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ORIGINAL ARTICLE

Comparison of Two Different Methods of obtaining Strain by Perioperative Transesophageal Echocardiography in Patients undergoing Coronary Artery Bypass Graft Surgery: A Prospective Observational Study

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ABSTRACT

Introduction: Tissue deformation imaging enables the objective assessment of regional myocardial deformation assessed by ultrasound-based strain and strain rate. There are two ways to compute myocardial deformation (strain) using echocardiography: One-dimensional tissue Doppler (DTI)-derived strain and two-dimensional (2D) strain derived from B-mode images (speckle tracking, 2D-ST). This study compares the myocardial deformation parameter (i.e., strain) by these two techniques in the perioperative period using transesophageal echocardiography (TEE) in patients undergoing surgery for coronary artery bypass graft (CABG).

Materials and methods: We performed preoperative global longitudinal strain (GLS) of left ventricle (LV) using 2D-ST and DTI, three-dimensional (3D) left ventricular ejection fraction (LVEF) and 2D LVEF in a consecutive series of 50 adult patients scheduled for on-pump CABG.

Result: There was no difference between 2D and 3D LVEF ($p < 0.0001$), GLS using 2D-ST and DTI (p-value = 0.0005). The 3D LVEF correlated well with GLS using 2D-ST ($r = 0.54$, $p < 0.0001$) and less with tissue Doppler-derived GLS ($r = 0.35$, p-value = 0.0131).

Conclusion: The LV GLS calculated using 2D-ST correlates well with LV GLS derived from DTI using TEE. The LV GLS also correlated well with the 3D LVEF.

Keywords: Global longitudinal strain, Speckle tracking, Three-dimensional transesophageal echocardiography, Tissue doppler strain, Transesophageal echocardiography.

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Conflict of interest: None

INTRODUCTION

Myocardial deformation expressed as strain is defined as the deformation or systolic shortening during the cardiac cycle relative to the initial length, and is expressed in percentages. Therefore, longitudinal and circumferential shortening are negative strain and radial thickening is a positive strain. Tissue deformation imaging enables the objective assessment of regional myocardial deformation assessed by ultrasound-based strain using Doppler tissue imaging (DTI) or two-dimensional speckle tracking (2D-ST). Assessment of wall motion requires training[1] and depends upon various factors.[2] The peak systolic strain rate correlates well to load independent indices of contractility and hence provides valuable information on regional contractile function.[3,4]

Because DTI interrogates motion in one dimension of the myocardium, it is influenced by translational motion and tethering and does not fully capture true myocardial mechanics. Two-dimensional ST imaging using B-mode images is performed at much lower frame rates (40–90 frames per second) and may not be as accurate in timing mechanical events as Doppler-based imaging (100–250 frames per second).[5]

There are limited numbers of studies comparing the myocardial deformation parameters (i.e., strain and strain rate) by two different echocardiographic techniques, viz. DTI and 2D-ST in the perioperative period. In this study, our primary objective was to compare the two strain parameters in patients undergoing coronary artery bypass grafting (CABG) surgery using transesophageal echocardiography (TEE) and secondary objective was to see their correlation with 2D and 3D left ventricular ejection fraction (LVEF).

MATERIALS AND METHODS

The study was conducted after obtaining institutional ethical committee clearance. After obtaining written informed consent, 50 adult (>18 years) patients undergoing CABG under cardiopulmonary bypass (CPB) were included in the study.

Anesthesia Technique

Standard anesthesia technique was used for all the patients. Balanced narcotic technique was used in all cases. After induction of general anesthesia, a 3D multiplane 6VT-D TEE probe was introduced, and comprehensive TEE examination was performed using the GE vivid E9 echocardiography system (GE Medical Systems, Horten, Norway) in all the patients.

Echocardiography Data

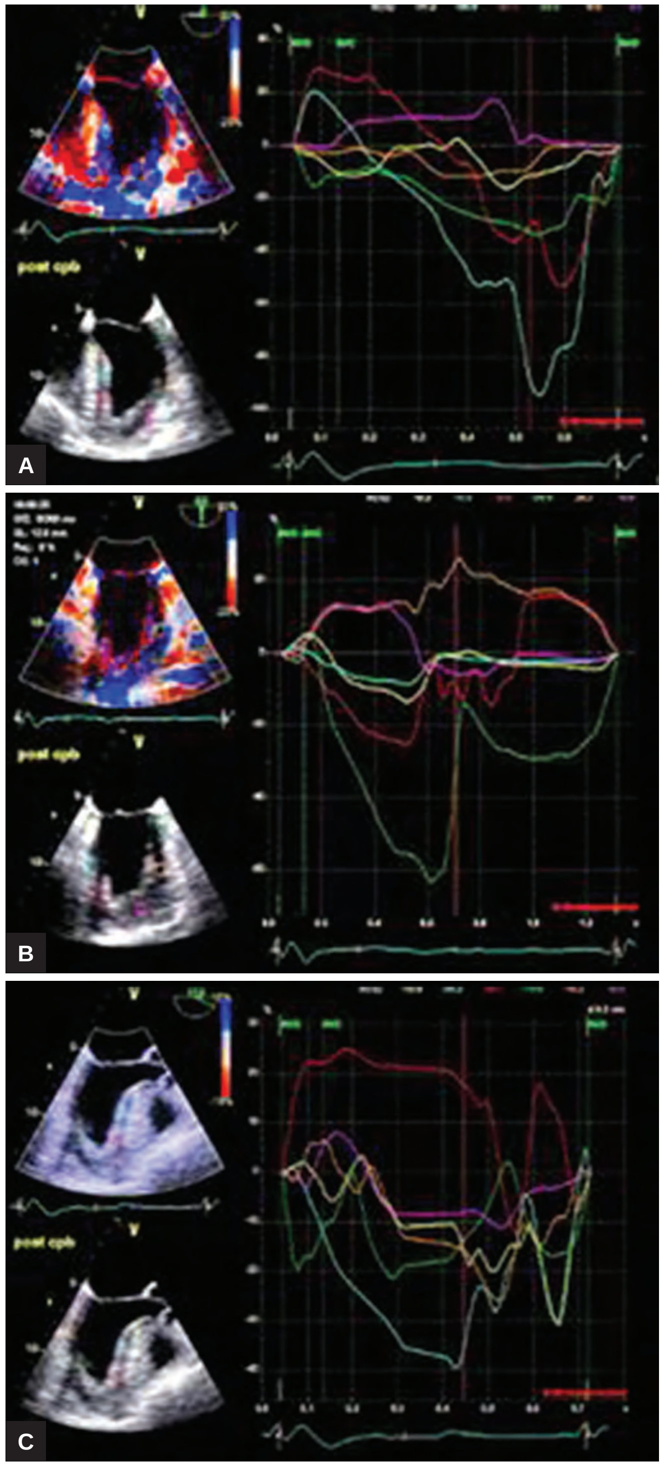
The following parameters were noted before instituting CPB:

- 2D LVEF using Simpson's method from midesophageal (ME) four-chamber and ME 2-chamber views.
- 3D LVEF from ME four-chamber and ME 2-chamber views.
- DTI derived regional longitudinal strain of myocardium from ME four-chamber, ME 2-chamber, and ME long-axis views. Global longitudinal strain (GLS) was calculated by averaging peak systolic strain values from all walls (anterior, anteroseptal, lateral, septal, inferolateral, and inferior). Base, mid, and apical segments were chosen and averaged to give regional wall strain for each walls (Figs 1A to C).
- 2D-ST imaging derived GLS (by automated function imaging, AFI) from ME four-chamber, ME 2-chamber, and ME long-axis views. For strain processing, the peak of the R wave on the electrocardiogram was used as the reference time point. Segments with poor-quality tracking were manually discarded. Global longitudinal strain was only computed from patients with >14 segments adequately tracked for an 18-segment model and was calculated by averaging the peak strain values of 18 segments.

The mean frame rate was 87 per sec. To minimize noise, the pulse repetition frequency was set to 0.5 to 1.0 kHz. Four cardiac cycles were stored in cineloop format for offline analysis. Offline analysis was performed by observers blinded to clinical data using the EchoPAC program (EchoPac PC; GE Health care, Waukesha, Wisconsin).

Reproducibility

The studies were analyzed offline by a second blinded observer for 20 patients for both 2D-ST strain and DTI strain. Intraobserver variability was calculated by the average difference between the 20 measurements realized. Interobserver variability was calculated as the absolute difference divided by the average of the two observations for all parameters.



Figs 1A to C: Doppler tissue imaging LV GLS from ME four-chamber: (A) ME 2-chamber; (B) ME long-axis; and (C) views showing peak systolic strain from base, mid, and apical segments of all walls

Statistics

Statistical analysis was performed using Statistical Package for the Social Sciences software (IBM SPSS

Table 1: Demographic and clinical characteristics and imaging data

Sl. No.	*Parameters*	*Mean ± SD (n = 50)*
1	Age (year)	59.18 ± 8.08
2	Gender, n (%)	Female – 9 (18%)
		Male – 41 (72%)
3	Height (cm)	164.61 ± 8.47
4	Weight (kg)	63.29 ± 11.7
5	BSA	1.67 ± 0.16
6	NYHA Class, n (%)	II – 30 (60%)
		III – 18 (36%)
		IV – 2 (4%)
7	Rhythm (n)	LBBB – 2 (49%)
		NSR – 48 (96%)
8	Serum creatinine (mg/dL)	1.014 ± 0.35
9	Coronary vessels involved, n (%)	SVD: 1 (2%)
		DVD: 7 (14%)
		TVD: 42 (84%)
10	Euro score, n (%)	0–2: 24 (48%)
		2–6: 21 (42%)
		>6: 5 (10%)

BSA: Body surface area; DVD: Double vessel disease; LBBB: Left bundle branch block; NSR: Normal sinus rhythm; NYHA: New York Heart Association; SD: Standard deviation; SVD: Single vessel disease; TVD: Triple vessel disease

Table 2: Operative and perioperative imaging characteristics

Sl. No.	*Parameters*	*Mean ± SD (n = 50)*
1	Type of surgery, n (%)	CABG: 45 (90%)
		CABG ± MVR: 3 (6%)
		CABG ± AVR: 2 (4%)
2	Cross clamp time (min)	103.64 ± 35.68
3	Bypass time (min)	151.70 ± 45.32
4	Temperature (°C)	33.59 ± 2.23
5	MAP (mm Hg)	92.09 ± 20.65
6	HR (bpm)	74.93 ± 13.69
7	VIS	9.48 ± 8.29
8	Diastolic parameters	
	E/A ratio	1.34 ± 0.49
	Mitral E′ velocity (cm/s)	4.66 ± 3.93
	E/E′ ratio	11.50 ± 4.91
8	2D LVEF (%)	44.19 ± 11.63
9	3D LVEF (%)	41.88 ± 12.95
10	Speckle tracking LV GLS (%)	–12.27 ± 5.26
11	DTI LV GLS (%)	–13.52 ± 5.29

AVR: Aortic valve replacement; E: Early mitral flow velocity; E′: Early tissue Doppler lengthening velocity; HR: Heart rate; MAP: Mean arterial pressure; MVR: Mitral valve replacement; SD: Standard deviation; VIS: Vasopressor inotrope score

Statistics 21, Chicago IL). Since this is a novel study, we included 50 consecutive patients as a pilot project. Demographic data are presented as mean ± standard deviation. The left ventricle (LV) strain as derived from DTI and 2D-ST imaging is compared with 2D and 3D LVEF using linear regression analysis. The strain values obtained by the two methods were compared by Bland and Altman analysis. Intraobserver and interobserver variability were tested for both the strain measurements using linear regression test and Bland–Altman plot of differences of the two measurements against mean values. A p-value less than 0.05 was considered significant.

RESULTS

Clinical data and echocardiographic characteristics are summarized in Tables 1 and 2. Most of the patients were male with triple vessel disease and with no valve disease or renal dysfunction. The 2D LVEF and 3D LVEF were comparable ($r = 0.91$, $p < 0.0001$). The LV GLS derived from 2D-ST and DTI correlated, and no significant difference was found between the paired values ($r = 0.52$, $p = 0.0005$) (Graphs 1A and 1B). Graphs 2A and B displays individual data and demonstrates LVEF3D and 2D, which correlated well with 2D-ST LV GLS ($r = 0.54$ and $r = 0.47$, $p < 0.0001$ and $p = 0.0005$ respectively). Correlation of LVEF3D and 2D was poor with DTI LV GLS ($r = 0.35$ and $r = 0.34$, $p = 0.0131$ and 0.0151 respectively) (Graphs 3A and 1B).

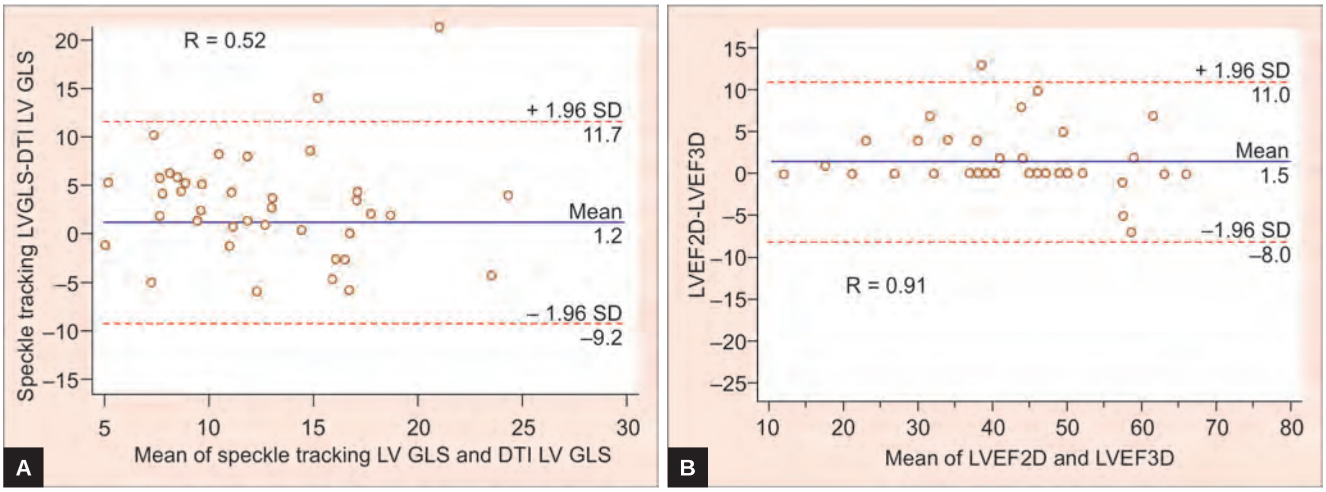
The LVEF3D, 2D-ST, and DTI LV GLS correlated well with each other both preoperatively and postoperatively. The LVEF3D correlated more significantly with 2D-ST than with DTI LV GLS (Table 3) also on comparing the preoperative and postoperative values of LVEF3D, 2D-ST, and DTI LV GLS (Table 4).

Bland–Altman plot in Graphs 4A and 4B shows very good intraobserver and interobserver correlation for 2D-ST LV GLS ($r = 0.98$ and 0.96 respectively, $p < 0.0001$) and in Graphs 5A and 5B for DTI LV GLS ($r = 0.95$ and 0.83 respectively, $p < 0.0001$).

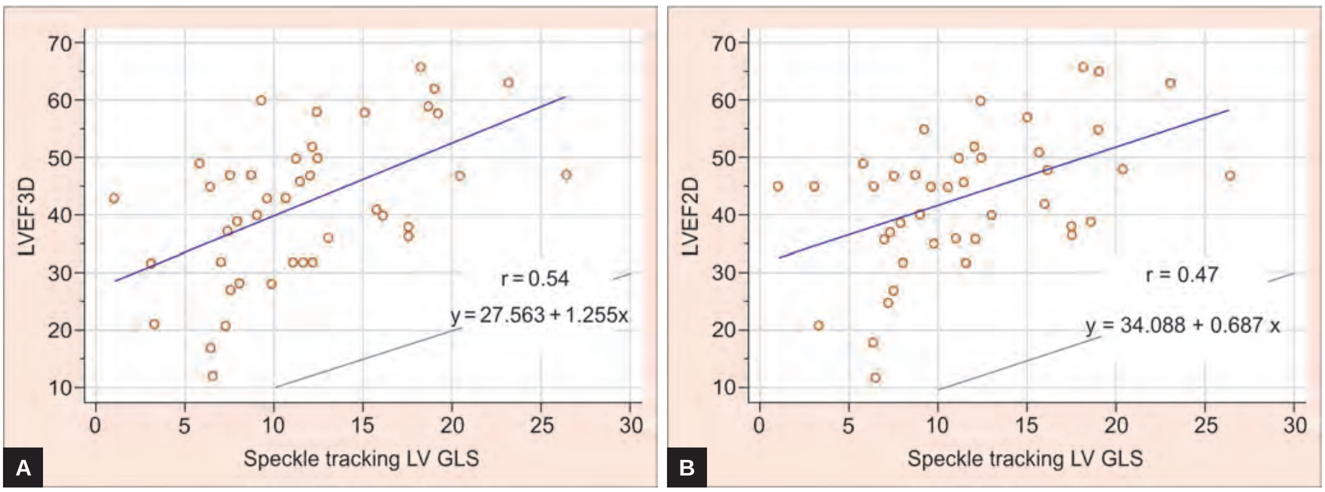
DISCUSSION

Strain and strain rate are strong noninvasive indices of LV contractility both in non operative[4] and perioperative settings.[6] The DTI and 2D-ST are two major ultrasound techniques for quantitatively assessing myocardial mechanics. The 3D global cardiac motion is difficult to appreciate during conventional TEE imaging.[7] Evaluation of regional LV motion is also not accurate because of a noncontracting segment and tethering effect on adjacent segments. Many of these limitations can be overcome by assessing myocardial deformation (strain). Echocardiographic deformation can be measured from velocity gradient using DTI or non-Doppler tracking of speckles (speckle track imaging).

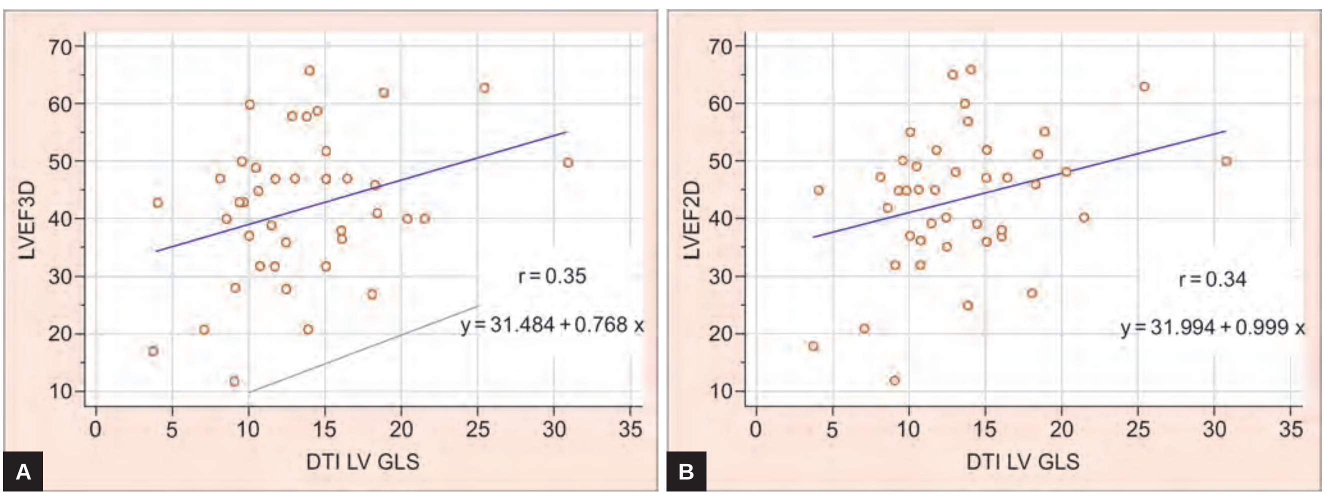
Strain and strain rate calculated from myocardial velocity gradients using DTI have been validated with



Graphs 1A and B: Bland–Altman plot, no significant difference between the two paired values. (A) Speckle tracking LV GLS and DTI LV GLS; and (B) 2D LVEF



Graphs 2A and B: Linear regression plot of speckle tracking LV GLS and 3D LVEF and 2D LVEF



Graphs 3A and B: Linear regression plot of DTI LV GLS and 3D LVEF and 2D LVEF

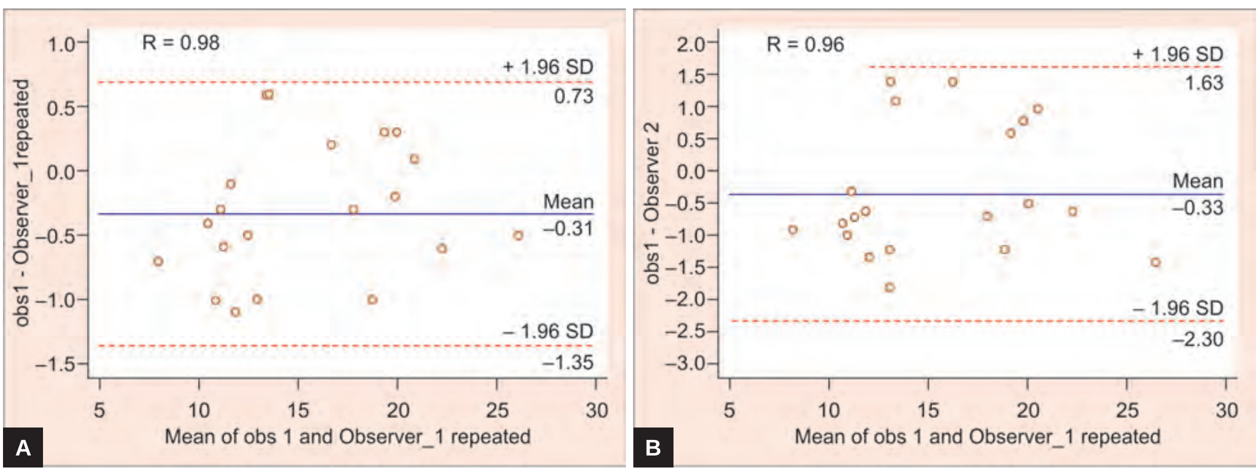
Table 3: Correlation between 3D LVEF, speckle tracking LV GLS, and DTI LV GLS

		3D LVEF	*Speckle tracking LV GLS*	*DTI LV GLS*
Preoperative correlations (n = 50)				
3D LVEF	Pearson correlation	1	0.617**	0.373*
	Sig. (2-tailed)		0.000	0.014
Speckle tracking LV GLS	Pearson correlation	0.617**	1	0.424**
	Sig. (2-tailed)	0.000		0.005
DTI LV GLS	Pearson correlation	0.373*	0.424**	1
	Sig. (2-tailed)	0.014	0.005	
Postoperative correlations				
3D LVEF (n = 43)	Pearson correlation	1	0.480**	0.289
	Sig. (2-tailed)		0.003	0.087
Speckle tracking LV GLS (n = 36)	Pearson correlation	0.480**	1	0.421*
	Sig. (2-tailed)	0.003		0.011
DTI LV GLS (n = 36)	Pearson correlation	0.289	0.421*	1
	Sig. (2-tailed)	0.087	0.011	

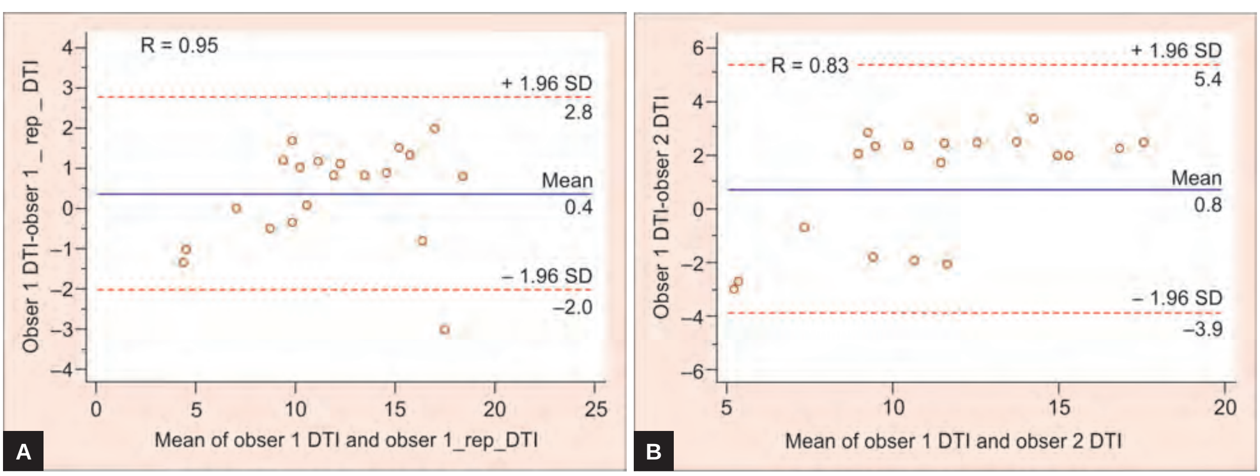
*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table 4: Preoperative and postoperative correlation between 3D LVEF, Speckle tracking LV GLS, and DTI LV GLS

Sl. No.	*Parameters*		*Mean±SD*	*Pearson correlation (Significance)*	*t-value paired differences (Significance) (2-tailed)*
1	3D LV EF (%)	Preoperative (n=50)	41.88±12.95	0.594 (0.000)	–3.83 (0.000)
		Postoperative (n=43)	48.32±13.04		
2	Speckle tracking LV GLS (%)	Preoperative (n=50)	–12.27±5.26	0.738 (0.000)	–0.47 (0.639)
		Postoperative (n=36)	–12.15±5.68		
3	DTI LV GLS (%)	Preoperative (n=50)	–13.52±5.29	0.422 (0.010)	–2.77 (0.009)
		Postoperative (n=36)	-15.92±5.93		



Graphs 4A and B: Bland–Altman plots of intraobserver and interobserver differences for speckle tracking LV GLS variables



Graphs 5A and B: Bland–Altman plots of intraobserver and interobserver differences for DTI LV GLS variables gold standards over a wide range of strain values using sonomicrometry in animals[8,9] and 3D tagged magnetic resonance imaging (MRI) in humans.[10,11] However, DTI strain is technically demanding, is time consuming, and has certain important limitations. The dropout artifacts from neighboring structures can affect the measured velocity gradient and interfere with calculation of deformation parameters. The DTI strain is a Doppler technique and can display deformation along a single dimension only. Therefore, the displayed value (strain rate and strain) may not relate to the true (longitudinal, radial, or circumferential) deformation. In ME views, when the ultrasound beam is parallel to the myocardial wall, the actual (longitudinal) velocity can be accurately measured, but the velocity of radial (transverse) deformation will be zero because radial motion will be perpendicular to the ultrasound beam. As a result, when using TEE, longitudinal strain and strain rate should be recorded only from ME views, and radial strain and strain rate from TG views. Furthermore, if the angle between the Doppler and motion plane is greater than 20°, the true myocardial velocity gradient (and the calculated strain and strain rate) will be underestimated.[9] At an angle of 45°, the measured DTI strain is zero.[8] Because of this angle dependency, DTI should be used primarily to assess longitudinal deformation parameters. This requirement limits DTI strain's general applicability to myocardial disease diagnosis. To limit this error, we calculated strain from all possible 18 segments of LV wall and averaged them together. This covers myocardial motion in maximum possible longitudinal direction. This has reduced not only the error but also the variation in calculation of the strain as evident in our study.

Automated function imaging is a regional assessment tool of the LV systolic function in an adult patient. It is a proprietary software of Echopac, GE software. The AFI derived from 2D strain calculates the myocardial tissue deformation based on a featured tracking on 2D gray scale loops. The tracking of each segment is visually controlled and validated. The AFI can be performed for standard views acquired with either transthoracic echocardiography (TTE) or TEE probe. The result is presented as a Bull's eye display showing color-coded and numerical values for peak systolic longitudinal strain. In addition to global strain for each view, average global strain (GLS) for the whole LV is also displayed (Fig. 2). A frame rate of 80 to 90 is recommended. A higher frame rate is recommended for high heart rate.

Global strain values for all three views (ME four-chamber, ME 2-chamber, and ME long-axis views) are defined as the percentage of maximal contraction over the whole cardiac cycle of the entire myocardial wall relative to its end diastolic length. If the tracking quality is scored as not acceptable (X) in more than one segment, the GS will not be calculated. In 2D-ST strain imaging the speckled pattern is followed frame by frame and can follow the movement of myocardium in any direction. This characteristic, in contrast to DTI-derived parameters, makes it an angle-independent technique. Therefore, radial and longitudinal strain can be measured in the ME views and radial and circumferential strain in the trans-gastric short-axis views. In a study by Korinek et al,[12] good correlation was found between the 2D-ST strain and those obtained using sonomicrometry. The 2D-ST strain has also been validated in patients with myocardial infarction.[13] Importantly, both DTI and STI strain data are highly reproducible and analysis is affected by only small intraobserver and interobserver variability.[14]

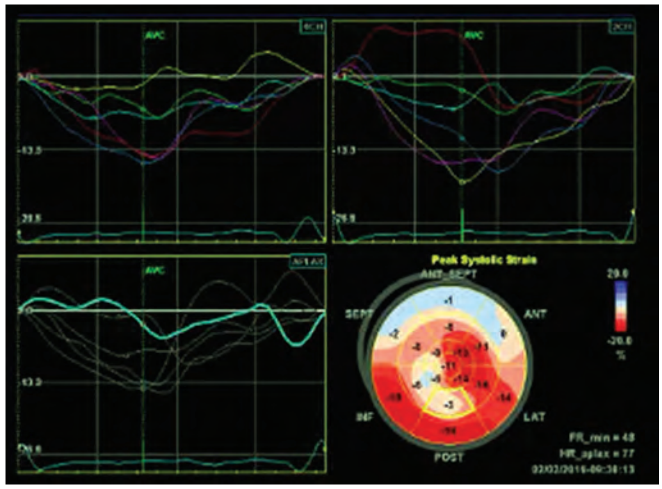


Fig. 2: Speckle tracking LV GLS (by AFI) from ME four-chamber, ME 2-chamber, and ME long-axis views and the result presented as a Bull's eye display showing color coded and numerical values for peak systolic longitudinal strain

As in previous studies comparing myocardial strain parameters by DTI and 2D-ST using TTE, we could also show good correlation between these two methods, although 2D-ST strain has been shown to better differentiate between dysfunctional myocardial segments.[15-19]

The current standard for global systolic function is the conventional 2D LVEF by Simpson method. The accuracy of measured LVEF is variable due to its subjective interpretation and limited in cases of regional wall motion abnormalities. The LVEF is dependent not only upon echocardiographer's experience but also on variable preloading conditions in the perioperative period as well as available acoustic windows.[6] The 3D LVEF is a proven accurate marker for LV systolic function. The 3D echocardiography overcomes geometric assumptions and enables an accurate and reproducible assessment of LVEF.[20] The 3D TTE volumes when compared with the gold standard cardiac MRI has less inter- and intraobserver variability than 2D TTE volumes.[21,22] Our study also showed greater agreement of strain values with 3D LVEF than 2D LVEF. This suggests strain as a novel echocardiographic technique with its accurate and angle-independent assessment of myocardial deformation, which accurately reflects LV contractility.

The assessment of myocardial function in the context of valvular heart disease remains highly challenging especially when LVEF is often unable to disclose initial LV dysfunction in these patients. Also, postoperatively acoustic shadow of metallic prosthetic valves casts its shadow on the walls and it is difficult to assess 2D-ST GLS. Speckle tracking in assessing the components of LV contraction is important because subclinical LV dysfunction can be picked by this method which otherwise would be difficult to measure by conventional echocardiography LV indices, such as LVEF.[23] The DTI STE is particularly suited for the estimation of systolic function, and is, therefore, easy to interpret and apply in routine clinical practice using GLS. Sometimes, it is difficult to obtain ME four-chamber, 2-chamber, and long-axis views in TEE due to cardiomegaly to obtain 2D-ST GLS. The possible advantage of DTI strain over 2D-ST strain could be appreciated at such scenarios whenever it is difficult to obtain 2D-ST LV GLS.

Study Limitations

We did not analyze the segmental strain values which could have given us the insight for poor correlation of DTI strain with LVEF. Tracking of myocardial borders and acoustic patterns may be challenging when image quality is poor. Strain by either DTI or 2D-ST technique was not validated by an independent technique, such as magnetic resonance. Our study was meant to determine whether there was a close correlation between the two techniques and was not a validation study. With the present method, we cannot confirm that we have demonstrated the same region of interest while calculating the DTI strain for each segment and the lack of fixed reference points or identical sampling points could have caused greater variability in DTI strain values.

CONCLUSION

Our pilot initiative is the first study showing results of strain analysis by TEE in the perioperative setting. We found that LV myocardial deformation expressed as GLS using 2D-ST correlates closely with manual TDI measurements over a wide range of global systolic function using TEE. The 2D-ST LV GLS and DTI LV GLS also correlated well with 3D LVEF. This also suggests that this novel technique using DTI may help to facilitate the implementation of strain echocardiography in a clinical setting where 2D-ST GLS is difficult to estimate due to difficulty in imaging.

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