atrial septal defect	· 3D right ventricular ejection fraction and apical strain more sensitive predictors of unfavorable outcome than 2D Doppler indexes.

Limitations:

One of the important limitations of 2D STE is the lack of reproducibility of values obtained by this imaging modality. Although this problem is much less compared with TDI (Table I), it is imperative that for any given 2D or 3D STE study a thorough intra- and inter observer variability testing be performed before the results are considered accurate.[64] Inter vendor variability, lack of standardization and frequent upgrades of the speckle tracking software result in changes to reference values which are currently other major limitations for wider clinical acceptance of both 2D and 3D STE.[64]Also, most of the clinical applications of 2D and 3D STE need further confirmation using a much larger number of patients and different investigators.

In some clinical applications, the epicardial border is automatically tracked assuming uniform thickness of the myocardial wall which is not true. The calculated deformation parameters are averaged over a myocardial segment and hence it overlooks regional differences in myocardial strain and strain rate within the segment. The constraints have limiting consequences in the detection of early stages of disorders like arrhythmogenic RV dysplasia, where there are significant regional abnormalities. Even though 2D imaging is mostly angle independent, it is still subject to imaging pitfalls such as lateral wall dropout and rib artifacts. Rotation measurements are highly dependent on good data acquisition techniques. Transducer angulation can result in oblique short-axis views.

Conclusion:

Two dimensional &three dimensional STE have emerged as promising new tools for evaluation of regional & global cardiac function in different clinical condition. These imaging modalities provide new insights into cardiac physiology. Reduction in strain by STE is more objective & accurate than the visual assessment of RWMA or a reduction of EF. Real time 3DSTE was found to predict early LV subclinical systolic dysfunction among patients with systemic diseases with preserved LVEF. Patient selection for new therapies may rely on these new parameters, which better predict individual patient response.

Conflict of Interest - None.

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