

# 2D- Speckle Tracking Echocardiography: A Review of the Literature

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## Abstract

2D speckle-tracking echocardiography (STE) is an advanced, non-invasive cardiac imaging technique that uses ultrasound to assess myocardial strain, which measures myocardial tissue deformation and detects cardiac dysfunction, even before symptoms appear. It is particularly useful in evaluating left ventricular function across longitudinal, radial, and circumferential planes, with global longitudinal strain (GLS) being the most commonly used. STE has numerous clinical applications, including the assessment of coronary artery disease, cardiomyopathies, valvular heart disease, and heart failure. For instance, in coronary artery disease, STE identifies ischemic regions and correlates well with cardiac MRI for infarct sizing. It is also valuable in cardio-oncology, detecting early cardiac dysfunction from treatments. Additionally, STE is beneficial in managing high-risk pregnancies, familial hypercholesterolemia, and kidney disease. Future advancements may involve standardizing methodologies and integrating 3D STE for enhanced insights, reinforcing STE's importance in early detection and management of cardiac conditions.

**Keywords:** Echocardiography, Strain Imaging, Speckle Tracking Echocardiography, Global Longitudinal Strain, Left Ventricular Function

## Introduction

Speckle tracking echocardiography (STE), a relatively new and progressively useful modality of non-invasive cardiac imaging, has many advantages. It provides more quantitative data on cardiac function, is highly feasible and reproducible and can detect subclinical cardiac dysfunction in diverse clinical scenarios such as coronary artery disease, cardiomyopathies, valvular disease, cardio-obstetrics and fetal echocardiography, amongst others.<sup>1</sup> This technique is based on the mechanics of myocardial fibers, which occur in systole, where fibers shorten and thicken, while the reverse happens in diastole. 2-dimensional speckle tracking echocardiography is derived from electrocardiogram-gated apical view images (long, four-chamber and two-chamber). Images obtained are processed semi-automatically by vendor-based software either offline or online. Strain parameters, such as strain and strain rate, are derived from strain analysis as applied to all cardiac chambers. Currently, 2-dimensional speckle tracking echocardiography is the predominant modality, with a wealth of data derived

from left ventricle assessment. 3-dimensional speckle tracking echocardiography is increasingly being investigated and improved.<sup>2-4</sup>

## Objectives

- describe the fundamental concepts pertaining to speckle tracking echocardiography.
- Highlight the utility of STE in different clinical situations.

## Materials and Methods

A search was conducted in the PubMed database for articles from 2019 to 2024. Keywords searched for included “speckle tracking echocardiography” and “strain imaging.” Systematic reviews, clinical guidelines, and prospective and retrospective studies were all included. 159 articles were found. Headings and abstract snippets were reviewed for appropriateness, and 93 articles were selected. Each of these 93 articles were reviewed, and it was decided if it was appropriate to be included based on its relevance to the objectives

of this study. 77 articles were selected for inclusion. 16 additional articles, known to the authors, and considered appropriated were added to this pool for review.

### Relevant Anatomy

The left ventricle (LV) uses deformation (change shape) to achieve its contractile function. During systole, the LV shortens along its long axis (basal-to-apical direction) where the base approaches the apex, radial thickening, and rotation (clockwise at the base and counterclockwise at the apex). This produces torsion (twist) of the base to the apex in the longitudinal direction and approximation of opposite walls in the transverse plane. The opposite occurs during diastole. The apex is relatively fixed during this process.<sup>5,6</sup> The orientation of myocardial fibers makes this possible. In the LV, both subendocardial and subepicardial fibers are obliquely oriented. However, the subendocardial fibers are in an anticlockwise direction, while the subepicardial ones are in a clockwise direction, forming a helical structure. The midsection, which contains the bulk of myocardial tissue, has a circumferential orientation of these fibers.<sup>6-8</sup>

### Myocardial Mechanics

Strain ( $\epsilon$ ), a measure of tissue deformation, is a dimensionless quantity, which is the ability of a tissue to shorten or thicken (L) as compared to a baseline value ( $L_0$ ) proportionally. It is calculated as  $\epsilon = (L - L_0)/L_0$ . This and other strain parameters can be measured in the longitudinal, radial, and circumferential planes. Myocardial strain is positive with lengthening and negative with shortening. With left ventricular contraction, there is a shortening (negative strain) of the myocardial in the longitudinal and circumferential plane and thickening (positive strain) in the radial plane.<sup>6,9</sup>

Several parameters are studied in strain analysis, such as peak strain, peak systolic strain, and strain rate. Peak strain is the maximum strain. Peak systolic strain is the maximum strain during the ejection period of the left ventricle before the closure of the aortic valve. Strain rate is less load-dependent than strain.<sup>5-7</sup>

### Measurement of Strain Modalities

Two technologies have been applied to measure strain: tissue Doppler imaging (TDI) and 2-dimensional

(2D) speckle tracking strain.<sup>7</sup>

#### TDI Strain

This angle-dependent technique derives velocity data, such as strain rate.<sup>2</sup> The integration of strain rate in terms of time will yield corresponding strain values. Being an angle-dependent procedure and requiring high frame rates (> 100 frames per second), which is a significant limitation, TDI strain can only evaluate longitudinal strain and limited radial strain (in the anterior and inferior segments). Manually tracking the sample volume throughout the cardiac cycle is also required to ensure it is within the myocardial segment being examined, which is time-consuming. It, however, does not depend on 2D image quality and has excellent temporal resolution.<sup>7,10</sup>

#### 2D Speckle Tracking Strain

This semi-automated method evaluates global and regional myocardial function from multiple planes and does so quickly. From routine 2D images, ultrasonic speckles of the myocardial tissue are tracked throughout the cardiac cycle by software, independent of the vendor. This technique is angle-independent; therefore, LV strain and strain rate can be determined in longitudinal, radial, and circumferential planes, although afterload can affect it. It is performed optimally using conventional 2D greyscale images with low frame rates (> 60 per second) and has a low temporal resolution.<sup>2,7</sup>

A point-and-click method tracks the endocardium, while the epicardium tracing is automatically generated using a "region of interest" (ROI). This ROI can be manually adjusted, after which the software divides it into six segments for each apical view. Each segment is tracked and scored as acceptable or not, with the option of manual correction. If image quality is inadequate, they are rejected by the software and excluded from the analysis. After the ROI is optimized, the software generates strain curves. Strain measurements should be excluded if two or more segments have poor tracking quality. Using data from all three apical views, the software automatically generates a topographic representation of all 18 analyzed segments (bull's eye or polar map).<sup>2,7</sup>

#### Basic Concepts in Strain Analysis: Longitudinal, Radial, and Circumferential Strain

Left ventricular myocardial fibers form two helices in opposite directions. This architecture has been arbitrarily divided into subepicardial, mid-wall, and subendocardial layers. This description has questionable clinical use, as the ventricular wall shows mechanical layer interdependence, and insufficient lateral resolution to distinguish between layers and the use of only a third of the wall thickness for speckle tracking echocardiography. For clinical application, deformation is described in three orthogonal components: longitudinal, radial, and circumferential.<sup>2,11</sup> Longitudinal myocardial fibers shorten during systole and are depicted by negative strain curves. Global longitudinal strain (GLS) derived from apical long-axis, apical four-chamber, and apical two-chamber views have been validated as an index of global LV function against the left ventricle magnetic resonance imaging standard. GLS is, therefore, now routinely measured in many echocardiographic laboratories. The values of LV-GLS vary according to age, gender, weight, systolic blood pressure and ultrasound vendor systems. As a guide, the expected value in a healthy individual is around -20%. LV-GLS correlates well with LVEF and detects subclinical systolic dysfunction even when LVEF is preserved. It also serves as a quantitative tool for segmental LV function. LV-GLS has an increased prognostic value over LVEF, especially when the latter is >40%.<sup>7,12</sup>

Radial strain, which represents myocardial deformation across the cross-section of the LV wall during systole, is measured as a positive curve. It is derived from images acquired from the parasternal short-axis (PSAX) at the mid-cavity of the papillary muscle level. Circumferential strain depicts LV myocardial fiber shortening along the circular perimeter as observed in the PSAX at the mid-level. It is measured as a negative curve. Currently, radial and circumferential strains need to be adequately reproducible in routine clinical work and are only commonly used in research.<sup>7</sup>

Strain values are affected by three groups of factors. First, hemodynamic factors such as preload have a direct and indirect relationship with afterload and heart rate. Secondly, by geometric factors which translates how chamber pressure translates into wall stress (Laplace's law). And lastly, myocardial tissue characteristics, for example, reduced contractility (e.g., in coronary artery disease), inhomogeneous tissue characteristics (e.g., infiltrative and storage diseases),

and desynchrony (e.g., in bundle branch blocks).<sup>2</sup>

Compared to tissue Doppler imaging-based strain, 2D-STE is superior due to its better correlation with cardiac MRI, improved feasibility and reduced inter- and intraobserver variability. STE is applicable in diverse clinical scenarios, even in subclinical stages.<sup>8,13,14</sup> STE is an acceptable alternative to cardiac magnetic resonance imaging for tissue characterization, where the latter is unavailable for any reason.<sup>15,16</sup>

Apart from the LV, strain imaging can study other cardiac chambers, such as the right ventricle and the left atrium. The clinical utility of STE in these different structures is continuously being investigated and consolidated.<sup>17</sup> Left ventricular strain imaging and other parameters, such as non-invasive blood pressure recordings, can be applied in myocardial work using a pressure-strain loop.<sup>18,19</sup>

## Specific Clinical Scenario

### Coronary Artery Disease

The utility of echocardiography in coronary artery disease (CAD) cannot be over-emphasized. However, there is no visual manifestation of myocardial ischemia on echocardiography in certain instances. A meta-analysis involving 1385 patients, where LV-GLS was assessed for those with and without coronary artery disease, showed mean values of -16.5% [95% confidence interval (CI): -15.8% to 17.3%] and -19.7% [95% CI: -18.8% and -20.7%]. For those with moderate-to-severe CAD, abnormal LV-GLS had a pooled sensitivity of 74.4% sensitivity, 72.1% specificity, 2.9 positive likelihood ratio, and 0.35 negative likelihood ratio. The area under the curve (AUC) and diagnostic odds ratio (OR) were 0.81 and 8.5, respectively.<sup>14,20</sup>

LV-GLS correlated well with LV infarct size and peak cardiac troponin T levels in patients with acute myocardial infarction. End systolic, rather than peak systolic strain, is helpful as segments affected by acute myocardial ischemia demonstrate post-systolic shortening. Furthermore, LV-GLS excellently predicts segments with potential for improvement, LV remodeling, and adverse events (death from arrhythmias and heart failure) following reperfusion. There is a good relation between LV-GLS and transmural of scar tissue, using contrast-enhanced MRI as a benchmark.<sup>7</sup>

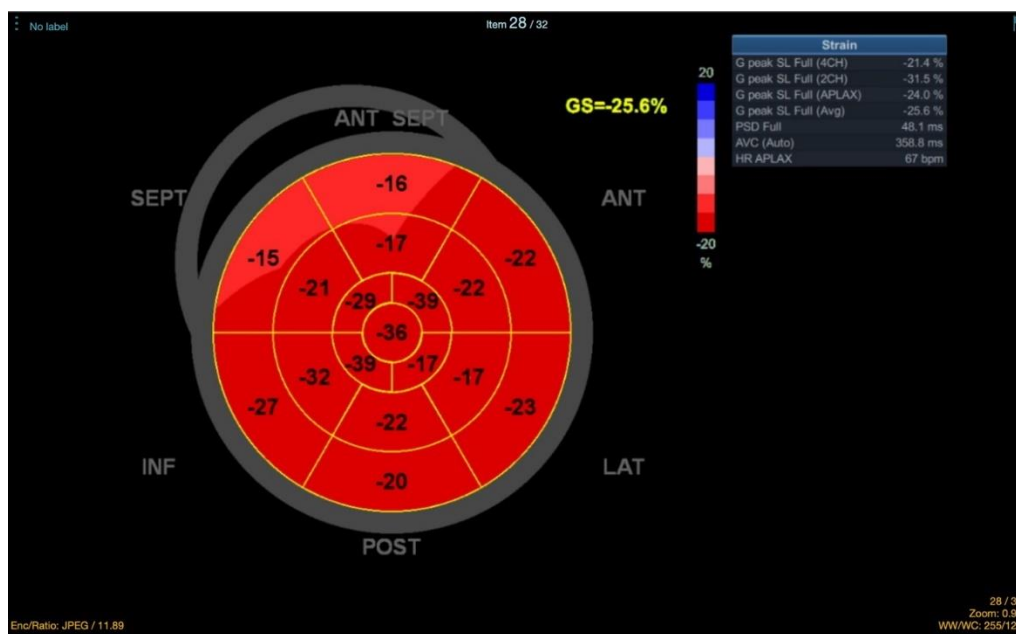
LV-GLS bull's eye polar map offers a quick and relatively easy assessment of the regional distribution of myocardial necrosis through regional LS. Based on

the 17-segment LV myocardial proposed by Cerqueira et al<sup>21</sup>, specific segments with abnormal LS are color-coded to show blood flow abnormalities, which would typically follow the distribution of a particular culprit epicardial coronary artery. Regional maps are also helpful for differential diagnoses such as Tako-tsubo syndrome and acute myocarditis, where the regional maps show impaired blood flow to the apex and impaired LS not corresponding to any specific coronary artery topography, respectively.<sup>14</sup>

STE is superior to the wall motion score index in determining which patients would benefit more from revascularization in the setting of Non-ST-segment elevation acute coronary syndrome (NSTEMI-ACS), even with patients with normal global and regional systolic function (as measured by traditional methods): LV-GLS was significantly impaired in significant coronary artery stenosis than those without ( $16.3 \pm 3.4\%$  vs.  $22.4 \pm 2.9\%$ ,  $P < 0.001$ ) and was able to identify the location of coronary stenosis (of the major epicardial coronary arteries).<sup>7,14</sup>

LV-GLS is also valuable for excluding significant coronary artery stenosis in patients with suspected NSTEMI-ACS who have unremarkable ECG and normal cardiac biomarkers. In one study, that focused on patients referred to an emergency department with suspected NSTEMI-ACS, LV-GLS performed better than conventional echocardiography in distinguishing between patients with and without significant coronary artery stenosis ( $>50\%$  luminal narrowing), having a sensitivity and negative predictive value (AUC = 0.87, 93% sensitivity and 78% sensitivity, 0.74 positive predictive value (PPV), 0.92 NPV).<sup>7,14</sup> The use of STE for predicting myocardial contractile function after revascularization has also been demonstrated by Ballo et al.<sup>22</sup>

STE has the potential to analyze myocardial work, assess left ventricular function in patients with coronary artery disease and track improvement in cardiac regenerative therapy.<sup>23,24</sup> Strain analysis is also useful when applied to the left atrium and right ventricle in coronary artery disease, involving the circumflex and right coronary arteries, respectively.<sup>14</sup>



**Figure 1.** Hypertensive Heart Disease (mild) with Strain Reduction in the Septum.

### Left Ventricular Hypertrophy

Left ventricular hypertrophy (LVH) is a frequent finding in diseases such as arterial hypertension, hypertrophic cardiomyopathy (HCM), aortic stenosis (AS), cardiac amyloidosis (CA) and Fabry disease (FD), amongst others. Differential diagnosis using echocardiography can be challenging. These diseases have different

regional variabilities on STE, which may help correctly identify each of them and improve the accuracy of diagnosis. Mild basal septum or generalized GLS abnormalities are observed in hypertensive heart disease (HHD) (Figure 1). At the same time, HCM, which shows asymmetric ventricular hypertrophy, identifies abnormal GLS in the affected regions, usually

in the interventricular septum (Figure 2), apex, or another region (Figure 3). Worsening LV-GLS was found to be associated with significant adverse cardiovascular events, even in asymptomatic patients with HHD, and beta-blockers have been demonstrated to improve GLS in these patients. The degree of compromise in LV-GLS in HCM is marked more than in HHD.<sup>7,25-29</sup> LV-GLS in HCM is a marker of ventricular arrhythmias. LV-GLS  $\leq 15\%$  is associated with better survival.<sup>7,25,30,31</sup>

The apical sparing pattern (“cherry-on-top”) of GLS has been described in CA (Figure 4) and basal inferolateral GLS abnormalities are described in FD.<sup>32,33</sup> The athlete’s heart has preserved LVGLS.<sup>7,25,34,35</sup> LV-GLS can track therapy in patients with AL amyloidosis, where strain rate values improve in patients with complete response.<sup>36</sup> LV-GLS may be reduced in patients with sarcoidosis, even those without the diagnostic criteria for cardiac sarcoidosis.<sup>37</sup>

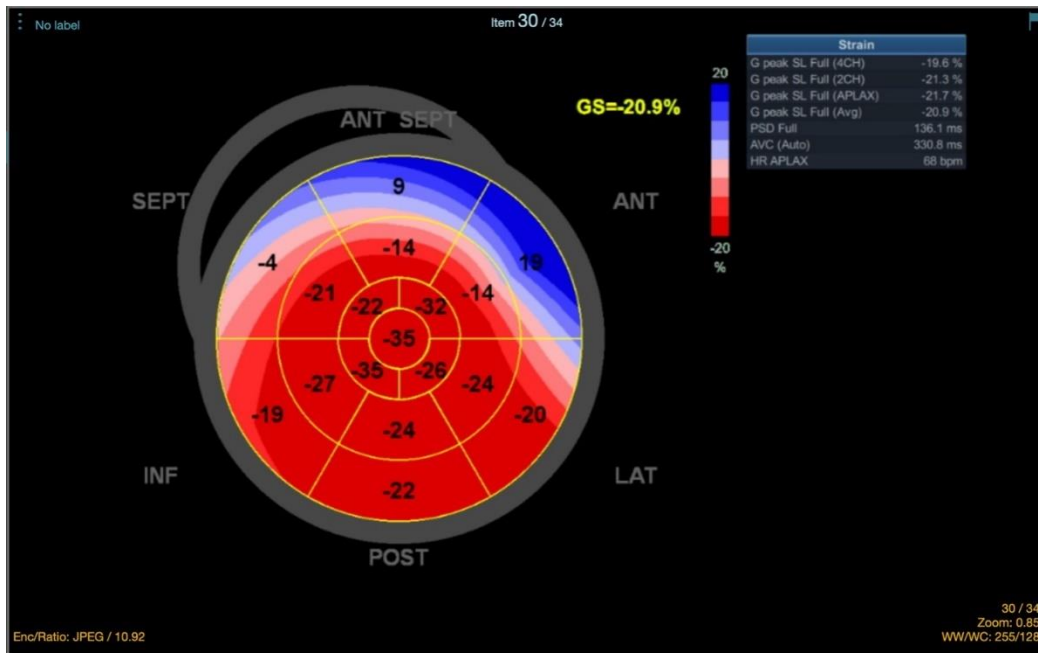


Figure 2. Hypertrophic Cardiomyopathy Involving the Anterior/Septal Regions.

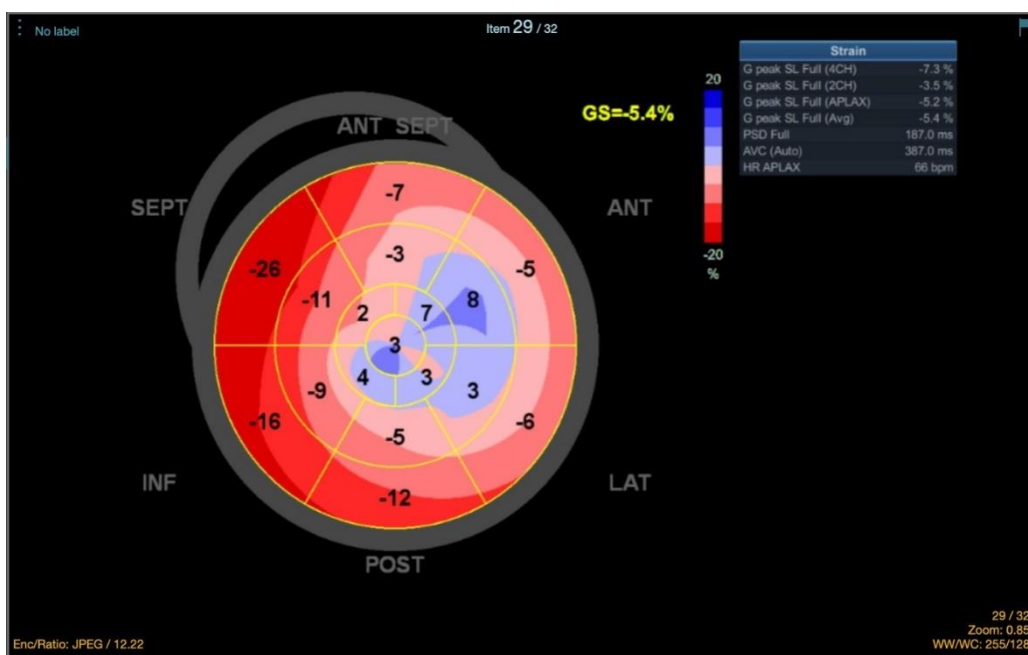
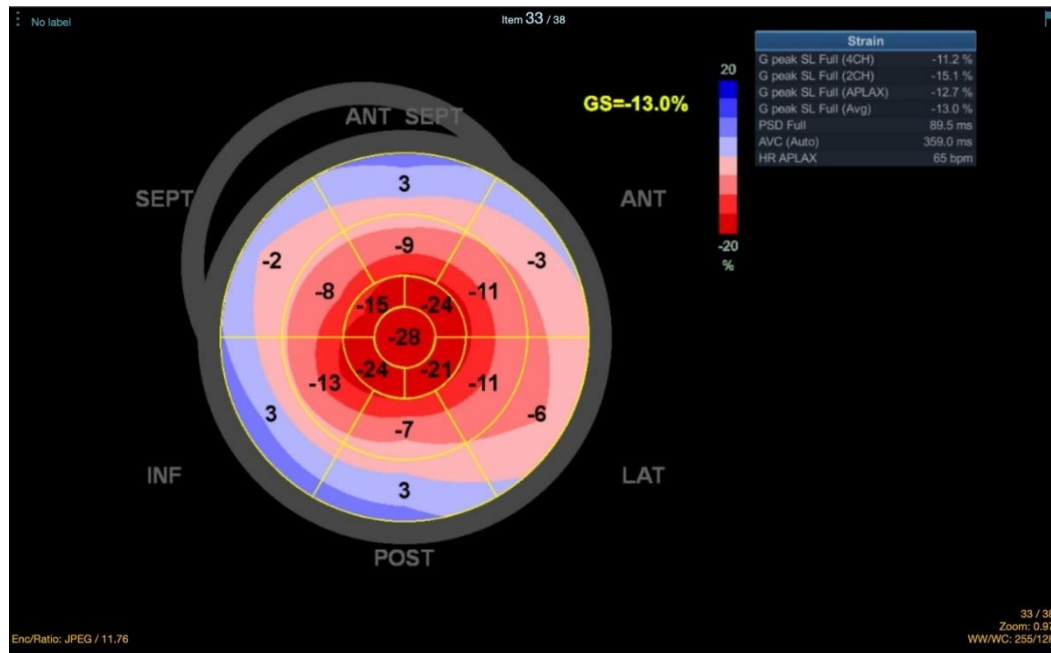


Figure 3. Hypertrophic Cardiomyopathy Involving the Anterior Region.



**Figure 4.** Cardiac Amyloidosis, with the Typical Apical Sparring (cherry-on-top) Pattern.

### Cardiomyopathy

In dilated cardiomyopathy, there is a reduction in strain in all three planes, i.e., longitudinal, radial and circumferential. Reduction in LV-GLS is associated with poor long-term prognosis. In diabetics who are asymptomatic for heart failure, LV-GLS may be reduced, highlighting a subclinical myocardial dysfunction even before there is overt diabetic cardiomyopathy. This is also associated with adverse long-term prognosis. LV-GLS independently predicts heart failure (HF) mortality across the ejection fraction (EF) spectrum. In patients with HF with reduced EF, strain analysis can predict response to cardiac resynchronization therapy using parameters such as early-systolic shortening and rebound stretch in the septum, combined with early-systolic lengthening and peak shortening after aortic valve closure. In Tako-tsubo cardiomyopathy, peak systolic strain and strain rate are reduced in basal and apical regions during the active phase. However, the reduction is more in the apical region. These abnormalities improve during recovery.<sup>7,38</sup>

STE has been used in screening presymptomatic relatives of an index case of inherited cardiomyopathies such as dilated cardiomyopathy, hypertrophic cardiomyopathy, and arrhythmogenic cardiomyopathy, where, among other observations, there could be a reduction in LV-GLS. In presymptomatic relatives of patients with HCM, there may be a reduction in the LS in the basal anterior septal region.<sup>39</sup>

Goudarzi et al. discussed the sensitivity of 2D-STE in identifying subclinical myocardial dysfunction in patients with COVID-19 and other infectious states, including sepsis, even before overt myocardial dysfunction.<sup>40-44</sup> A more negative LV-GLS is associated with better survival.<sup>45</sup> STE can detect subclinical myocardial dysfunction due to “neurogenic stress cardiomyopathy” in patients with acute ischemic stroke.<sup>46</sup> LV-GLS may be reduced in patients with diabetes mellitus, especially those with a higher body mass index,<sup>47-50</sup> patients with systemic sclerosis,<sup>51,52</sup> cirrhotic cardiomyopathy,<sup>53</sup> acromegaly cardiomyopathy,<sup>54</sup> primary Sjogren syndrome,<sup>55,56</sup> sickle cell cardiomyopathy,<sup>56</sup> congenital heart disease<sup>57</sup> and children with Duchenne muscular dystrophy.<sup>58</sup>

These clinical scenarios may represent stage B (presymptomatic heart failure) and abnormal LV-GLS may progress to symptomatic HF when LVEF is preserved or mildly reduced. This suggests that LV-GLS, solely or in combination with other strain parameters such as left atrial strain, could be included as a risk stratification tool in the spectrum of HF.<sup>59-64</sup> Increasing therapeutic arsenal for HF exists. These treatment modalities lead to reverse remodeling, which can be demonstrated using STE.<sup>65</sup>

### Valvular Heart Disease (VHD)

The optimal timing for surgical intervention in asymptomatic individuals with moderate-severe valvular

heart disease is a difficult task. It has, therefore, been based on the presence of symptoms, lesion severity and its impact on LV volume and LVEF. Identifying myocardial dysfunction earlier, through data such as LV-GLS, leads to a paradigm shift towards earlier intervention before the reduction in LVEF. In mitral regurgitation, it has been demonstrated that LV-GLS at rest and with exercise better correlated LV contractile reserve and predicted improvement in LV systolic function postoperatively. This was different from LVEF. Low pre-operative LV-GLS also predicts post-operative LV dysfunction in the long term. The lack of augmentation of LV-GLS ( $>2\%$ ) with exercise predicted a two-fold increase in cardiovascular events, while a 4% increase in LVEF did not affect the outcome. Apart from the pattern described, more severe LV remodeling correlates with lower LV-GLS in aortic stenosis. Values of LV-GLS  $\geq -15.9\%$  were a predictor of adverse outcomes.<sup>7,66-71</sup> Lower preprocedural LV-GLS was significantly associated with post-TAVR morbidity and mortality.<sup>72</sup>

### Sudden Cardiac Death (SCD)

LV-GLS improves risk stratification for SCD in individuals with ischemic cardiomyopathy and, even in those with relatively preserved LVEF. A heterogeneous myocardial dispersion on strain analysis demonstrates the heterogeneity of repolarization that characterizes long QT syndrome and other cardiac diseases. This heterogeneity is associated with an increased risk of ventricular arrhythmias.<sup>7,73</sup>

### Cardio-Oncology

Significant progress has been made in oncological therapy, systemic treatment and radiotherapy for cancer. This progress has unfortunately resulted in frequent organ complications, such as cardiac dysfunction, due to side effects of treatment.<sup>74,75</sup> Chemotherapy may be cardiotoxic, the reason why in the evaluation of patients with cancer, baseline echocardiographic and LV-GLS parameters should be obtained. LV-GLS is superior to LVEF in detecting cancer therapy-related cardiac dysfunction (CTRCD), especially subclinical dysfunction.<sup>76,77</sup> With a baseline LVEF of 50-59%, patients with LV-GLS  $> -17.5\%$  were six times more likely to suffer cardiac death or symptomatic heart failure. In patients receiving chemotherapy, absolute LV-GLS  $> -15\%$  is diagnostic of subclinical LV

dysfunction, similar to a relative reduction of  $>10\%$  (Figure 5).<sup>78,79</sup> Lu et al., amongst other researchers, found that 2D-STE provides a moderate predictive accuracy for predicting cardiotoxicity in such patients.<sup>80-83</sup> Beta-blockers have been suggested for managing CTRCD. Exposition of the heart field to radiation can injure cardiac structures, leading to coronary artery disease, cardiomyopathy, conduction abnormalities, valvulopathies and pericardial disease. The incidence of ischemic heart disease increases by 7.4% with each gray (Gy) increase in radiation exposure to the heart field.<sup>6,7,84</sup>

### Fetal Cardiology

STE has excellent potential in fetal echocardiography as it demonstrates adequate frame rates, is reproducible and is easy to obtain while providing simultaneous measurements of ventricular size, shape, and contractility.<sup>85</sup>

### Cardio-Obstetrics

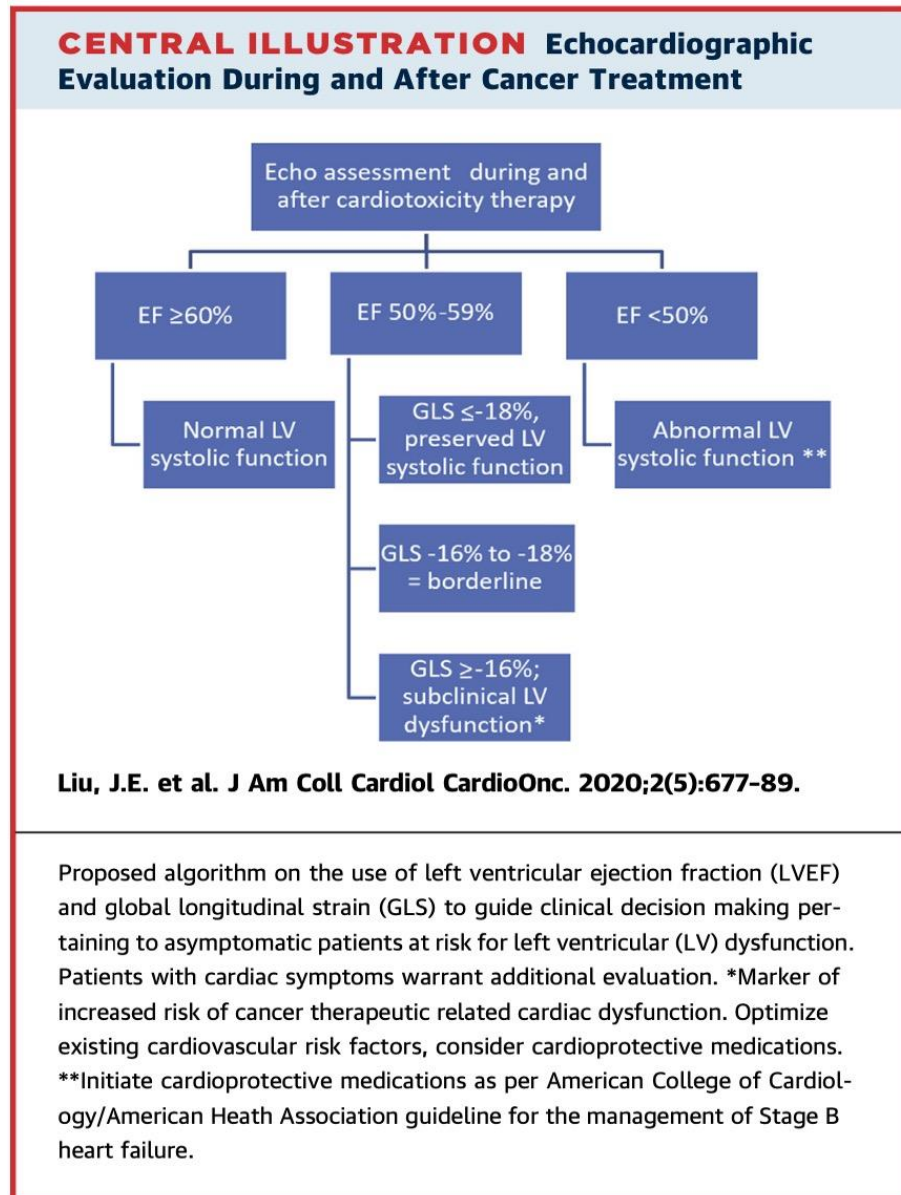
Li et al., in their study of 47 women with gestational diabetes (GDM) and 62 healthy pregnant women as control, found that average LV-GLS was significantly lower in the GDM group ( $18.14 \pm 2.53$  vs.  $22.36 \pm 6.33$ ,  $P < 0.001$ ), with no significant difference in 2-D echocardiography parameters such as LVEF.<sup>86</sup> Gestational diabetes and hypertensive disorders of pregnancy are often associated with subtle myocardial changes, which are frequently missed by conventional echo cardiography but readily detected by STE. These abnormalities may persist after the postpartum period and, therefore, warrant follow-up.<sup>86-88</sup>

### Familial Hypercholesterolemia

Li et al. found that increased LDL-cholesterol in patients with familial hypercholesterolemia presented with significantly decreased average strains in the three coronary artery territories, especially in the longitudinal and circumferential.<sup>89</sup>

### Kidney Disease and Transplant

In a retrospective study of 285 chronic kidney disease (CKD), 193 in stage 3 and 92 in stage 4, and 34 controls, STE allowed for the prediction of cardiovascular and all-cause mortality in patients with CKD stages 3 and 4.<sup>90</sup> Barczy et al, in their study of 42 kidney transplant patients, compared to thirty-nine healthy age and gender-matched children, LV-GLS was significantly lower in the earlier group ( $P = 0.002$ ).<sup>91</sup> Levy et al.



**Figure 5.** The proposed Algorithm by Liu et al. for Evaluating LV systolic Function in Cancer therapy patients (<https://doi.org/10.1016/j.jacc.2020.10.011>). (Reproduced under the Creative Commons license CC BY-NC-ND).

also suggest using STE to assess candidates for kidney or liver transplants since it predicts short- and long-term cardiovascular events risk.<sup>92</sup>

### 3-dimensional STE

Compared with 2D-STE, 3D-STE can track the speckle patterns in any direction and out-of-the-imaging plane, offering additional deformation parameters such as area strain and a more comprehensive quantification of LV geometry and function.<sup>2,93</sup>

### Future Perspectives

It is expected that different vendors will harmonize

their methods of implementing strain imaging, which will lead to much more reproducible results. It is also expected that more data on STE will become available, and hence normative values will be more reliable and can also be adapted more specifically for different clinical situations. STE will become part and parcel of standard cardiac imaging in a matter of years.

### Conclusion

Despite being a relatively newer imaging modality, especially compared to traditional echocardiography, speckle-tracking echocardiography has shown significant utility and superiority. It is reliable, feasible, reproducible,

and provides more quantitative information for assessing cardiac function and detecting sub-clinical dysfunction in many clinical scenarios. This advantage of providing incremental data, even in the presence of preserved systolic and diastolic function, is helpful in risk stratifying patients and in informing decision-making towards improving prognosis. There is increasing advocacy for cardiac imagers, cardiologists, and other clinicians to routinely perform and incorporate STE in the assessment and management of their patients. Additional research is required to explore the full potential and limitations of STE.

### Conflict of Interest

The authors declare no conflicts of interest.

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