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Editorial

# How do I do it? Speckle-tracking echocardiography

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Speckle-tracking echocardiography (STE) is a recently developed technique for the characterization and quantification of myocardial deformation. By allowing measurement of the different components of myocardial deformation, it provides information which is not available with any of the currently used echocardiographic parameters, including left ventricular ejection fraction (LVEF). The potential clinical value of such information is clearly reflected in the explosive increase over the last decade in the number of publications on STE. However, STE has its own limitations which need to be overcome before it can be incorporated into regular clinical practice. Nevertheless, given the enormous interest generated by STE, it is only timely for those involved in the practice of echocardiography to acquaint themselves with this technique. The present document aims to provide the basic understanding of myocardial deformation as relevant to the application of STE and then describes the step-by-step approach to the performance, interpretation and the use of STE.

## 1. Myocardial deformation: a multi-dimensional process

The left ventricular (LV) myocardium undergoes a complex multi-dimensional deformation during the cardiac cycle. However, for simplicity, the myocardial deformation on echocardiography is described in the form of three principle strains – longitudinal, radial and circumferential (Fig. 1).[1–3] The longitudinal strain denotes shortening of the LV along its long-axis. The circumferential strain depicts reduction in the circumference of the LV cavity during the cardiac cycle whereas radial strain denotes the thickening of the LV wall along its radius. In addition to the contraction and relaxation, the LV also undergoes rotation around its long-axis. When viewed from the apex, the apex rotates in anticlockwise direction during systole whereas the based rotates in the clockwise direction. This opposite rotation of the LV apex and base during systole produces a wringing motion or twist of the LV which is critical to the normal systolic functioning of the LV. The subsequent untwist during diastole generates a suction force that appears to be the key mechanism driving the early diastolic filling of the LV.

The complex LV myocardial deformation is brought about by an equally complex arrangement of the myofibers within the LV wall. The LV myocardium is composed of a continuous sheet of myofibers which are arranged in a multi-layered, helical manner. The inner subendocardial fibres are oriented relatively parallel to the long-axis of the LV and determine predominantly the longitudinal contraction. In contrast, the fibres in the mid-myocardial and subepicardial layers are arranged more parallel to the circumference of the LV and hence govern the radial, circumferential and rotational mechanics.[1,2] As discussed below, these mechanistic properties of the LV have important bearing on the effect of different cardiac pathologies on LV systolic and diastolic function.

## 2. What is speckle-tracking echocardiography?

One of the most important goals of echocardiography, performed for almost any indication, is to provide an estimate of LV systolic function. A number of echocardiographic parameters have been developed over the years to accomplish this task. Among them, LVEF appears to be the most robust and clinically the most relevant parameter for this purpose. However, despite its overwhelming clinical utility, LVEF has several limitations. First, it provides only an indirect estimate

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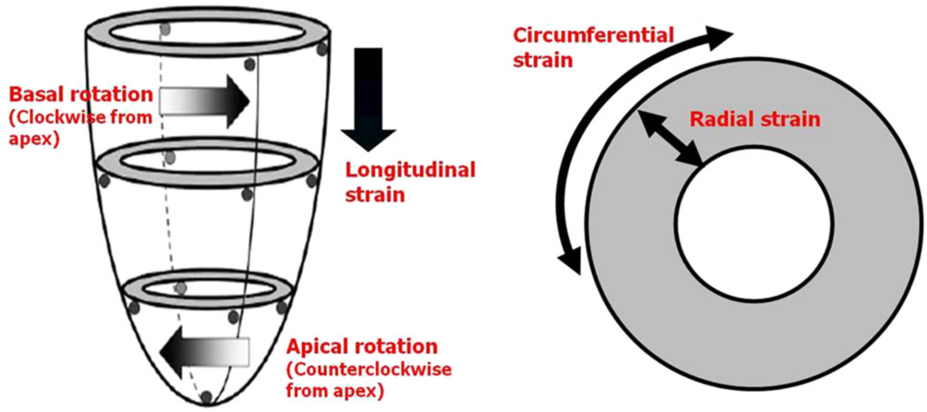


**Fig. 1 – Different components of left ventricular myocardial deformation that can be measured by speckle-tracking echocardiography.**

of myocardial contractile function and does not measure it directly. Second, it is readily influenced by a number of factors including loading conditions, heart rate, etc. Third, and the most important, it is not sensitive enough to detect subtle changes in the contractile function and therefore not suitable for detecting subclinical myocardial damage which may have major therapeutic and prognostic implications in a variety of clinical conditions. Strain imaging, or more appropriately called 'myocardial deformation imaging', offers a means to directly quantify the extent of myocardial contraction and promises to overcome many of the limitations of LVEF. Strain is the percentage change in the length of a myocardial segment during a given period of time and has a unit of %. Strain rate is the rate at which shortening or lengthening is taking place and has a unit of 1/s. As the myocardium shortens during systole, the strain and strain rate have negative value but when there is stretch or lengthening of the myocardium, the strain and strain rate become positive.

The myocardial strain imaging was initially developed as an extension of the Doppler velocity imaging. However, given the angle-dependence of Doppler imaging, only longitudinal strain could be measured with this approach and very little information could be derived about the other components of myocardial deformation. The more recently developed STE is a gray-scale based technique which is angle-independent and hence permits more comprehensive assessment of myocardial deformation. As we know, a gray-scale image on echocardiography is composed of several bright speckles that are produced as a result of the scatter of the ultrasound beam by the tissue. The STE software identifies these speckles and then tracks them frame-by-frame using a 'sum-of-the absolute-differences' algorithm. From this data, the software automatically resolves the magnitude of myocardial deformation in different directions and generates strain and strain rate curves (Fig. 2).[1–3] The longitudinal strain is measured from the apical long-axis images whereas the short-axis images are used for measuring radial and circumferential strain and rotation. Since STE utilizes gray-scale images, the strain derived by STE is also known as two-dimensional strain, to differentiate it from the Doppler-based strain.

Recently, three-dimensional STE has been developed which permits measurement of all the different components of myocardial deformation from one single, pyramidal, three-dimensional data set.[2] The detailed description of three-dimensional STE is beyond the scope of the present document.

## 3. How to perform speckle-tracking echocardiography?

A number of ultrasound systems are now available that offer STE capabilities. All these systems use their own proprietary software for myocardial deformation imaging but the basic steps involved are same. First, the necessary gray-scale images are acquired on the echocardiography machine and stored on a digital media for transfer to a workstation. The offline software is then used to analyze these images and to generate the strain data. Some of the currently available ultrasound systems also offer online STE analysis, on the echocardiography machine itself. However, it is relatively cumbersome and also ties down the machine time and is therefore used primarily for a quick assessment of the longitudinal strain only.

### 3.1. *Image acquisition*

Since STE is a gray-scale based technique, obtaining high-quality gray-scale images is the most critical requirement for STE. The following points need to be considered during the image acquisition-

- Images from the apical four-chamber, two-chamber and three-chamber views are required for the measurement of LV longitudinal strain whereas short-axis views at basal, mid and apical levels are needed for the measurement of radial and circumferential strain. The basal and apical short-axis images are also used for the measurement of LV rotation and torsion.
- Utmost attention should be paid to the quality of the images. The gain settings should be optimized. The depth should be reduced so that the LV occupies most of the image sector. In long-axis views, care should be taken to avoid foreshortening of the LV. In short-axis views, the LV cavity

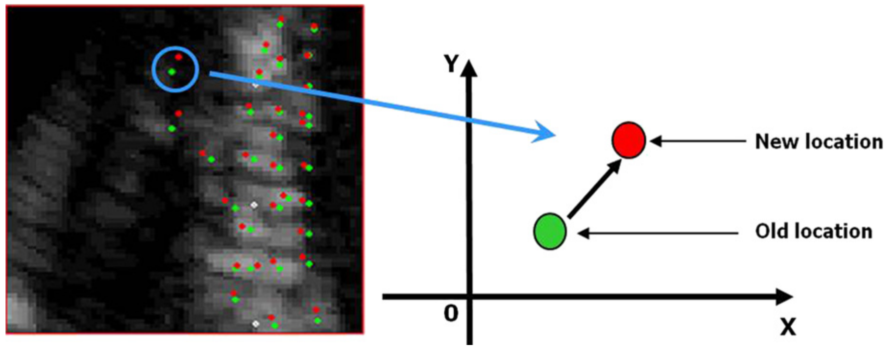


**Fig. 2 – The fundamental basis of speckle-tracking echocardiography. Myocardial speckles in a gray-scale image are tracked frame-by-frame to resolve myocardial deformation in different directions. Modified from reference 3.**

should be as circular as possible to ensure that the imaging plane is perpendicular to the long-axis of the LV.

- The gray-scale frame-rate should be kept between 30 and 70 frames/s. At lower frame rates, large displacement of the speckles between the successive frames precludes satisfactory tracking of the speckles whereas at higher frame rates spatial resolution of the image gets compromised.
- ECG gating is must. High-quality ECG signal is required to allow proper gating of the images. Effort must be made to obtain all the images at nearly identical heart rates.
- Minimum three cardiac cycles should be acquired for each loop. This ensures that at least one complete cardiac cycle (the middle one), without any truncation, is always available for analysis.
- All the images should be acquired in breath-hold to avoid any breathing artifacts.

STE can also be used for analyzing right ventricular (RV) and left atrial (LA) myocardial deformation. For RV function assessment, the RV-focussed apical four-chamber view is required. For LA strain imaging, apical four-chamber, two-chamber and three-chamber images, optimizing the visualization of LA, need to be obtained.

### 3.2. *Image analysis*

- Once the images are transferred to the workstation, the speckle-tracking application is launched and the image is opened in the application.
- It is advisable to analyze the apical long-axis image (i.e. three-chamber view) first. In this view, the movement of aortic valve leaflets helps in timing the aortic valve closure which is essential for the software to be able to perform the deformation analysis.
- 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 in its entirety, 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. 3). The width of the ROI can be manually adjusted as required. Care should be taken to avoid including 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. 3).
- 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 images that provide quick, visual impression of the timing and the extent of segmental myocardial deformation is also generated by some systems (Fig. 3).
- The same process is then repeated with the apical four-chamber and two-chamber images also. 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. 4).
- 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. 5).
- 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.

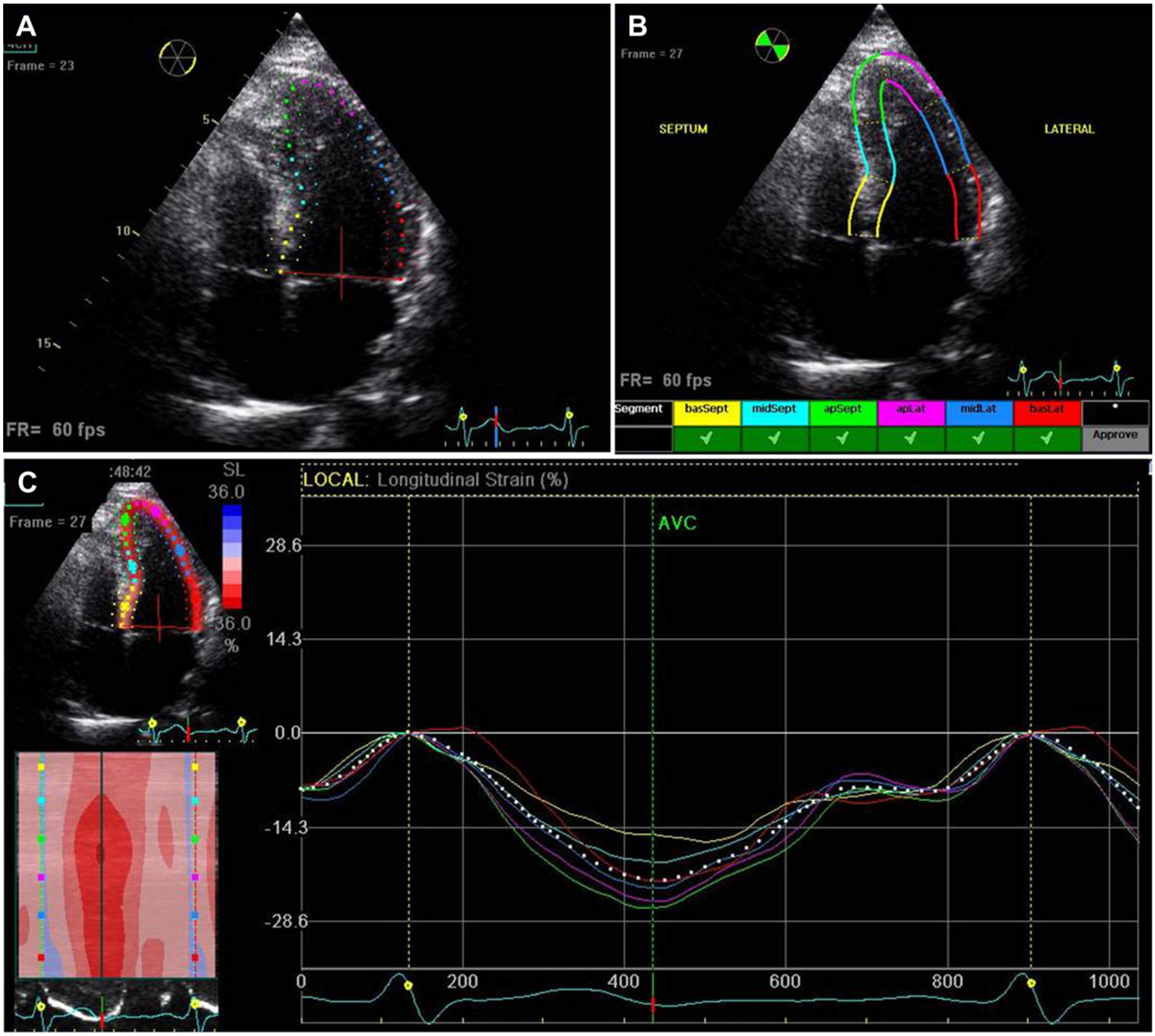


**Fig. 3 – Steps involved in speckle-tracking echocardiography. A. The endocardial border is manually traced in the end-systolic frame. The automated software creates a region-of-interest that includes the entire myocardial thickness. B. The operator is prompted to review and approve the adequacy of 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 LV twist is calculated by subtracting basal rotation from the apical rotation and torsion is calculated by dividing twist with the LV length. For example, if the apical rotation is 6.2°, basal rotation −3.4° and the LV length 6.4 cm, then the net twist angle will be 6.2° − (−3.4°) or 9.6° and the LV torsion will be 1.5°/cm.

### 3.3. *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, etc. as well as technical factors such as the orientation of the imaging planes, quality of the gray-scale images etc. In addition, there are significant inter-vendor differences in the STE-derived measurements which means 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.[2,4–7]

Among all the strain parameters, longitudinal strain is more reproducible than the radial and circumferential strain and rotation. Similarly, global strain has much better

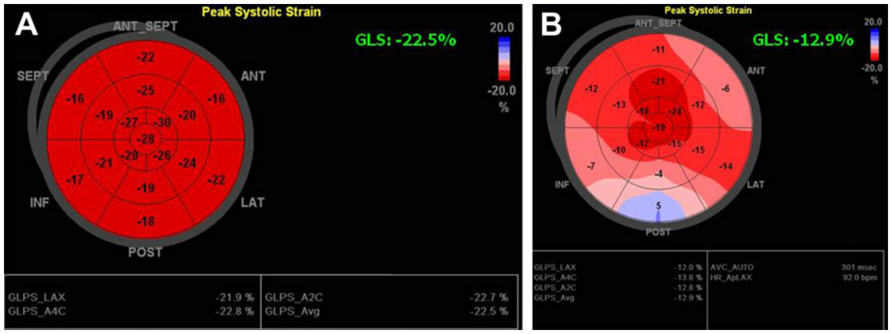


**Fig. 4 – Bull's eye display of segmental and global peak-systolic longitudinal strain. A. Normal individual with normal (−22.5%) global longitudinal strain (GLS). B. A patient with severe aortic stenosis with markedly reduced GLS (−12.9%) despite the preserved left ventricular ejection fraction.**

reproducibility than the segmental strain. The normal GLS is usually in the range of −16 to 18% or more (i.e. more negative).[8] 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 by the tethering effect of the mitral annulus.

### 3.4. *Clinical applications*

The most important role of STE is to provide a quantitative, objective measure of LV systolic function which can accurately detect subtle changes in the myocardial function. Of all 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 of the other deformation parameters.

As described above, 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 remain preserved or may even be accentuated during the early stages to compensate for the loss of the longitudinal function.[1,2] 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 following section provides a brief introduction to the potential clinical applications of STE. For a more detailed description, the readers are encouraged to refer to some of the recently published excellent review articles/consensus statement on this topic.[1,2,8,9]

A. Detection of subclinical myocardial dysfunction
  - As discussed above, a fall in the LVEF represents a relatively late stage in the development of myocardial dysfunction when sufficient myocardial damage has already occurred. Detection of the myocardial dysfunction in the early, subclinical stage may have significant diagnostic and therapeutic implications and appears to be one of the most promising indications for STE. For example, impairment of GLS despite preserved LVEF in patients receiving cancer chemotherapy may warrant discontinuation of the treatment regimen. Similarly, an evidence of early myocardial damage in patients with severe aortic stenosis or mitral regurgitation may help in timing the surgical intervention in these patients. Impairment of GLS is also helpful in documenting cardiac involvement in a variety of disorders such as diabetes mellitus, obesity, obstructive sleep apnea, systemic diseases such as amyloidosis, Fabry's disease, etc. and may also be helpful in differentiating hypertrophic cardiomyopathy from hypertensive heart disease or athletes' heart.

B. As a surrogate for LVEF
  - STE has the potential to render LVEF estimation simpler and more reproducible. At least one vendor now allows quick estimation of LVEF from GLS using the in-built regression equation.

C. Monitoring response to treatment
  - GLS can be used as an objective, quantitative parameter for monitoring response to therapies aimed at improving LV contractile function such as myocardial revascularization, stem cell therapy, drugs etc.

D. Role in acute coronary event
  - In patients presenting with acute coronary events, GLS has been shown to be a predictor of the final infarct size, patency of the infarct related artery, outcome after revascularization and the extent of long-term LV remodeling.

E. As a measure of myocardial ischemia and viability
  - The longitudinal strain, when combined with dobutamine echocardiography, improves the accuracy of the

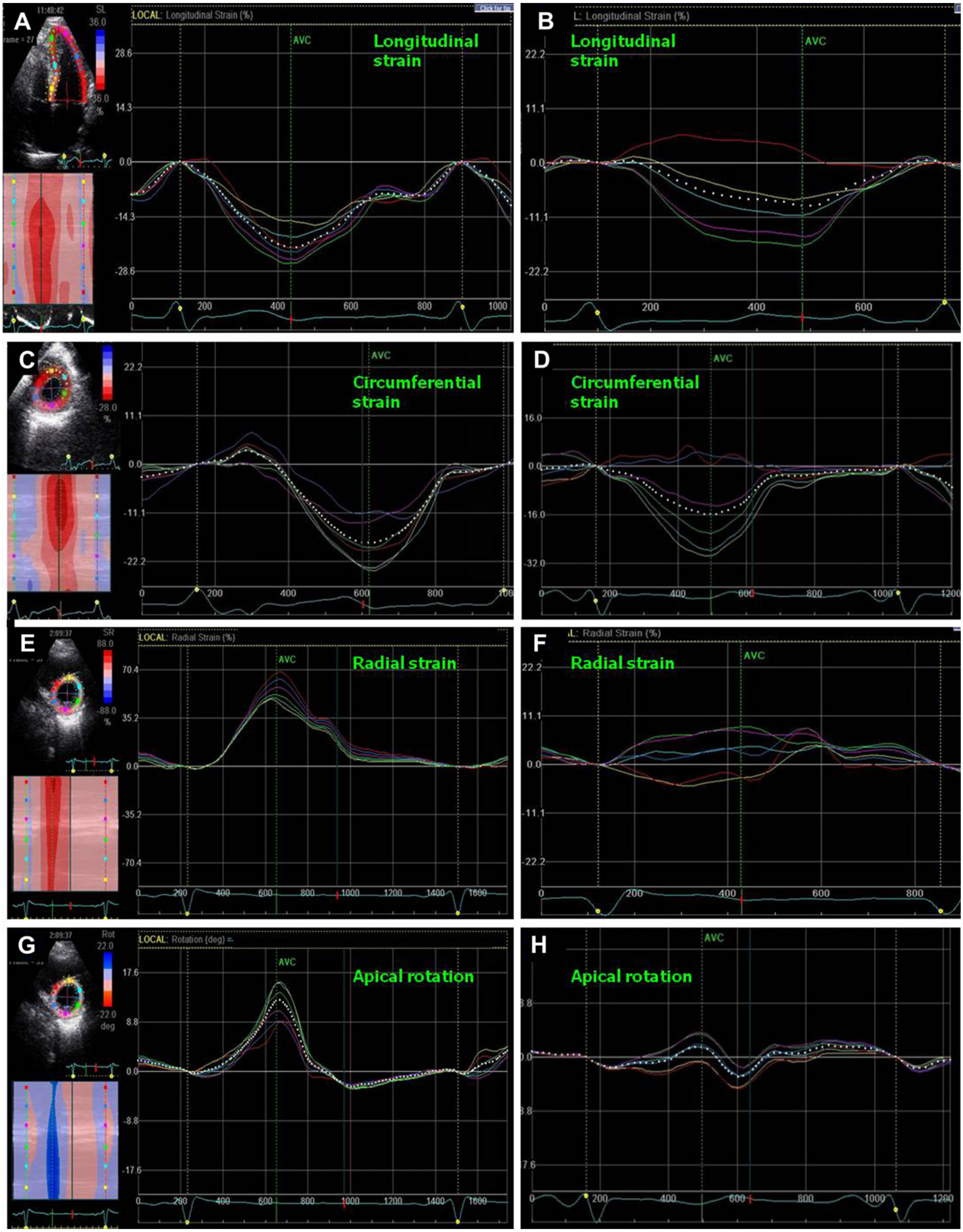


**Fig. 5 – Examples of normal and abnormal longitudinal (A, B), circumferential (C, D) and radial (E, F) strain and apical rotation (G, H).**

assessment of myocardial ischemia and viability. However, because of the issues related to the image-quality, the predictive accuracy of the longitudinal strain for this purpose is good mainly for the anterior circulation (i.e. left anterior descending artery territory) and not so much for the posterior circulation.
- The resting longitudinal strain itself has also been shown to be a predictor of myocardial viability. In addition, impairment in circumferential strain also indicates lack of myocardial viability as it reflects greater transmural extent of the infarct.

F. Role in cardiac resynchronization therapy
- Radial strain measured by STE has been shown to be a robust measure of intraventricular mechanical dyssynchrony and a reliable predictor of the response to cardiac resynchronization therapy.
- Time to peak radial strain can also help in identifying the site of latest activation and thus help in guiding the LV lead placement.

G. Assessment of LV diastolic function
- Early diastolic strain rate, peak untwist velocity and time to peak untwist velocity have all been used as measures of LV diastolic function with variable results.

H. Assessment of RV function
- Similar to the LV, longitudinal strain can be measured from the RV free wall also and has been shown to be a reliable measure of RV systolic function in a variety of clinical conditions such as pulmonary hypertension, RV cardiomyopathies, congenital heart diseases, etc.

I. LA function
- STE, being an angle-independent technique, also permits measurement of LA strain which can be used for the same clinical indications as LA volume.

J. Other uses
- As discussed above, early impairment of circumferential strain may help in differentiation between constrictive pericarditis and restrictive cardiomyopathy.

## 4. Future directions

STE has rapidly evolved as a promising technique for the measurement of myocardial deformation with numerous, potential clinical applications. However, the significant, inter-vendor variability remains the most important limitation precluding its widespread use in clinical practice at present. Standardization of the image processing and analysis algorithms is therefore urgently required to minimize this variability. This, coupled with some other technical refinements, should see STE evolve into an integral component of the standard practice of echocardiography.

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