My Approach to Left Ventricular Strain Assessment

Como eu faço a Avaliação do Strain do Ventrículo Esquerdo

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Introduction

Strain and strain rate are regional and global myocardial deformation indexes that provide data to enable the early detection of possible cardiac changes, thus improving therapeutic approaches. Strain corresponds to a myocardial deformation represented as the percentage of muscle shortening/stretching compared to the initial measurement, while strain rate indicates the rate of myocardial deformation or, in other words, the speed of this deformation. The three main patterns of heart deformation during systole include longitudinal shortening, circumferential shortening, and radial thickening. The latter occurs due to transverse fiber thickening due to its incompressibility (therefore, secondary to its shortening) and apposition (Figure 1). Ultimately, it accounts for a decreased ventricular cavity.[1,2]

The strain can be evaluated using the tissue Doppler technique based on mathematical calculations that convert speed to deformation. Although useful in some specific contexts, this technique has significant limitations, such as the following: a low signal-to-noise ratio, high intra- and inter-observer variability, and dependence on the angle of insonation, which greatly limits the assessment of radial and circumferential deformations.[3]

As a result, strain analysis with two-dimensional (2D) speckle tracking (ST) is the most widely validated technique used in clinical practice. This technique is based on the tracking (on all planes) of natural myocardial acoustic markers present in the 2D image in grayscale throughout the cardiac cycle based on the comparison of frame-by-frame patterns. Strain represents the relative mean myocardial fiber deformation between two adjacent points. When there is systolic fibrous shortening (longitudinal and circumferential directions), the strain has a negative value. Radial systolic thickening, on the other hand, gives the strain a positive value. The ST technique is less dependent on the angle of insonation, enabling deformation measurements in different directions: circumferential and radial in left ventricular (LV) short-axis cuts and longitudinal in the apical view.[1,2]

Each myocardial segment can be subjected to strain evaluation (regional strain), and the global strain reflects the relative contraction (in percentage) of the entire LV myocardium. Some authors believe that ST allows for the differentiation between active versus "passive" myocardial segment deformation, that is, the one occurring due to dragging (and not deformation) of the changed segment caused by the traction suffered by another adjacent segment with preserved contractility.[4] Load conditions are also known to affect myocardial deformation, with the strain being a more vulnerable parameter in this condition compared to the strain rate.[5]

The ventricular systolic function assessment is a fundamental part of echocardiography, being extremely important for the management and prognosis of patients with heart disease. In clinical practice, ejection fraction is routinely used to assess ventricular systolic function. However, over the past decade, myocardial strain has become an important predictor of morbidity and mortality in several heart diseases, providing additional prognostic information compared to ejection fraction alone.[6]

The objective of this study was to explore the main points of strain measurement variability using the ST technique in daily practice and discuss the methods that should be considered to increase parameter accuracy and reproducibility, particularly longitudinal global strain (LGS).

Left ventricle longitudinal strain measurement by speckle tracking

Subendocardial myocardial fibers are longitudinal (parallel to the wall), progressively changing their orientation to slowly become more perpendicular to the cavity so that the subepicardial fibers are in a circumferential direction (Figure 1). The structural arrangement of LV myocardial fibers, their shortening in the longitudinal and circumferential directions, and radial thickening result in the mechanical processes that compose the LV systolic function. All these movements act synergistically to culminate in volumetric variations of the ventricular cavity.[7]

Longitudinal strain evaluates deformation of the

Keywords

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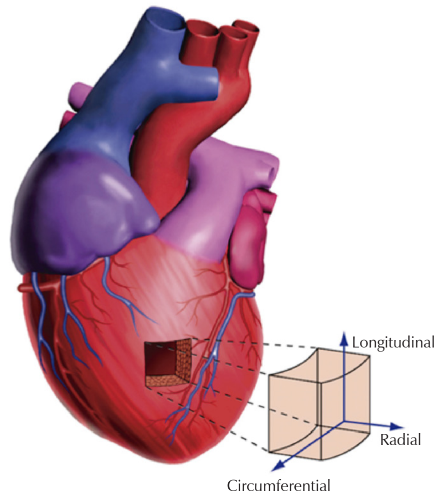


Figure 1 – *Different components of left ventricular deformation.*

subendocardial fibers, which tend to be involved in myocardial diseases. The circumferential strain measurement detects more significant myocardial lesions, as it measures the deformation produced by the subepicardial fibers affected by transmural lesions.[6] The study of circumferential and radial deformations is mostly intended for scientific research due to its low clinical applicability and reproducibility in echocardiography services.[4] Thus, this article focuses on LV LGS using the 2D ST technique, as it is the most widely studied and validated parameter as well as the most useful for prognostic stratification in several diseases and determining incipient myocardial involvement.

Images should be carefully acquired for LV LGS analysis using ST to obtain good technical quality for interpreting the results. The patient must be monitored and electrocardiogram tracing must be satisfactory. If possible, expiratory apnea should be attempted, avoiding the translation movements of the heart with respiratory incursions. Clips of four-, two-, and three-chamber apical acoustic windows must be acquired with at least three beats, excluding extrasystole. For device adjustments, the focus must be properly positioned and sector angle depth and width must be adjusted to include mainly the image of interest (i.e. LV). Likewise, the gain of the 2D image must be correctly adjusted, and the frame rate (FR) must be maintained at 40–80 frames/second in patients with a normal heart rate but may be higher in tachycardic patients or in those undergoing stress echocardiography (a low FR can result in loss of speckles, while a very high FR reduces spatial resolution, decreasing image quality).[4,8,9]

As the longitudinal strain presents higher values from the base to the apex, ventricular cavity shortening (foreshortening) should be avoided during image acquisition.[10] Artifacts, reverberations, and myocardial visualization limitations can result in the following of speckles outside the area of interest, leading to false results. Images must be acquired with a harmonic feature to obtain maximum quality.[9]

The LV segmentation model can have 16, 17, or 18 segments (the former being used in echocardiography and other diagnostic modalities) and reflects the myocardial perfusion territory used to analyze regional longitudinal strain values.[4,11,12]

The region of interest (ROI) must be adjusted to incorporate the entire analyzed wall thickness, leaving its shape and width as close as possible to the myocardial anatomy. Special care must be taken in segments with previous infarction or an asymmetric increased thickness. ROI angles and encompassing the pericardium and extracardiac spaces should be avoided, as these may erroneously reduce strain values.[9,12,13] Particularly in healthy people, the mitral ring presents a strong systolic movement toward the apex, sometimes leading to suboptimal ST in that region and impairing the basal segment strain analysis.[13]

Myocardial segment tracking is initially semi-automatically adjusted but then manually corrected according to the visual impression when necessary. Segments not properly read after an initial adjustment should be discarded. The greater the number of discarded segments, the lower the reliability of the LGS result.[2,8,12] Thus, when more than two myocardial segments are not clearly visible in a single window, use of the LGS calculation should be avoided.[14] A software was recently developed to automatically recognize echocardiographic windows, position the ROI, and provide strain results and curves with the ST technique using "just one button."

The ROI is outlined on the final diastole or systole (depending on the manufacturer), being divided into equidistant segments according to the segmentation model used. The ROI can include the entire wall or be divided into endocardial, mesocardial, and epicardial layers, with each contour being automatically or manually defined. When no layer is selected, the results usually correspond to the results of all forces, representing the entire wall thickness. The measurements obtained in isolation are greater in the endocardial layer and smaller in the epicardial layer.[9,12]

The topographic definitions that form the ROI in the apical windows are the right and left bases at their endocardial borders immediately below the mitral valve, apex, and basal midpoint (midpoint between the right and left basal points).[12]

Event markers must be adjusted to define the beginning (final diastole) and the end (final systole) of the myocardial contraction in the cardiac cycle. Final diastole is the moment characterized by mitral valve closure. Other events related to this phase of the cycle are the beginning of the QRS complex (peak of the R wave) or the positive peak of the LGS curve. It should be considered that the mitral valve closure may dissociate from the electrocardiogram parameters in patients with conduction disorders or regional dysfunction. Thus, the software commonly uses the QRS complex peak to define the final diastole, marking it automatically without examiner interference.[12]

Closure of the aortic valve corresponds to the final systole and can be viewed in the apical three-chamber window (the reason why this window is the first to be analyzed by the software, followed by 4C and 2C windows) or detected by the end of the pulsed Doppler flow trace of the LV outflow tract. Substitute parameters can signal the end of the aortic flow by continuous Doppler, the nadir of the strain curve, or the volume curve. Most software asks the examiner for this mark, but it can be done automatically.[12]

The heart rate must be regular and without major variations for the software to allow the combination of strain values obtained in the three different apical windows (coincident curves) to obtain the LGS value and its representation in a polar map graph (better known as the bull's eye) (Figure 2)[9].

Strain analysis with the ST technique using the three-dimensional (3D) method is also possible, which has the relevant characteristic of acquiring the total heart volume in a single beat (full volume).[15] Comparison of the 3D- and 2D-methods showed no longitudinal displacement differences; however, the first method presented higher radial displacement values, indicating the limitation of the 2D method to track speckles coming out of the image plane. The 3D method allows area strain calculation (which integrates longitudinal and circumferential strain data) to reduce this tracking error.[16,17] The 3D strain technique requires image acquisition and analysis training as well as guidelines that incorporate their values into clinical practice. Thus, its applicability remains limited to research laboratories.

It is extremely important to know how to interpret the morphology and relevant values of the strain curves while considering amplitude and time in relation to the cardiac cycle in which they appear. The following parameters can be evaluated: positive systolic peak strain (occurs in final diastole with myocardial elongation or may represent relevant deformation in cases of regional dysfunction), systolic peak strain (the highest negative deformation value during systole), final systolic strain (deformation value coinciding with aortic valve closure), and post-systolic strain (maximum strain value that can appear after aortic valve closure).[12,13] The final systolic strain should be considered as a standard parameter to describe myocardial deformation (Figure 3).[12]

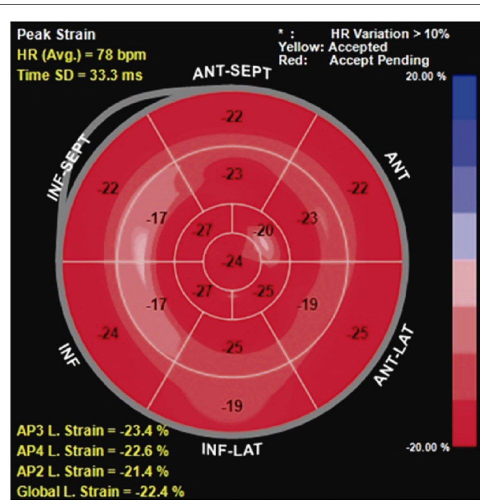
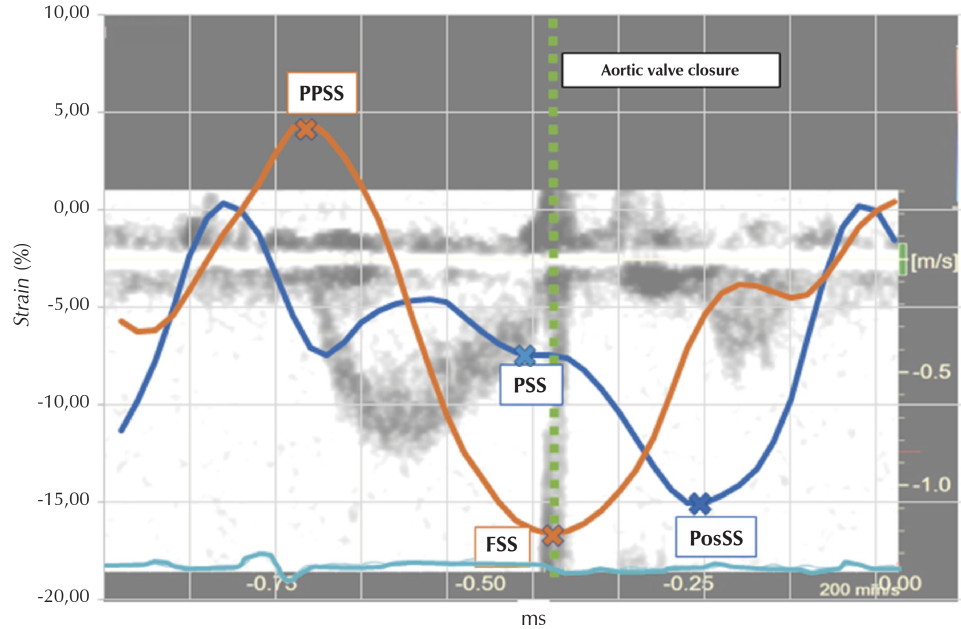


Figure 2 – *Graphical representation of longitudinal strain polar mapping in all segments as well as the global mean (longitudinal global strain) and means obtained in three-, four-, and two-chamber views.*



FSS, final systolic strain; PosSS, post-systolic strain; PPSS, positive peak systolic strain; PSS, peak systolic strain

Figure 3 – *Strain curves and their relationship with the cardiac cycle.*

Post-systolic strain, which reflects the deformation of segments that contract after aortic valve closure and do not contribute to ventricular ejection, is a common finding in acute or chronic myocardial ischemia.[8,18] Some software has softening filters to reduce noise and improve curve interpretation. Excessive softening should be avoided when small time events are being investigated, such as segmental post-systolic shortening.[13]

Strain and strain rate can be assessed in each ventricular segment (regional strain), and the mean of these values now represents the global strain, which reflects global ventricular function.[19] An LGS is within the normal range when a module value is ≥20% (or ≤-20% when the strain is considered negative). Some authors currently prefer to use absolute values (in module) to avoid interpretation errors. There is evidence that women have slightly higher strain values than men and that strain values decrease with age.[12,14]

Farsalinos et al.[20] observed variability of LGS measurements obtained with seven different devices and software from different manufacturers. The largest absolute difference in LGS values between manufacturers was 3.7 percentage units of strain ($p < 0.001$, analysis of variance), with a significant and strong correlation between measures using different devices and with the mean measure of all manufacturers. There was slight variability between manufacturers in the mean LGS calculation or the 4C longitudinal strain, but the difference was statistically significant. These findings support the use of longitudinal strain in clinical practice, as long as the exams are repeated on machines produced by the same manufacturer.[20] A recent study suggested that software updates can also impact LGS calculations.[21] On the other hand, regarding the accuracy identify segmental abnormalities, manufacturers diverge significantly.[22]

Comparison of the different available software products revealed that LGS was a more robust and concordant parameter than the circumferential or radial global strain in the assessment of myocardial function.[23]

Despite these considerations, LGS was more reproducible than ejection fraction for assessing systolic function regardless of the echocardiographer's experience.[24] Another study also emphasized the intra- and inter-observer reproducibilities of the mean and 4C LGS as being superior to those of the LV ejection fraction measurement and other echocardiographic parameters.[20] These findings support the use of LGS in daily practice as an additional assessment tool in heart disease.[25]

Thus, inter-manufacturer biases must be considered when comparing LGS measurements acquired on different devices or analyzing them using different software. Thus, echocardiographic follow-up should ideally be performed using the same device under similar hemodynamic conditions, especially in situations in which LGS variation can have profound therapeutic implications, such as in the context of chemotherapy-induced cardiotoxicity assessments.

Step by step strain measurements for most manufacturers involve the following actions (Figure 4): perform cardiac monitoring; obtain three-, four-, and two-chamber acoustic windows with an FR of 40–80 QPS; mark the aortic valve closure; mark topographic definitions to define the ROI in three-, four-, and two-chamber windows; accept or

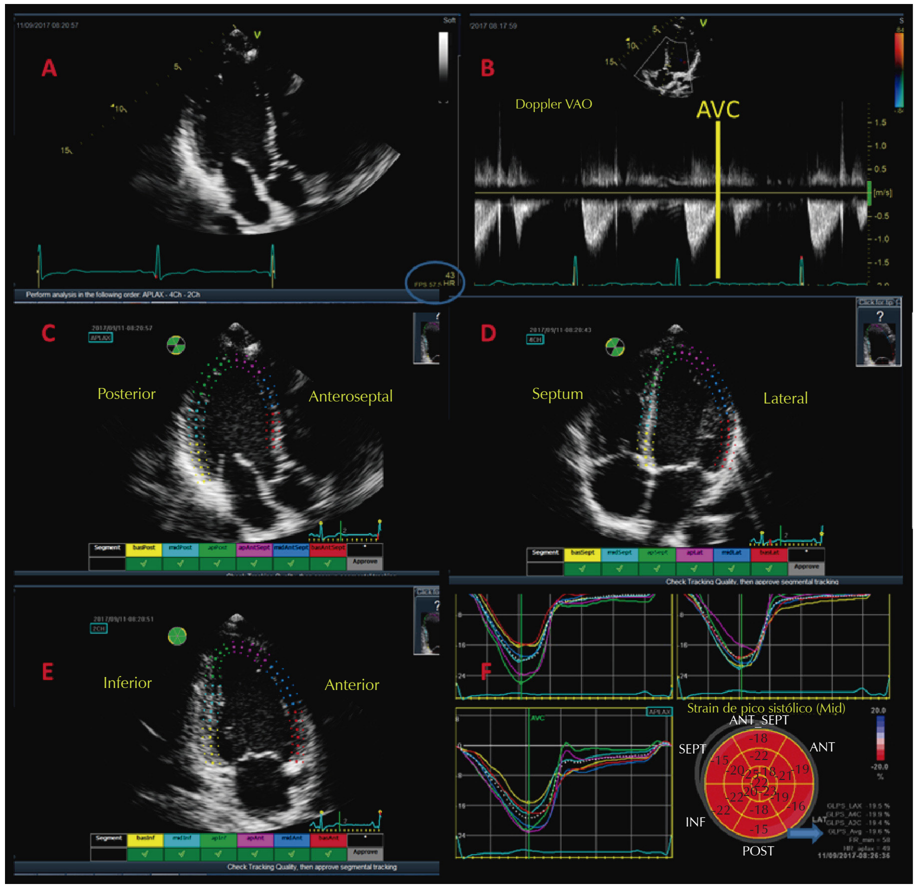


Figure 4 – *Sequence of steps followed to determine the longitudinal global strain (F, blue arrow). Initially, images are acquired in three-, four-, and two-chamber windows on a good-quality electrocardiogram with an adequate frame rate (40–80 frames/second) (A, blue ovoid). Aortic valve closure (AVC) was marked on a pulsed or continuous Doppler tracing (B). Then, three points are marked (two at the base, one at the apex) in the three acquired images and adequate monitoring by region of interest is ensured (C, D, and E). Finally, the curves, bull's eye, and global longitudinal strain values are observed (F).*

discard the myocardial segments tracked in each window and make adjustments as necessary; and evaluate the curves and interpret the results obtained on the polar map.

Authors' contributions

Manuscript writing: Peçanha MM, Tressino CG, Ortegal RA; critical review of the manuscript for important intellectual content: Barreto RBM, Bihan D.

Conflict of interest

The authors have declared that they have no conflict of interest.

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