Review Article

Studying Diastology with Speckle Tracking Echocardiography: The Essentials

Abstract

Diastolic dysfunction is common in cardiac disease and an important finding independent of systolic function as it contributes to the signs and symptoms of heart failure. Tissue Doppler mitral early diastolic velocity (Ea) combined with peak transmitral early diastolic velocity (E) to obtain E/Ea ratio provides an estimate of the left ventricular (LV) filling pressure. However, E/Ea has a significant gray zone and less reliable in patients with preserved ejection fraction (>50%). Two-dimensional echocardiographic speckle tracking measure myocardial strain and strain rate (Sr) avoiding the Doppler-associated angulation errors and tethering artifacts. Global myocardial peak diastolic strain (Ds) and diastolic Sr (DSr) at the time of E and isovolumic relaxation combined with E (E/Ds and E/10 DSr) have been recently proposed as novel indices to determine LV filling pressure. The present article elucidates the methodology of studying diastology with strain echocardiography along with the advantages and limitations of the novel technique in light of the available literature.

Keywords: *Diastolic function, diastology, speckle tracking echocardiography, strain, strain analysis, strain rate*

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Introduction

The accurate measurement of the left ventricular (LV) filling pressures remains an important assessment tool to evaluate, stratify, and guide the overall management of the cardiac surgical patients.[1] The quantification of LV diastolic function is mandatory to diagnose heart failure (HF) in face of an adequate systolic function.[2] Furthermore, the serial estimation of filling pressures serves as an important guide for titration of diuretic therapy and also helps predict the survival in HF patients.

The pulmonary artery balloon occlusion catheter (PAC), when wedged, provides a reliable estimate of the LV filling pressures. The invasiveness and inherent complications associated with PAC insertion and maintenance have evoked interest in noninvasive echocardiographic methods of determining LV filling pressures.

Doppler Echocardiography in Study of Diastolic Function

Doppler echocardiography has been widely used for noninvasive echocardiographic evaluation of diastolic function.[3,4] Tissue Doppler mitral early diastolic velocity (Ea) combined with peak transmitral early diastolic velocity (E) to obtain a dimensionless index E/Ea [Figures 1 and 2] provides a fair estimate of LV filling pressure.[5-7] However, E/Ea has a significant gray zone,[5-7] where if fails to predict the filling pressures and is also less reliable in patients with preserved LV ejection fraction (LVEF) (>50%).[8,9]

Several studies based on tissue Doppler echocardiography have shown that the LV filling pressures are usually >15 mmHg when E/E_a is >15 (E_a from the medial annulus) or >12 (E_a from lateral annulus).[2,5] At the same time, if E/E_a is <8, LV filling pressures are usually not elevated. However, many patients in these studies with increased filling pressures had an E/Ea lower than 15/12, especially with preserved ejection fraction (EF).[10] Thus, with an E/E_a between 8 and 15 (the indeterminate zone), estimation of other parameters is necessary to predict filling pressures.

Speckle Echocardiography in Study of Diastolic Function

In a system based on the speckle echocardiography, the displacement of

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speckles of the myocardium in each given spot is analyzed and tracked from one frame to another. In each of the mid-esophageal – 4-chamber, 2-chamber, and long-axis views, the entire LV endocardium is traced in the frame with the best definition.[11] The software package is well equipped to automatically track the motion through the rest of the cardiac cycle. LV global longitudinal strain and strain rate (Sr) in each view is calculated with the use of the entire length of the LV myocardium [Figures 3 and 4]. Peak global Sr during the isovolumic relaxation (IVR) period (Sr_{IVR}) and early diastole (SrE) are thereby measured. The global strain and Sr values from the above discussed three echocardiographic views are also averaged to be subsequently used for final analysis [Tables 1 and 2].

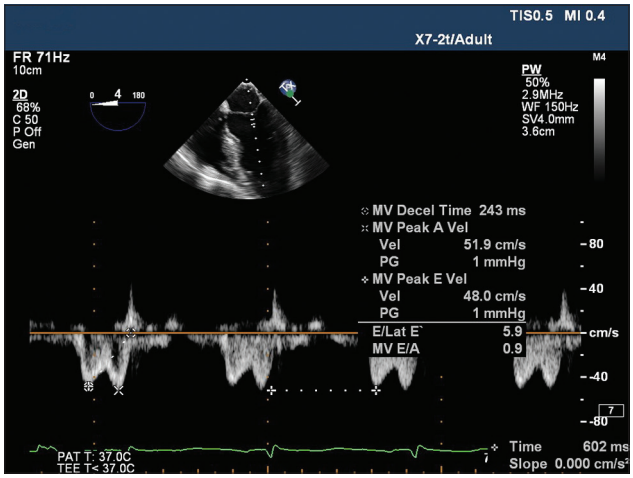

Figure 1: Pulse Doppler across the mitral showing the peak transmitral early diastolic velocity (E) and the duration from R wave (in the electrocardiograph) to peak E of mitral inflow is 602 ms (0.6 s)

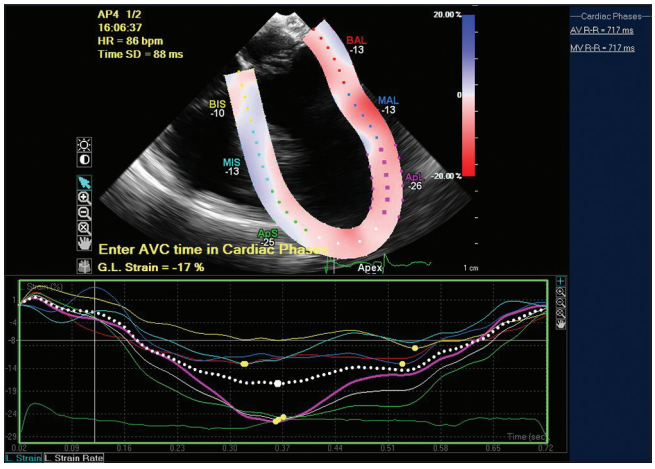

Figure 3: Longitudinal strain analysis averaged from the various myocardial segments in a mid-esophageal-4C view, to determine the strain (diastolic strain) at peak mitral filling (E) and isovolumic relaxation time. The duration from R wave (in the electrocardiograph) to peak E of mitral inflow is 602 ms (0.6 s). The red line denotes strain at E; yellow line denotes strain at isovolumic relaxation time measured at 420 ms (average of 300 and 543 ms) and aortic valve closure. E = 48 cm/s, Ds at E = −8%; E/Ds at E = 48/8 = 6. E = 48 cm/s, Ds at IVRT = −15%; E/Ds at IVRT = 48/15 = 3.2. Ds: Diastolic strain, IVRT: Isovolumic relaxation time

Two-dimensional (2D) echocardiographic speckle tracking measure myocardial strain and Sr using deformation analysis, thereby avoiding Doppler-associated angulation errors and tethering artifacts.[13,14] The measured global myocardial peak diastolic strain (Ds) and diastolic Sr (DSr) at the time of E and IVR time (IVRT) can be combined with E to produce novel indices (E/Ds and E/10 DSr) to predict the LV filling pressure.

The Evidence in Support

In a study by Dokainish *et al*. involving fifty patients, 2D echocardiographic global longitudinal Ds and DSr were

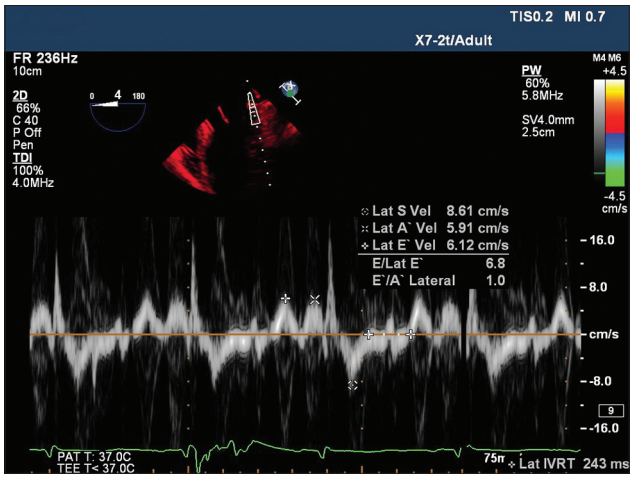

Figure 2: Estimation of E'a (at the lateral annulus) with the use of tissue Doppler echocardiography to compute the E/E'a. The figure also marks the duration (AB) of isovolumic relaxation time, along with the onset (A) and end (B) of isovolumic relaxation time as measured from the R (electrocardiograph) wave. Isovolumic relaxation time is 243 ms. Measured from peak R, isovolumic relaxation time begins at 300 ms and ends at 543 ms

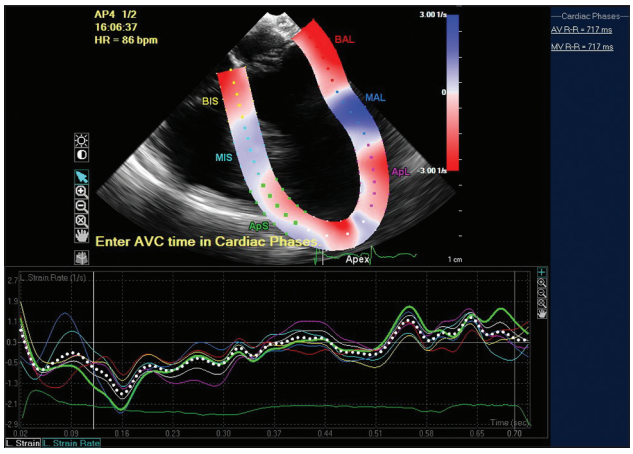

Figure 4: Longitudinal strain rate analysis averaged from the various myocardial segments in a mid-esophageal-4C view, to determine the strain (diastolic strain rate) at peak mitral filling (E) and isovolumic relaxation time. The duration from R wave (in the electrocardiograph) to peak E of mitral inflow is 602 ms (0.6 s). The red line denotes strain at E; yellow line denotes strain at isovolumic relaxation time measured at 420 ms (average of 300 and 543 ms) and aortic valve closure. E = 48 cm/s, Dsr at E = 1.0/s; E/10 Dsr at E = 48/10 × 1 = 4.8. E = 48 cm/s, Dsr at IVRT = 0.3/s; E/10 Dsr at IVRT = 48/10 × 0.3 = 16. Dsr: Diastolic strain rate, IVRT: Isovolumic relaxation time

measured during peak mitral filling and combined with E to compute the two indices: E/Ds and E/10 DSr. These indices were correlated simultaneously with the invasively measured LV preatrial (pre-A) contraction pressure and the E/Ea ratio. The correlation between E/Ds and E/10 DSr with LV pre-A pressure was much stronger, $r = 0.81$ and 0.80, respectively ($P < 0.001$), compared with $r = 0.63$ between E/Ea and LV pre-A pressure.[7]

E/Ds >8.5, E/10 DSr >11.5, and E/Ea >15 were the derived cutoff values to predict the filling pressures of more than 15 mmHg in the study. E/Ds >8.5 was found to have a much higher sensitivity and specificity (95% and 94%, respectively; area under the curve = 0.96, $P < 0.0001$) than E/Ea >15 (sensitivity 81%, specificity 75%; area under the curve = 0.85, $P < 0.0001$) for the prediction of LV pre-A pressure >15 mmHg. In patients with LVEF >50% and 8< E/Ea <15 (the gray zone), E/Ds and E/10 DSr correlated much accurately with the LV pre-A pressure as compared to E/Ea.

Wang *et al*. studied DSr during IVR (when the mitral valve is still closed) and compared the derived indices with invasive LV diastolic function.[15] Involving fifty patients with simultaneous cardiac catheterization and echocardiographic imaging, mitral E/Sr_{IVR} ratio emerged to have the best correlation with mean wedge pressure ($r = 0.79$, $P < 0.001$). Receiver operating characteristic analysis (area under the curve = 0.93, $P < 0.0001$) showed that a cutoff value of E/Sr_{IVR} >236 cm had the best accuracy in identifying patients with a mean pulmonary capillary wedge pressure >15 mmHg, with a resultant sensitivity of 96% and a specificity of 82%. In striking contrast, the E/Ea ratio only had an area under the curve of 0.85.

E/Sr_{IVR} predicted LV filling pressures with a reasonable accuracy in the study, especially in patients with a preserved EF and in those with regional dysfunction. The research group proposed an explanation that the global Sr_{IVR} measured by 2D speckle tracking is strongly dependent on

Table 1: Technical considerations before acquiring echo loops for strain analysis

Steps	General descriptions
Step 1	Ensure that the TEE probe is well lubricated before insertion, stomach is evacuated of air and gastric juices with nasogastric tube
Step 2	Before image acquisition, connect a standard three-lead ECG to the echo machine for synchronizing cardiac motion with electrical activity of the heart. This is a must because of timing purposes while postprocessing. Unfreeze the echo machine to run ECG strip
Step 3	Acquire digital loops as detailed below (the data should be store in a media e.g., CD/DVD) in DICOM format for offline/PC analysis
Step 4	Perform postprocessing of the acquired data either in the echo machine itself or in a PC wherever the "quantification" software is installed

TEE: Transesophageal echocardiography, ECG: Electrocardiograph

Table 2: Step-by-step methods of strain/strain rate analysis using cardiac motion quantification software: From data acquisition to postprocessing

Steps	Techniques of acquiring digital loops and its subsequent analysis
Step 1	Carefully optimize image quality for error-free acquisition of best B-mode images frame by frame; (as temporal resolution cannot be improved afterward) to ensure accurate assessment of myocardial deformation and strain quantification. Most importantly, adjust 2D images in such a way that the frame rate remains more than 50 FPS. Furthermore, make sure that the ROI is included in the scanned sector
Step 1A	For longitudinal strain analysis, acquire standard ME-4C, 3C (AV LAX), and 2C views as described by the ASA/SCA guidelines[12]
Step 1B	For circumferential strain analysis, acquire standard TG LV basal, mid-papillary and apical SAX views as described before
Step 2	Postprocessing: Q-lab is selected and wait until the program loads if it is done in the echo machine itself, the loop is preselected, otherwise in a PC, go to file tab and select the desired loop .xls file
Step 3	Next select the CMQ/aCMQ button in the left panel. Choose the cardiac cycle with the best image quality in the loop by QRS skip key at the bottom left corner of the screen
Step 4	Select an ROI to be analyzed by confirming one of the long axis views and assigning anterior and inferior annular and center of the apex points. Let the software automatically detect the timing of end-diastole and suggest the ROI segmental breakups (it automatically divided the myocardium into seven segments). The software spontaneously starts tracking myocardial deformation and its computation simultaneously
Step 5	A time-strain curve depicting both global and segmental strain with respect to time is displayed at the bottom of the screen by default. Click "Sr" button below this graph to visualize global and segmental Sr. Click result button to get the numeric data both segmental and global average strain values in the "bulls eye" format
Step 6	Inspect and verify the tracking quality as suggested by the software. To do so, critically control all the myocardial segments to be analyzed are completely covered by the ROI during the entire cardiac cycle. If needed, manually reposition or even redraw the ROI coverage to the best position and appropriate width of the myocardium

ROI: Region of interest, 2D: Two-dimensional, AV LAX: Aortic valve long-axis, ME: Mid-esophageal, ASA: American Society of Anesthesiologists, SCA: Society of Cardiovascular Anesthesiologists, TG: Transgastric, LV: Left ventricular, SAX: Short-axis, Sr: Strain rate

LV relaxation and is not affected by preload in comparison to that measured at peak mitral filling (E).

Limitations

Although some studies have been able to show the utility of speckle echocardiography in studying diastolic function, most of these had a limited sample size. Nonetheless, the authors recommended larger prospective validation studies using these novel strain-based indices for estimation of LV filling pressures, especially in patients with preserved EF and with $E/E_{a.}$ in the indeterminate zone.

Moreover, no general consensus on the optimal cutoff for the strain- and diastolic-based indices, both at E and IVRT, has been achieved, inspite of the studies demonstrating a much stronger correlation as compared to E/E_a.

Conclusion

The available literature on the application of speckle echocardiography for studying the diastolic function is encouraging. The results of the studies in the future involving a larger number of patients might help reinforce the present findings, especially in patients with preserved EF and with $E/E_{a.}$ in the indeterminate zone. The combined results of these studies can thereby help formulate appropriate cutoffs for these novel strain-based indices to predict increased LV filling pressures with a high sensitivity and specificity.

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Conflicts of interest

There are no conflicts of interest.

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