

# Effect of pericardial incision on left ventricular morphology and systolic function in patients during coronary artery bypass grafting

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## Research

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# Abstract

**Background:** Accurate assessment of left ventricular (LV) systolic function is important after coronary artery bypass grafting (CABG). LV ejection fraction (LVEF) is conventionally used to evaluate LV systolic function; deformation parameters can be used to detect subtle LV systolic dysfunction. It is unclear whether an incised pericardium without sutures during CABG could affect LV morphology and function. We investigated the effect of pericardial incision on LV morphology and systolic function during CABG.

**Methods:** Intraoperative transesophageal echocardiography was performed in 27 patients during elective CABG 5 minutes before and after pericardial incision. LV longitudinal and mid-cavity transversal diameters, sphericity index, volumes, and LVEF were measured. LV global longitudinal strain (GLS), global circumferential strain (GCS), global radial strain (GRS), and twist obtained by two-dimensional speckle tracking echocardiography were measured simultaneously.

**Results:** LV mid-cavity transversal diameter increased, while the LV sphericity index decreased ( $P<0.001$ ) immediately after pericardial incision. The GLS, GCS, and twist significantly decreased, while the GRS notably increased ( $P<0.001$ ). The LV volumes and LVEF remained unchanged. The SYNTAX score was an independent predictor of reduction of GLS by  $>15\%$  immediately after pericardial incision ( $P<0.001$ ).

**Conclusions:** Pericardial incision immediately transformed LV morphology from an ellipsoid to sphere, with decreased longitudinal and circumferential strain and twist, and increased radial strain, while LVEF remained unchanged. This should be considered when evaluating LV systolic function in patients after CABG, especially in those with a lower SYNTAX score.

## Background

As a coronary artery revascularization therapeutic strategy, coronary artery bypass grafting (CABG) can effectively improve the myocardial blood supply for complex coronary artery disease. Echocardiography is an optimal, noninvasive method for precisely evaluating left ventricular (LV) systolic function, which has an important role in estimating the therapeutic effect in patients after CABG.

LV ejection fraction (LVEF) is conventionally used as a marker of LV systolic function. Deformation parameters obtained by two-dimensional speckle tracking echocardiography (2D STE) can sensitively detect subtle LV dysfunction at an early stage, LV global longitudinal strain (GLS), in particular, appears to be a more robust parameter and has incremental value in patients referred for cardiac surgery including CABG [1–6].

The pericardium is often incised during CABG without sutures after the surgery, which may affect ventricular morphology and systolic function. Unsworth et al. [7] reported that pericardial incision induced a reduction in right ventricular (RV) systolic function in 9 patients who underwent CABG; however, it is still unclear whether it can affect LV systolic function. Therefore, we sought to investigate the effect of

pericardial incision on LV morphology and systolic function during CABG using intraoperative transesophageal echocardiography (TEE).

## Methods

### Study population

Patients who underwent elective off-pump beating heart CABG between January 2019 and June 2019 in our hospital were consecutively recruited for this study. Patients were excluded if they had a combination of other cardiac surgery, pericardial disease, arrhythmia, or contraindication to TEE. All patients underwent coronary angiography before CABG and their results were assessed by experienced cardiologist. The SYNTAX score was calculated using the SYNTAX score algorithm ([www.syntaxscore.com](http://www.syntaxscore.com)) [8]. All procedures performed in the studies involving human participants were in accordance with the ethical standards of the Ethics Committee of the China Medical University. Informed consent was obtained from all individual participants included in the study.

### Intraoperative echocardiographic image acquisition

After induction of anesthesia, an intraoperative TEE examination was performed 5 minutes before and after pericardial incision during the surgery using the CX50 ultrasound system (Philips Healthcare, Andover, MA, USA) equipped with an X7-2t transducer. The TEE probe was inserted into the patient's esophagus to obtain mid-esophageal 4-chamber (ME 4C), 2-chamber (ME 2C), and long-axis (ME LAX) views, and into the patient's stomach to obtain transgastric basal, mid-papillary, and apical short-axis views. The basal level was identified by the mitral valve, and the apical level was defined as proximal to the level with ventricular cavity obliteration at end-systole. All manipulations of image acquisition were performed according to the American Society of Echocardiography recommendations [9]. Images were obtained at a frequency of 50-70 frames per second, and three consecutive cardiac cycles for each view were stored in cine-loop format.

### Echocardiographic image measurements and analyses

All data were transferred to a workstation for further offline analysis using the Qlab software package (Philips Healthcare). LV longitudinal and mid-cavity transversal diameters were measured at end-diastole in ME 4C view, and the LV sphericity index (LVSI) was defined as the ratio of the LV longitudinal to mid-cavity transversal diameter [10]. The LV internal diameter and posterior wall thickness were measured at end-diastole in ME LAX view, and the relative wall thickness was calculated simultaneously [1]. The LV end-diastolic volume, end-systolic volume, stroke volume, and LVEF were measured using the biplane modified Simpson's method with ME 4C and ME 2C views.

Deformation parameters, including LV GLS, global circumferential (GCS), and global radial strain (GRS), were measured using 2D STE (Fig 1). Endocardial contour was manually adjusted to optimize tracking when necessary, and patients with inadequate tracking of more than two segments were excluded from

the study. The degree of LV peak systolic apical and basal rotation was measured at the apical and basal levels, respectively. Twist was defined as the net difference between apical and basal rotation (Fig 2). The absolute change rates of LV GLS, GCS, GRS, twist, and LVSI were calculated as the percentage of the difference in these parameters before and after pericardial incision divided by that before pericardial incision. A significant reduction of GLS was defined as a decrease of GLS by >15% immediately after pericardial incision [11].

The RV basal, mid-cavity transversal, and longitudinal diameters were measured at end-diastole in ME 4C view, and the RV sphericity index was defined as the ratio of the RV longitudinal to mid-cavity transversal diameter [10]. The RV end-diastolic and end-systolic areas were measured in ME 4C view, and the RV fractional area change was calculated simultaneously [1].

### **Hemodynamic measurements**

Hemodynamic monitors were supplemented by radial arterial and central venous catheters. Hemodynamic parameters including systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial blood pressure (MAP), central venous pressure (CVP), and heart rate (HR) were recorded simultaneously at the time of image acquisition.

### **Statistical analysis**

Statistical analyses were performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Normally distributed continuous variables are expressed as the mean  $\pm$  standard deviation. Comparisons of continuous variables before and after pericardial incision were made using the paired Student *t*-test. Comparisons of SYNTAX score between patients with and without reduction of GLS by >15% were made using the independent Student *t*-test. The Pearson coefficient was used for correlation analysis. The relationship between the change rate of GLS and continuous variables was analyzed using simple linear regression analysis. The selection of independent variables for predicting the change rate of GLS was performed using multivariate analysis. Intra-observer and inter-observer agreement analyses of global strain and rotation were assessed using Bland-Altman analysis in 10 randomly selected patients. A *P*-value <0.05 was considered significant.

## **Results**

### **Baseline characteristics**

Twenty-seven patients (18 men; mean age, 61.22 $\pm$ 6.72 years) were enrolled in the study (Fig 3). The baseline characteristics of these patients are shown in Table 1.

### **Hemodynamics measurements before versus after pericardial incision**

Immediately after pericardial incision, there was no significant change in CVP, SBP, DBP, MAP, and HR (Table 2).

## LV morphology and systolic function before versus after pericardial incision

The LV mid-cavity transversal diameter increased ( $P<0.001$ ), while the LV sphericity index significantly decreased immediately after pericardial incision ( $P<0.001$ ), and the posterior and relative wall thicknesses increased ( $P<0.05$ , Table 3).

LV GLS and GCS decreased, and the GRS increased simultaneously ( $P<0.001$ ), while the LV volumes and LVEF remained unchanged. Meanwhile, the reduction of LV twist was accompanied by decreased apical and basal rotation ( $P<0.001$ , Table 3 and Fig 4). Furthermore, the change rate of GRS was correlated with the change rate of GCS ( $r=.438$ ,  $P=.022$ ), and the change rate of GLS was significantly and inversely correlated with the SYNTAX score ( $r=-.629$ ,  $P<0.001$ ).

17 patients had a significant reduction of GLS by  $>15\%$  immediately after pericardial opening, and the SYNTAX score was lower in these patients than in the other 10 patients with nonsignificant variability of GLS ( $24.09 \pm 6.03$  versus  $37.40 \pm 8.59$ ,  $P<0.001$ ). Moreover, the SYNTAX score was the only independent predictor of reduction of GLS by  $>15\%$  immediately after pericardial incision ( $P<0.001$ , Table 4).

## RV morphology and systolic function before versus after pericardial incision

The RV mid-cavity transversal diameter significantly increased and the RV sphericity index decreased ( $P<0.05$ ), while the RV fractional area change remained unaltered, which indicated that the right ventricle became more round in shape (Table 5).

Results of the intra-observer and inter-observer agreement analyses of global strain and rotation are presented in Table 6.

## Discussion

In the present study, we found that pericardial incision immediately induced obviously change in LV morphology and the contractile pattern. LV morphology changed from an ellipsoid to a sphere, and the relative wall thickness increased immediately after pericardial incision. Additionally, LV deformation parameters markedly changed with a reduced LV global longitudinal and circumferential strain and twist, and an increased global radial strain; however, LV volumes and ejection fraction remained unchanged.

The pericardium maintains the anatomic position of the heart and limits its displacement through ligaments; besides, the relatively inelastic parietal pericardium retracts when it is cut, indicating that it exerts pressure on the underlying myocardial chambers [12–14]. It is often incised during CABG and not sutured after the surgery, and previous studies have found RV systolic function decreased postoperatively. Intraoperative studies suggested that the reduction occurred immediately after pericardial opening and persisted throughout the surgery, which indicated that pericardial incision induced change in RV geometry and the contractile pattern [7, 15–17]. In the current study, we also noted that the right ventricle had increased sphericity despite the unchanged RV fractional area change immediately after pericardial incision.

However, only a few studies have researched the effect of the pericardium on LV morphology and systolic function. Tanaka et al. [18] reported that congenital pericardial defects caused depressed apical and basal rotation, and consequently, LV twist was reduced. A canine experiment also showed that twist was reduced after pericardial opening and restored after suturing the pericardium, which suggests the importance of the pericardium in sustaining LV twist [19]. It is still unclear whether pericardial incision could affect LV morphology and systolic function during CABG.

The LV myocardium is made up by the three-dimensional arrangement of the myocardial cells, which are supported loosely within a continuous matrix of fibrous tissue. Groups of myocytes are surrounded by condensations of the endomysial weave, thus forming the perimysium, which aggregates a meshwork of myocytes into the so-called myofibers [20, 21]. For describing the global arrangement, most studies have depicted LV myocardium as a transmural continuum which changes continuously from a right-handed helical subendocardium to a left-handed helical subepicardium with the mid-myocardium has a circumferential orientation [22, 23]. The unique structure of myofibers results in complicated myocardial motion during systole, and speckle tracking-derived strain could be used to evaluate ventricular systolic function by detecting myocardial deformation in longitudinal, circumferential, radial direction and wringing from base to apex [24].

Deformation parameters change in different directions during the progression of myocardial disease, however, its instantaneous change in this investigation could not be attributed to this. The paradoxical phenomenon in our study that decreased longitudinal and circumferential shortening with preserved ejection fraction is commonly seen in patients with hypertension [25–27]. As the afterload increased, longitudinal and circumferential shortening decreased while the wall thickened as a compensation allowing a preserved ejection fraction. However, there was no significant hemodynamic change immediately after pericardial incision in our study, hence we speculated that the change in myocardial contractile pattern may not result from the physiopathology condition but from the cardiac geometric change.

Left ventricular ejection fraction is determined by both myocardial strain and wall thickness, which can increase with the increased strain and wall thickness, and even if the strain decreases, it could keep constant because of increased wall thickness [28–30]. Wall thickness is determined by end-diastolic wall thickness and radial thickening (ie radial strain), it has a substantial influence on ejection fraction: a 1 centimeter increase in thickness increased ejection fraction by approximately 13 percentage points [29, 30]. Sheet dynamic and sheet geometry between adjacent myocytes and matrix coupling are crucial for LV wall thickening and dynamics, regional ventricular wall thickening also reflects changes in cardiac fiber and sheet structure during contraction [31, 32].

We could not provide a definite mechanism for the change in contraction pattern in our study, we speculated that the variations in sheet dynamic and geometry caused by the changes in the arrangement of myocytes due to lack of pericardial constraints may play a potential role. Although we did not find significant correlation between wall thickness and ejection fraction, we found the decreased

circumferential strain was correlated with the increased radial strain. Therefore, we speculated that the increased radial strain may offset the reduction in longitudinal and circumferential shortening and twisting, allowing for an unchanged ejection fraction.

LV global longitudinal strain as a valuable parameter of LV systolic function has been used in clinical application with a better reproducibility, and it could be a predictor of prognosis and therapeutic effect in patients after CABG [1–4, 33, 34]. It is recommended to detect LV dysfunction early in chemotherapy patients with a percentage reduction of > 15% from baseline[11]. In this study, a significant reduction of global longitudinal strain was found in 17 patients immediately after pericardial incision, and it could be independently predicted by the SYNTAX score. The SYNTAX score of these 17 patients was significantly lower than that of the other 10 patients, probably because patients with a lower SYNTAX score may have few coronary lesions and more surviving myocardia with better movement; therefore, they may be more susceptible to pericardial incision than patients with a higher SYNTAX score.

Transesophageal 2D STE was used to evaluate LV systolic function during CABG in our study, which showed a high degree of intra-observer and inter-observer agreement. Intraoperative TEE is one of the cornerstones for evaluating immediate changes in myocardial function and helps provide critical information during cardiac surgery. Myocardial strain imaging derived from speckle tracking using TEE is a feasible, reproducible method for assessing LV deformation, which has good agreement with transthoracic strain imaging. [35–38]

## Study Limitations

This study has several limitations. First, the speckle tracking technique depend upon the quality of echocardiographic imaging, and the number of patients is limited in this study. Second, LV morphology and systolic function were investigated only immediately after pericardial incision, and a long-term follow-up was not performed to assess whether any aspect of recovery of contractile patterns would occur because we could not eliminate the interference of myocardial revascularization after CABG. However, the depressed RV systolic function after pericardial incision did not recover within 1 month after CABG in patients without interference of the right coronary artery, [7] suggesting that the effect of pericardial incision on RV systolic function may have persisted. Gozdzik A et al. in their study, observed that global longitudinal strain was still reduction two years after CABG [39]. Thus, we speculate that the altered LV morphology and contractile pattern may also persist after CABG, and a well-designed animal experiment should be performed in the future.

## Conclusions

Pericardial incision immediately transformed LV morphology from a prolate spheroid to a sphere during CABG, the LV contractile pattern changed with a decrease in longitudinal and circumferential shortening and twisting, and radial thickening increased despite an unchanged ejection fraction. Moreover, the SYNTAX score was an independent predictor of the reduction in global longitudinal strain immediately

after pericardial incision. Considering the significant impact of these findings, the altered global longitudinal strain resulting from pericardial incision should be taken into account when evaluating LV systolic function in patients after CABG, especially in patients with a lower SYNTAX score.

## **Declarations**

### **Acknowledgements**

Not applicable.

### **Authors' contributions**

LTZ observed indicators, analyzed the data, wrote the manuscript and interpreted the data. LL, PPM, YHW and ML performed the experiment. JY analyzed the data. CYM and TXG designed the study and revised the manuscript. All authors read and approved the final manuscript.

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### **Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### **Ethics approval and consent to participate**

The study protocol was approved by the Ethics Committee of the China Medical University. Informed consent was obtained from all individual participants included in the study.

### **Consent for publication**

Not applicable.

### **Competing interests**

The authors declare that they have no competing interests.

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# Abbreviations

LV, Left ventricular; RV, Right ventricular; TEE, Transesophageal echocardiography; 2D STE, Two-dimensional speckle tracking echocardiography; CABG, Coronary artery bypass graft; LVEF, Left ventricular ejection fraction; GLS, Global longitudinal strain; GCS, Global circumferential strain; GRS, Global radial strain; ME 4C, Mid esophageal 4-chamber view; ME 2C, Mid esophageal 2-chamber view; ME LAX, Mid esophageal long-axis view; TGB, Transgastric basal short-axis view; TGM, Transgastric mid-papillary short-axis view; TGA, Transgastric apical short-axis view.

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## Tables

**Table 1** Patient baseline characteristics

Variable	Value (n=27)
Age (y)	61.22±6.72
Male sex	18 (66.7%)
Body mass index (kg/m <sup>2</sup> )	25.76±3.29
Smoker	10 (37.0%)
<b>Medical History</b>	
Hypertension	17 (63.0%)
Diabetes mellitus	8 (29.6%)
Previous myocardial infarction	13 (48.1%)
Dyslipidemia	8 (29.6%)
Pulmonary hypertension	1 (3.7%)
Previous PCI	4 (14.8%)
Peripheral vascular disease	4 (14.8%)
Troponin I level (ng/ml)	0.12±0.32
Brain-type natriuretic peptide level (pg/ml)	114.70±266.04
NYHA class (I/II/III/IV)	4 (14.8%)/17 (63%)/6 (22.2%)/0 (0%)
SYNTAX score	29.02±9.53
Euroscore II	1.34±0.64
<b>Medications</b>	
Aspirin	18 (66.7%)
Beta-blockers	23 (85.2%)
Calcium channel antagonists	4 (14.8%)
Statins	21 (77.8%)
Nitrates	24 (88.9%)

Data are expressed as a mean ± standard deviation or n (%).

Abbreviations: PCI, percutaneous coronary intervention; NYHA, New York Heart Association.

**Table 2** Hemodynamic parameters before and after pericardial incision

Parameter	Before pericardial incision (n=27)	After pericardial incision (n=27)	<i>P</i> - value
Heart rate (beats/min)	60.67±14.05	64.56±10.90	.146
Central venous pressure (mmHg)	11.07±1.88	10.78±1.28	.058
Systolic blood pressure (mmHg)	124.67±12.89	122.93±8.83	.183
Diastolic blood pressure (mmHg)	69.37±6.22	68.56±5.44	.161
Mean arterial pressure (mmHg)	87.80±6.29	86.68±4.19	.146

Data are expressed as a mean ± standard deviation.

**Table 3** Changes in LV morphology and systolic function before and after pericardial incision

Parameter	Before incision (n=27)	pericardial	After incision (n=27)	pericardial	P- value
LV longitudinal diameter (mm)	71.48±7.48		70.19±8.00		.199
LV mid-cavity transversal diameter (mm)	36.74±3.99		41.41±4.59		.000
LV sphericity index	1.96±0.26		1.70±0.19		.000
LV internal diameter (mm)	42.34±5.27		43.23±6.51		.058
Posterior wall thickness (mm)	7.77±0.96		8.22±1.02		.000
Relative wall thickness (cm)	0.37±0.06		0.39±0.07		.046
LV end-diastolic volume (ml)	109.48±35.05		110.33±35.33		.245
LV end-systolic volume (ml)	47.85±22.12		49.04±22.58		.256
LV stroke volume (ml)	61.63±15.06		61.30±15.85		.743
LVEF (%)	57.41±6.08		56.63±6.82		.354
GLS (%)	-15.86±2.66		-12.39±3.27		.000
GCS (%)	-22.25±4.56		-18.45±5.07		.000
GRS (%)	18.41±6.05		23.13±7.32		.000
Apical rotation (°)	3.67±1.69		1.63±0.70		.000
Basal rotation (°)	-4.14±1.04		-3.08±1.12		.000
Twist (°)	7.81±2.12		4.71±1.22		.000

Data are expressed as mean ± standard deviation.

Abbreviations: LV, left ventricular; LVEF, left ventricular ejection fraction; GLS, global longitudinal strain; GCS, global circumferential strain; GRS, global radial strain.

**Table 4** Predictors of significant reduction of LV GLS with the baseline characteristics

	<i>r</i>	<i>P</i> -value	$\beta$	<i>P</i> -value	95% CI
SYNTAX score	-.629	<b>.000</b>	-.685	<b>.000</b>	-1.54 to -0.53
Euroscore II	-.055	.786	-.023	.906	-9.52 to 8.48
TnI	.038	.852	.033	.857	-15.27 to 18.20
BNP	.081	.688	.232	.204	-0.01 to 0.03
LVEF	.143	.478	.247	.156	-0.24 to 1.41

Abbreviations: LV, left ventricular; GLS, global longitudinal strain; TnI, troponin I; BNP, brain-type natriuretic peptide; LVEF, left ventricular ejection fraction; CI, confidence interval.

**Table 5** Changes in RV morphology and systolic function before and after pericardial incision

Parameter	Before pericardial incision (n=27)	After pericardial incision (n=27)	<i>P</i> -value
RV basal diameter (mm)	33.89±3.15	35.37±3.97	.106
RV mid-cavity transversal diameter (mm)	28.59±2.89	30.44±3.25	<b>.000</b>
RV longitudinal diameter (mm)	59.89±7.09	59.22±8.59	.538
RV sphericity index (mm)	2.11±0.29	1.96±0.31	<b>.026</b>
RV end-diastolic area (cm <sup>2</sup> )	13.83±1.56	13.88±2.51	.880
RV end-systolic area (cm <sup>2</sup> )	7.76±1.09	7.88±1.64	.676
RV fractional area change (%)	43.78±5.39	43.00±7.47	.603

Data are expressed as a mean ± standard deviation.

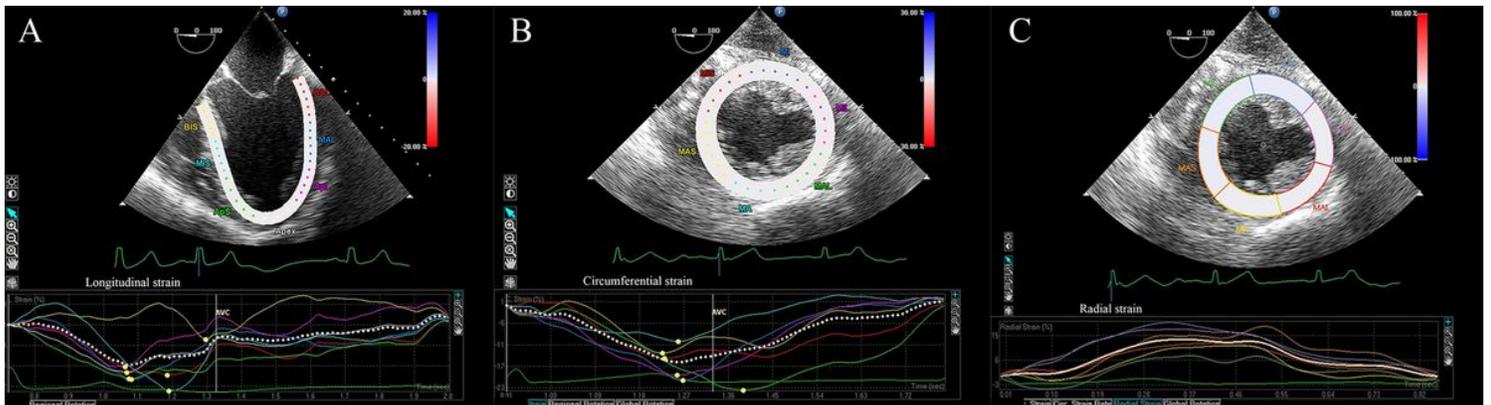
Abbreviations: RV, right ventricular.

**Table 6** Intra-observer and inter-observer agreement analyses of global strain and rotation

Parameter	Intra-observer agreement analysis		Inter-observer agreement analysis	
	Bias	95% LOA	Bias	95% LOA
GLS	-0.17	-2.94-2.6	-0.21	-3.08-2.65
GCS	0.22	-3.02-3.47	-0.36	-6.02-5.29
GRS	0.19	-3.72-4.10	0.24	-3.74-4.23
BR	0.33	-2.56-3.21	0.44	-2.52-3.41
AR	0.31	-2.63-3.26	0.55	-2.93-4.04

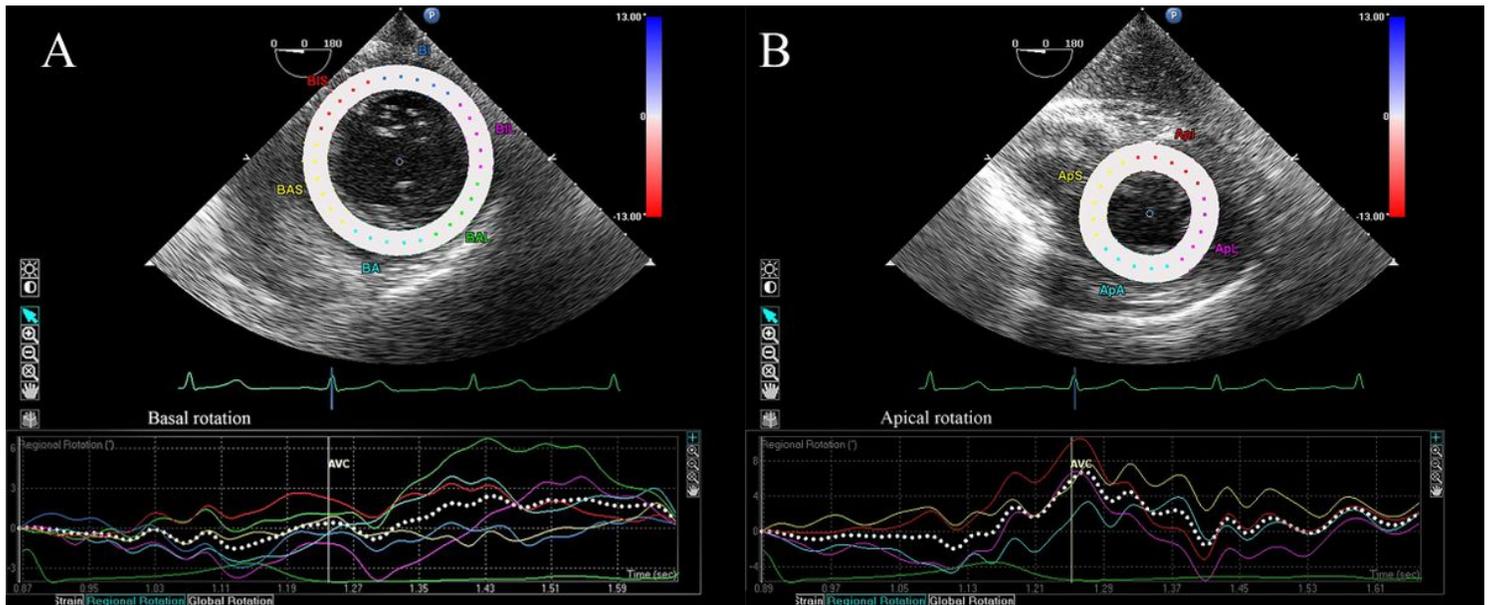
Abbreviations: LOA, limits of agreement; GLS, global longitudinal strain; GCS, global circumferential strain; GRS, global radial strain; BR, basal rotation; AR, apical rotation.

## Figures



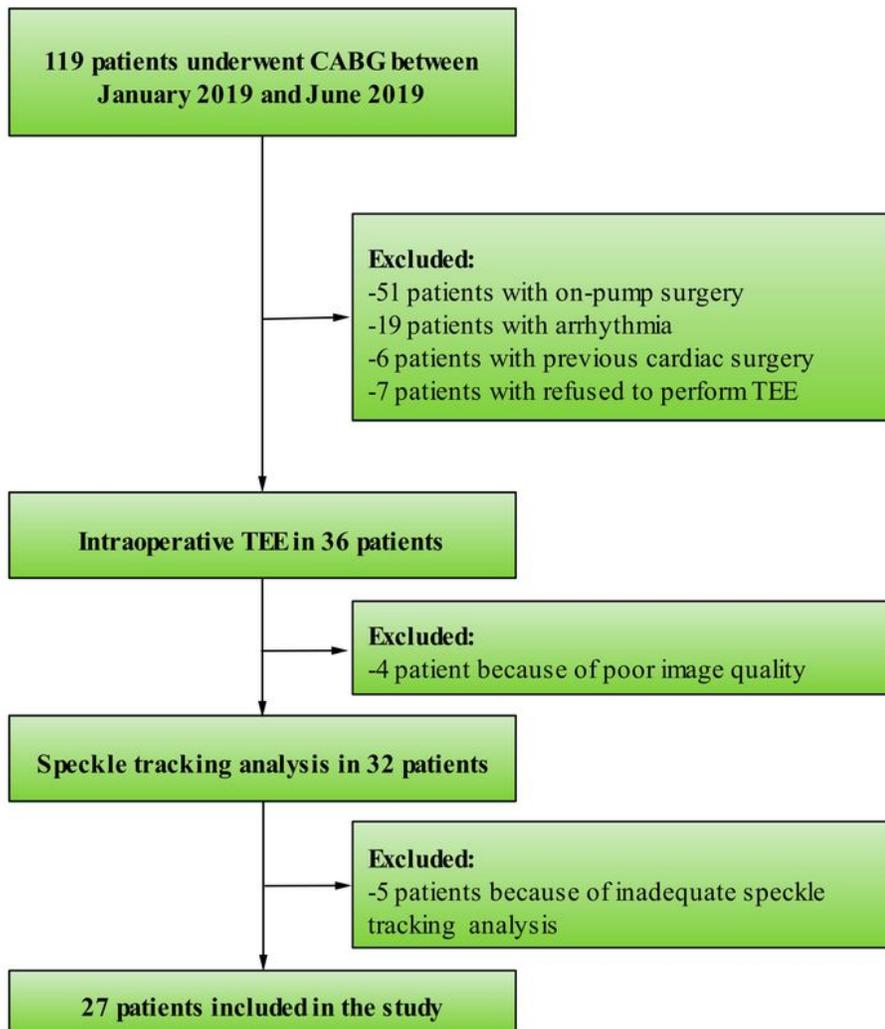
**Figure 1**

Two-dimensional speckle tracking images of LV strain using transesophageal echocardiography. A: Longitudinal strain in ME 4C view. B: Circumferential strain in TGM. C: Radial strain in TGM view.



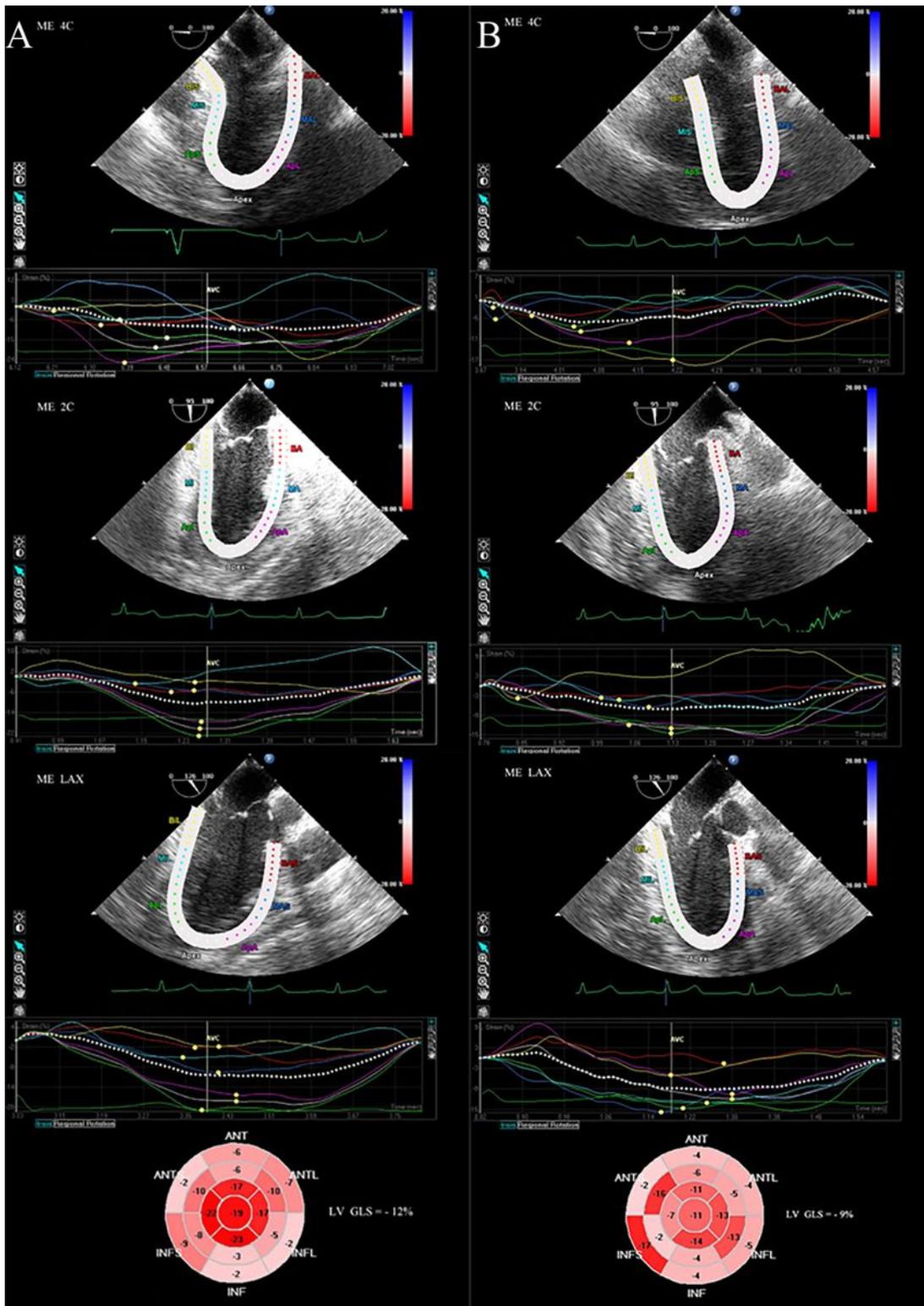
**Figure 2**

Two-dimensional speckle tracking images of LV rotation using transesophageal echocardiography. A: Basal rotation in TGB view. B: Apical rotation in TGA view. LV, left ventricular; TGB, transgastric basal short-axis; TGA, transgastric apical short-axis.



**Figure 3**

Patient flow chart.



**Figure 4**

Longitudinal strain in ME 4C, ME 2C, and ME LAX views with bull's-eye plot before (A) and after (B) pericardial incision. LV global longitudinal strain is significantly decreased immediately after pericardial incision. ME 4C, mid-esophageal 4-chamber; ME 2C, mid-esophageal 2-chamber; ME LAX, mid-esophageal long-axis; LV, left ventricular.