2D STRAIN IMAGING

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Last reviewed: October 2026

I CORE PRINCIPLES OF 2D STRAIN (SPECKLE TRACKING ECHOCARDIOGRAPHY)

- **Transition from Volume to Deformation:** Two-dimensional (2D) **Speckle Tracking Echocardiography (STE)** directly quantifies active **myocardial fiber deformation** rather than global cavity volume change (Ejection Fraction), detecting subclinical systolic dysfunction long before LVEF declines.
- **Physical Mechanism:** Grayscale B-mode ultrasound interaction with myocardial tissue generates stable, natural acoustic backscatter interference patterns (**"speckles"**, 20 to 40 pixels in size). Software tracks the spatial displacement of these speckle kernels frame-by-frame throughout the cardiac cycle (angle-independent, unlike Tissue Doppler Imaging).
- **Lagrangian Strain Formula: Strain (epsilon)** represents the fractional or percentage change in length of a myocardial segment relative to its baseline end-diastolic length (**L0**): **epsilon = [(L - L0) / L0] x 100** (note: the denominator is the original baseline length **L0**). **Strain Rate (SR)** is the temporal derivative of strain (speed of deformation per second, s-1).
- **17-Segment Polar Map ("Bull's-Eye" Plot):** Displays regional and **Global Longitudinal Strain (GLS)** across the basal (outer ring), mid-ventricular (middle ring), and apical (inner center) segments, alongside **Mechanical Dispersion** (standard deviation of time-to-peak longitudinal strain across 17 segments; normal <40 to 50 ms; prolonged in arrhythmogenic scar).

II COMPONENTS OF MYOCARDIAL DEFORMATION

- **Longitudinal Strain (Negative Value; Normal GLS: -18% to -22%, Lower Limit of Normal approx. -16% to -18% Depending on Vendor/Sex):** Measures base-to-apex shortening from the apical 4-chamber, 2-chamber, and 3-chamber (long-axis) views. Because longitudinal fibers reside predominantly in the **subendocardium** (which has the highest wall stress and lowest coronary flow reserve), **GLS is the earliest, most sensitive, and most reproducible marker of myocardial ischemia, toxicity, or fibrosis**. (By EACVI/ASE convention, when comparing values, use **absolute magnitude**—e.g., a change from -20% to -14% is a *reduction* in GLS.)
- **Circumferential Strain (Negative Value; Normal GCS: -20% to -26%):** Measures systolic shortening along the circular short-axis perimeter (driven mainly by mid-wall circumferential fibers, which often compensate early in HFpEF or HCM to preserve LVEF despite reduced GLS).
- **Radial Strain (Positive Value; Normal GRS: +35% to +50%):** Measures transmural systolic wall thickening toward the LV cavity center on short-axis views (highest inter-observer variability).
- **LV Rotation, Twist, and Torsion:** Oblique subepicardial and subendocardial helical fibers produce **counterclockwise apical rotation** and **clockwise basal rotation** during systole (viewed from the apex), generating a wringing **LV Twist** (and during early isovolumic relaxation, rapid **untwisting** generates the intraventricular suction gradient for early diastolic filling).

Cardiomyopathy / Disease State	Characteristic Bull's-Eye Polar Map Pattern	Key Clinical / Diagnostic Significance
Cardiac Amyloidosis (ATTR / AL)	**"Cherry-on-Top" (Relative Apical Sparing):** Severely reduced basal/mid strain with preserved apical GLS (Apical-to-[Basal+Mid] ratio >=1.0)	Differentiates Amyloidosis from HCM, hypertensive LVH, and aortic stenosis
Hypertrophic Cardiomyopathy (HCM)	Marked focal strain reduction at the **hypertrophied septum** (or **apical loss** in Apical HCM — "reverse cherry")	Correlates with **CMR Late Gadolinium Enhancement (LGE)** and predicts ventricular arrhythmias
Fabry Disease	Early focal reduction in the **basal inferolateral (posterolateral) segment**	Matches the classic site of early basal inferolateral LGE in Anderson-Fabry disease
Cancer Therapy Cardiotoxicity (CTRCD)	Diffuse global reduction; **relative drop in GLS >15%** from baseline with normal LVEF	Defines **Mild Asymptomatic CTRCD** in the **2022 ESC Cardio-Oncology Guidelines** (**SUCCOUR Trial**)
Coronary Artery Disease (CAD)	**Territorial segmental reduction** (LAD, RCA, or LCx distribution) + **Post-Systolic Shortening (PSS)**	Identifies subclinical territory ischemia in NSTE-ACS or chronic coronary syndromes

III CLINICAL APPLICATIONS AND GUIDELINE INDICATIONS

- **Cardio-Oncology (Class I Indication — 2022 ESC Cardio-Oncology Guidelines):**
  - **Baseline and Serial Surveillance:** Mandatory before and during **Anthracycline** or **HER2-targeted (Trastuzumab)** chemotherapy.
  - **Diagnostic Cut-off:** A **relative percentage reduction in GLS of greater than 15 percent from baseline** (e.g., from -20% to -16.5%) in a patient with preserved LVEF (>=50%) defines **Mild Asymptomatic Cancer Therapy-Related Cardiac Dysfunction (CTRCD)** and guides initiation of cardioprotective **ACEi/ARB and Beta-Blocker therapy** (as evaluated in the randomized **SUCCOUR Trial**).
  - **Heart Failure Phenotyping (HFpEF and HFrEF):**
  - **Occult Systolic Dysfunction in HFpEF:** Over 50 percent of patients with **HFpEF** (LVEF >=50%) exhibit impaired **GLS (absolute value less than 16 percent)**; impaired **GLS <16%** is a functional criterion in the **HFA-PEFF diagnostic algorithm**, and reduced **Left Atrial Reservoir Strain (PALS <18 to 24%)** is an increasingly used supportive marker.
  - **Superior Prognostication:** Across the entire LVEF spectrum, GLS outperforms LVEF in predicting cardiovascular mortality and HF hospitalization.
  - **Ischemic Heart Disease (ACS and CCS):**
  - **Post-Systolic Shortening (PSS):** Ischemic myocardial segments continue to contract briefly *after* aortic valve closure (during isovolumic relaxation); a **Post-Systolic Index (PSI) >20%** is a sensitive marker of acute or chronic regional ischemia ("ischemic memory").
  - **High-Risk NSTE-ACS:** Resting territorial GLS impairment (and global GLS worse than -14% to -15%) identifies **occult acute total coronary occlusion** (e.g., LCx occlusion with non-diagnostic ECG) or **Left Main / Triple-Vessel CAD** prior to angiography.
  - **Valvular Heart Disease (Timing Early Intervention):**
  - **Asymptomatic Severe Aortic Stenosis:** Impaired **GLS worse than -14.7% to -15.0%** despite a normal LVEF (>60%) is associated with myocardial fibrosis and predicts worse post-AVR survival.
  - **Asymptomatic Severe Primary Mitral Regurgitation:** Impaired **LV GLS (worse than -18% to -20%)**, **Right Ventricular Free-Wall Strain (worse than -20%)**, and **LA Reservoir Strain (<22%)** unmask early myocardial decompensation before LVEF drops below 60%.

IV TECHNICAL REQUIREMENTS, LIMITATIONS AND THE INDIAN CONTEXT

- **Frame Rate and Image Quality:** Optimal 2D speckle tracking requires high-quality grayscale endocardial/epicardial border definition at a **frame rate of 40 to 80 frames per second (fps)** (lower frame rates lose speckles; higher frame rates degrade spatial resolution).
- **Load Dependency:** Like LVEF, GLS is **afterload-dependent** (acute severe hypertension can reduce GLS; **Myocardial Work Index [Pressure-Strain Loops]** integrates cuff brachial systolic BP with GLS to provide a **load-independent** measure of Global Constructive and Wasted Work).
- **Inter-Vendor Standardization:** Although the **EACVI/ASE Industry Task Force** has reduced inter-vendor variability (between GE, Philips, Canon, and Siemens), serial follow-up in cardio-oncology or valvular disease must be performed on the **same vendor platform** (or using vendor-independent software such as TomTec).
- **Application in the Indian Context:** In Indian tertiary centers, **GLS** and **LA Reservoir Strain** are widely used for early detection of **Diabetic and Hypertensive Subclinical Cardiomyopathy**, risk-stratifying **Rheumatic Mitral Stenosis** (predicting atrial fibrillation and post-PTMC recovery), and correlating non-invasive territorial strain impairment with angiographic **SYNTAX / Gensini scores** in NSTE-ACS.

KEY REFERENCES

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