Original article

# Left ventricular mechanics before and after mitral valve replacement in patients with severe mitral regurgitation

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**Objectives**: Our study aimed to study left ventricular (LV) mechanics in patients with severe mitral valve regurgitation (MR) before and after mitral valve replacement (MVR). **Background**: Our study investigated the short-term follow-up of LV deformation mechanics twist and untwist and LV-global longitudinal strain as an LV function parameter affected by MVR in patients presented with severe mitral regurgitation. **Patients and methods**: We assessed LV deformations by Speckle-tracking echocardiography in 30 patients who had preserved LV ejection fraction before, 1 week after, and 3 months after MVR surgery. **Results**: Among the study population, 16 were men and the mean age was 54.9 ± 6.9 years. There was a significant decrease in LV ejection fraction, LV dimensions, and volumes during early follow-up, which recovered at 3-month follow-up. Right ventricular basal dimension, right ventricular systolic pressure, grade of tricuspid regurgitation, and functional capacity were significantly improved. There was significant deterioration of global longitudinal strain in the early postoperative period; however, it was improved 3 months later ($P1 < 0.001$, $P2 < 0.001$, and $P3 < 0.001$). There was a significant decrease regarding twist between preoperative, early, and late postoperative periods ($P1 < 0.001$, $P2 < 0.001$, and $P3 < 0.001$). There was a significant improvement regarding the untwist rate between preoperative and late postoperative periods (−103 ± 15.3 vs. −122.4 ± 15.3, $P2 < 0.001$). **Conclusions**: In patients with severe MR, Speckle tracking is a useful technique for assessing LV deformation mechanics and detect subtle affection before conventional echocardiography

**Keywords:**
echocardiography, heart valve prosthesis, left ventricle, mitral valve, rotation

## 1-Introduction

The mitral valve (MV) apparatus is a dynamic structure that has complex interactions with the surrounding anatomy. Disruption of any component of the apparatus or surrounding anatomy can lead to mitral valve regurgitation (MR) [1]. Untreated severe MR is associated with poor outcomes. Making early recognition, classification of etiology, and appropriate timing of intervention are crucial in patients presenting with severe MR [2].

In the early stages of MR, left ventricular (LV ) wall stress owing to volume overload is countered by increased LV fractional shortening because of a low resistance run-off into the low-pressure left atrium (LA). These compensatory mechanisms allow evolution from the acute to the chronic compensated stage of MR. Patients may remain asymptomatic during this phase for years [3]. However, with long-standing MR, there will eventually be progressive LV enlargement beyond that of a compensated stage, increasing severity of MR, continued compensatory chamber enlargement, or a combination of both. Progressive LV enlargement itself can cause increasing degrees of MR from altered ventricular geometry and annular dilatation, thus the term 'MR begets MR.' Systolic LV wall stress is increased owing to a larger ventricular minor axis as the ventricle assumes a more spherical shape. This outcome leads to an increase in end-diastolic pressure and eventually a decreased contractile state, with reduced myofiber content and interstitial fibrosis and then irreversible LV dysfunction occurs, which leads to the decompensated stage of MR [3].

Speckle-tracking echocardiography (STE) is a developed technique for the characterization and quantification of myocardial deformation. By allowing measurement of the different components of myocardial deformation, it provides information that is not available with any of conventional echocardiographic techniques. Nevertheless, given the enormous interest generated by STE, it is only timely for those involved in the practice of echocardiography to acquaint themselves with this technique [4].

In our study, we aimed to study LV mechanics in patients with severe MR before and 7 days and 3 months after mitral valve replacement (MVR).

## 2-Patients and methods

Among patients who were enrolled for MVR surgery, patients with degenerative MV were included in our study in the period between January 2020 and December 2021. Our exclusion criteria were refusing to participate in the study, having ejection fraction (EF) less than 50%, concomitant coronary artery disease, atrial fibrillation, other significant valve diseases except secondary tricuspid regurgitation (TR), infective endocarditis, and congenital and rheumatic heart diseases. The Ethics and Research Committee of Menoufia University's Faculty of Medicine in Egypt gave its approval to the study.

Echocardiographic was performed 2–3 days before and postoperatively within first weak and at 3-month follow-up. Commercially available (Vivid S6, E9; GE Vingmed, Horten, Norway) echocardiography system equipped with a 3.5-MHz probe was used. Frame rate was set in the range of 50–70 frames per second for two-dimensional image acquisition.

Images were adjusted manually to obtain optimal images. Three cardiac cycles were recorded at the end of expiration, and all data were transferred to a workstation (Echo PAC PC; GE Vingmed Ultrasound AS) for further offline analysis.

Conventional echocardiography included apical window (four-chamber, five-chamber, two-chamber, and three-chamber views) and parasternal window (short-axis and long-axis views); conventional M-mode and biplane Simpson's method to detected

EF at short-axis view; color, CW, and PW Doppler; and quantification of degree of MR mainly through PISA, VC, and EROA methods. STE included apical four-chamber, three-chamber, and two-chamber, parasternal short axis at MV level, papillary muscle level, and also apical view acquired at a frame rate ranging from 70 to 80% of the patient's heart rate (frame/s).

Using offline analysis global longitudinal strain (GLS) (Fig. 1), basal and apical LV rotation, peak twist (Fig. 2), and peak twist and untwist rates (Fig. 3) were automatically generated by the software. Time to peak twist and peak untwist rate was also measured.

All variables in this study represent the mean value of measurements taken in three consecutive cardiac cycles.

The data were analyzed by SPSS (Statistical Package for the Social Sciences), version 20 (SPSS Inc., IBM SPSS statistics for windows, version 20.0; IBM Corp., Armonk, New York, USA).

Two types of statistics were done: descriptive statistics, for example, percentage (%), mean, median, range, and SD, and analytic statistics, for example, $\chi^2$ test, Student $t$ test, analysis of variance ($F$) test, paired $t$ test, and repeated measure analysis of variance test.

Surgical MVR was done under normothermic conditions, median sternotomy was performed, and standard cardiopulmonary bypass was implemented for all patients. MVR using metallic prosthesis with chordae preservation with adjusting size of valve according to annular diameter was done.

## 3-Results

The mean age of study population was 54.9 ± 6.9 years. Of 30 patients in the study, 16 (53.3%) patients were males (Table 1). Our study showed significant decrease in LVEF, LV dimensions, and volumes during early follow-up, which is recovered at 3-month follow-up, whereas the other morphological parameters such as septal thickness and posterior wall thickness were not significantly changed (Table 2).

**Figure 1**

Figure (1) demonstrate the untwist rate in preoperative patient

| Parameters | Total studied patients (*n*=30) |
|---|---|
| Age (year) | 54.9±6.9 |
| Sex [*n* (%)] | |
| Male | 16 (53.3) |
| Female | 14 (46.7) |
| Height (cm) | 170.2±9.4 |
| Weight (kg) | 80.3±11.8 |
| BMI (kg/m$^{2)}$ | 27.6±2.1 |
| BSA (m$^{2)}$ | 1.9±0.19 |
| Valve nature [*n* (%)] | |
| FLAIL anterior mitral valve leaflet7 | (23.3) |
| FLAIL posterior mitral valve leaflet2 | (6.7) |
| FLAIL both anterior and posterior mitral valve leaflet2 | (6.7) |
| Prolapse of anterior mitral valve leaflet8 | (26.7) |
| Prolapse of posterior mitral valve leaflet2 | (6.7) |
| Prolapse of both anterior and posterior mitral valve leaflet9 | (30.0) |
| PISA | 1.1±0.11 |
| EROA | 0.48±0.07 |
| VC | 0.77±0.08 |

Table (1) demographic data of the study

BSA, body surface area; EROA, effective regurgitant orfice area; PISA, proximal isovelocity surface area; VC, vena contracta.

**Figure 2**

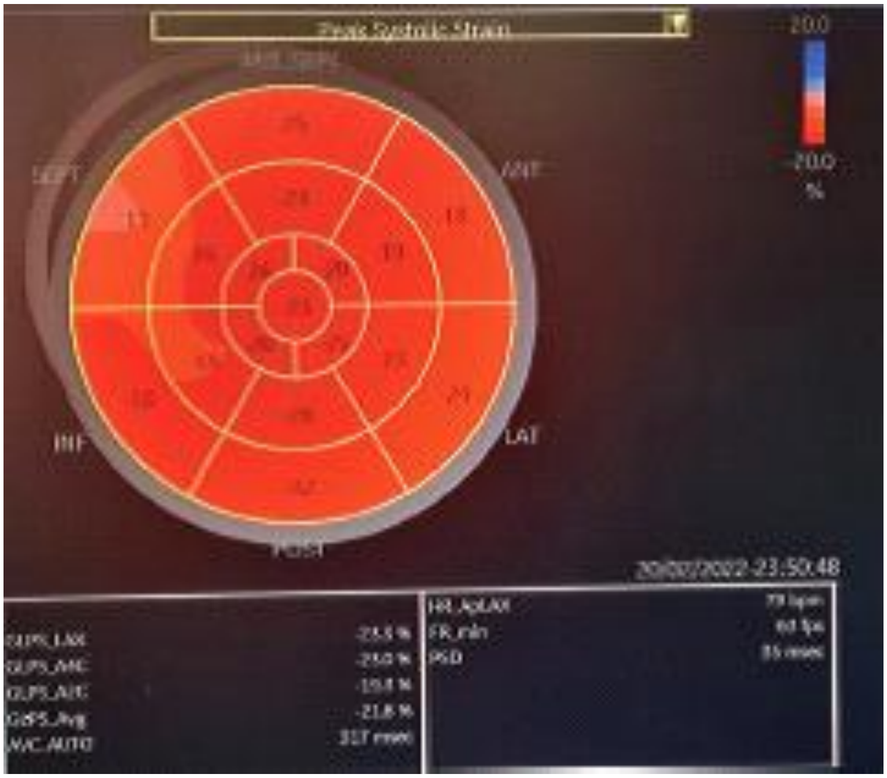

Figure (2) showed GLS of preoperative patient

**Figure 3**

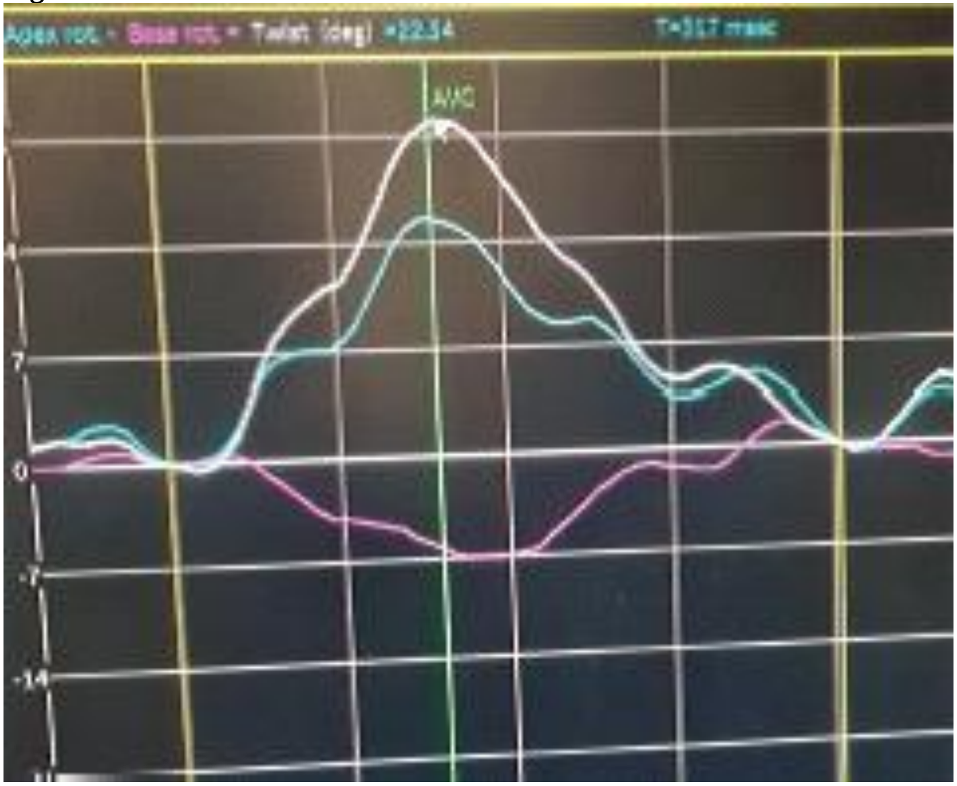

figure (3) showed twist of preoperative patient

Right ventricular basal dimension, right ventricular systolic pressure, grade of TR and functional capacity represented by NYHA class were significantly improved [Table 2].

There was a significant deterioration of GLS in the early postoperative period; however, it was improved 3 months later (P1 < 0.001, P2 < 0.001, and P3 < 0.001) (Table 3).

There was a significant decrease regarding twist between preoperative, early, and late postoperative periods (P1 < 0.001, P2 < 0.001, and P3 < 0.001).

Regarding untwist rate preoperative, early and late postoperative periods, we found that there was a significant increase regarding the untwist rate between preoperative and late postoperative periods (−103 ±15.3 vs. −122.4 ±15.3, P2 < 0.001) [Table 3].

## 4-Discussion

In patients with severe MR, LV is subjected to increased preload owing to chronic regurgitant volume and decreased afterload caused by the low impedance pathway of LV ejection as well as decreased LV function when evaluated with conventional echocardiographic parameters, which may be measured as normal or even increased in the presence of substantial myocardial damage. After surgical treatment of MR, LV afterload increases, and myocardial dysfunction becomes overt [5]. This results in decreased postoperative LVEF measurements. Reduced LVEF is associated with poor prognosis and increased mortality.

**Table 2 Preoperative and late postoperative periods regarding conventional echocardiographic**

| Parameters comparison | Total studied patients (*n*=30) | | | | *P* | Pairwise |
|---|---|---|---|---|---|---|
| | Preoperative period | Early postoperative period | Late postoperative period | Repeated measures ANOVA | | |
| IVS (mm) | 9.5±1.0 | 9.2±0.77 | 9.4±0.93 | 2.73 | 0.11 | *P*1=0.17 *P*2=0.55 *P*3=0.60 |
| PWD (mm) | 9.6±0.81 | 9.4±0.57 | 9.5±0.63 | 2.24 | 0.12 | *P*1=0.33 *P*2=0.31 *P*3=1.00 |
| LVEDD (mm) | 59.9±5.7 | 49.7±3.9 | 47.8±3.1 | 72.44 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3=0.002* |
| LVESD (mm) | 40.1±4.9 | 33.8±2.2 | 32.3±2.7 | 48.01 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3=0.006* |
| EDV (ml) | 151.4±14.1 | 122.6±13.8 | 104.2±15.9 | 164.88 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3<0.001** |
| ESV (ml) | 51.8±8.6 | 43.4±6.5 | 37.9±6.6 | 43.01 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3=0.005* |
| SV (ml) | 90.9±12.8 | 79.3±14.8 | 66.2±11.3 | 34.93 | <0.001** | *P*1=0.005* *P*2<0.001** *P*3<0.001** |
| EF% | 67.1±3.6 | 56.6±2.9 | 62.0±2.6 | 90.79 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3<0.001** |
| MPG (mmHg) prosthesis | | 4.7±1.0 | 4.2±0.47 | | 0.01* | |
| RVSP (mmHg) | 49.9±6.4 | 36.6±3.3 | 29.0±2.5 | 181.45 | <0.001** | *P*1<0.001** *P*2<0.001** *P*3<0.001** |
| TAPSE (mm) | 23.8±2.9 | 17.8±1.6 | 21.3±1.6 | 52.49 | <0.001** | *P*1<0.001** *P*2=0.002* *P*3<0.001** |
| TR [*n* (%)] | | | | | | |
| I | 4 (13.3) | 8 (26.7) | 20 (66.7) | 38.51# | <0.001** | *P*1=0.007* *P*2<0.001** *P*3=0.004* |

| | | | | | | |
|---|---|---|---|---|---|---|
| II | 11 (36.7) | 19 (63.3) | 10 (33.3) | | | |
| III | 11 (36.7) | 3 (10.0) | 0 | | | |
| IV | 4 (13.3) | 0 | 0 | | | |
| RV basal dimension (mm) | 38.9±3.9 | 34.2±1.7 | 33.6±3.0 | 27.66 | <0.001** | P1<0.001** P2<0.001** P3=0.36 |
| NYHA [*n* (%)] | | | | | | |
| I | 0 | 0 | 14 (46.7) | | | P1<0.001** P1<0.001** P1<0.001** |
| II | 0 | 16 (53.3%) | 16 (53.3) | | | |
| III | 0 | 14 (46.7%) | 0 | | | |
| III–IV | 30 (100) | 0 | 0 | | | |

Table (2) demonestrated the conventional echocardiograpy parameters between pre and post opertive. ANOVA, analysis of variance; EDV, end-diastolic volume; EF, ejection fraction; ESV end systolic volume; IVS, interventricular septum; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end systolic dimension; MPG, mean pressure gradient; NYHA, New York heart association; PWD, posterior wall dimension; RV, right ventricle; RVSP, right ventricular systolic pressure; SV, stroke volume; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurgitation. *P*1: preoperative parameter versus early postoperative parameter. *P*2: preoperative parameter versus late postoperative parameter. *P*3: early postoperative parameter versus late postoperative parameter. $^{\#}\chi^2$ test. *Significant difference. **Highly significant difference.

**Table 3 Comparison between the preoperative, early, and late postoperative periods regarding Speckle-tracking imaging parameters**

| Parameters | Total studied patients (*n*=30) | | | Repeated measures ANOVA | *P* | Pairwise comparison |
|---|---|---|---|---|---|---|
| | Preoperative period | Early postoperative period | Late postoperative period | | | |
| Apical rotation (deg.) | 11.3±1.6 | 7.5±1.5 | 10.0±1.5 | 72.25 | <0.001** | P1<0.001** P2=0.002* P3<0.001** |
| Basal rotation (deg.) | −4.4±1.3 | −2.5±0.68 | −3.6±0.62 | 45.56 | <0.001** | P1<0.001** P2=0.002* P3<0.001** |
| GLS AVG% | −22.3±1.9 | −16.2±1.8 | −19.3±0.88 | 140.65 | <0.001** | P1<0.001** P2<0.001** P3<0.001** |
| GLS A2C% | −22.4±2.9 | −16.5±2.4 | −19.8±1.2 | 70.23 | <0.001** | P1<0.001** P2<0.001** P3<0.001** |
| AGLS A4C% | −22.5±2.6 | −16.3±1.5 | −18.9±1.3 | 89.05 | <0.001** | P1<0.001** P2<0.001** P3<0.001** |
| GLSA3C% | −23.1±2.5 | −15.8±2.3 | −19.5±1.3 | 115.29 | <0.001** | P1<0.001** P2<0.001** P3<0.001** |
| TWIST (deg.) | 15.6±2.5 | 9.9±1.9 | 13.5±1.8 | 79.92 | <0.001** | P1<0.001** P2<0.001** P3<0.001** |
| TTP TWIST (ms) | 353.9±42.5 | 394.3±21.0 | 371.1±22.8 | 12.60 | <0.001** | P1<0.001** P2=0.16 P3=0.004* |
| Untwist rate (deg./s) | −103.8±15.3 | −98.2±7.7 | −122.4±15.3 | 31.21 | <0.001** | P1=0.24 P2<0.001** P3<0.001** |
| TTP untwist (ms) | 466.4±25.9 | 449.2±33.7 | 445.3±34.6 | 1.08 | 0.30 | P1=0.17 P2=0.08 P3=1.00 |

Table (3) demonstrate the change in pre and post operative regarding speckle tracking parameters. ANOVA, analysis of variance; GLS A2C, apical two global longitudinal strain; GLS A4C, apical four global longitudinal strain; GLS AVG, average global longitudinal strain average; GLSA3C, apical three global longitudinal strain. *P*1: preoperative parameter versus early postoperative parameter. *P*2: preoperative parameter versus late postoperative parameter. *P*3: Early postoperative parameter versus late postoperative parameter. *Significant difference. **Highly significant difference.

The present study demonstrated normal preoperative LVEF, which significantly decreased in the early postoperative follow-up and then improved at 3 months of follow-up. This finding was consistent with several previous studies. Shafii et al. [6] concluded that postoperative LVEF initially decreased and then increased slightly during the first postoperative year.

Dilip et al. [7] found that there was a better postoperative LVEF in patients with chordal preservation. This might be explained by the effect of low impedance of LA preoperative that might help in preserving the LVEF and the effect of cardioplegia in early postoperative period with relative increase of the afterload owing to MR correction. However, Coutinho et al. [8] argued that it is often not possible to completely preserve the subvalvular apparatus in rheumatic valves and even long-term survival benefits after chordae preservation are not evident.

In addition, there was a significant improvement in the grade of TR postoperatively, which might be explained by the deloading of LV and the postoperative decrease in right ventricular systolic pressure. Tricuspid annular plane systolic excursion was significantly decreased postoperatively. This was in agreement with the study by Gercek et al. [9], which demonstrated significant reduction of tricuspid annular plane systolic excursion. TR improved after MV surgery, which could be explained by the geometric changes of the right ventricular due to pericardial incision and the loss of pericardial support, the reduced mobility of the septum due to the increased LV impairment, the improvement of TR, as well as the incompletely understood cardioplegia effect.

GLS is a relatively new but underrated technique for assessment of global LV function. It can detect LV dysfunction at an early stage, whereas conventional parameters of LV function such as LVEF are still normal. In the present study, Speckle tracking was used to assess GLS as it was affected much earlier than LVEF. There was a significant decrease of GLS in the early postoperative period, which could be explained by stunning, effect of cardioplegia, and correction of the increased preload and low impendence of LA flow preoperative and then significant improvement of LV GLS at 3-month follow-up reverses remodeling due to abolishing effect of increased preload after MVR. This was concordant with Singh et al. [10], which showed that GLS changed significantly early after MVR (−15.57 ±4.98 to −8.97 ±3.66) then improved to −14.44 ±3.67% (change 7.26%) at 3-month follow-up as assessed by echocardiography. Gercek et al. [9] demonstrated deterioration of LV GLS from −9.2 ±4.1 to −15.7 ±3.8% ($P < 0.001$). Cho et al. [11] stated that preoperative GLS values strongly predicted postoperative LV remodeling or LV dysfunction. STE can be used to predict a decrease in LV function after MVR in patients with chronic severe MR.

Kim et al. [12] postulated GLS to better predict cardiac events and all-cause mortality than standard echocardiographic parameters. They concluded that GLS might be helpful to estimate the optimal timing for MV surgery. Pastore and colleagues in a meta-analysis performed on eight studies done on 2358 patients showed that patients with reduced GLS had worse long-term survival after MV surgery (mean difference = 5.06%; confidence interval: −8.97 to 1.16%) and patient who presented postoperatively with LV dysfunction had worse preoperative GLS [13]. Witkowski et al. [14] suggested that cutoff value of −19.9% of GLS showed sensitivity and specificity of 90 and 79%, respectively, to predict long-term LV dysfunction. Candan et al. [5] stated that GLS more than or equal to 18.4% predicted postoperative LVEF more than or equal to 50% with 85% sensitivity and 83% specificity.

The effect of volume overload on LV and GLS was assessed in the study done by Choi et al. [15]. They investigated the effect of preload prehemodialysis and posthemodialysis and demonstrated a significant decrease of GLS after 6-month follow-up, which signify the effect of volume overload on GLS and may help to establish GLS as an independent parameter for MVR in MR. Another study done by Alashi et al. [16] showed decreased GLS in patients with severe aortic regurgitation from −19.3 to −16.5, which can be explained by improving of volume overload postoperatively.

In the present study, by comparing peak twist to peak twist preoperatively as well as early and late postoperative, there was a significant deterioration of early twist parameter which improved in follow-up after 3 months. This was in agreement with Kazui et al. [17], who concluded that LV twist was significantly greater in the preoperative group than in other groups (11.7 ± 4.1 vs. 7.1 ± 3.8 and 8.2 ± 5.7; $P < 0.05$) and was normalized after surgery. Candan et al. [18] demonstrated a significant decrease in twist of LV after MV replacement (17.1 ± 5.7° vs. 10.1 ± 8.7°; $P < 0.001$), which could be explained be the preoperative increased preload and low impendence of LA flow. Candan et al. [5] studied the relation between twist and postoperative EF. They concluded that postoperative LVEF significantly correlated with preoperative twist ($r = 0.42$; $P = 0.001$). The study by Verseckaite et al. [19] suggested that in the moderate and severe aortic regurgitation, apical systolic rotation increases with a preserved or higher LV twist and torsion, as the LV twist is greater with higher preload.

There was a significant decrease regarding untwist ratio in the early postoperative period, which might be explained by the affection of diastolic function as well as effect of cardioplegia, relative increased of afterload after replacement of MV, and loss of low impedance LA pathway, which improved after 3 months, explained by reverse remodeling and improvement of both systolic and diastolic functions of the heart after correction of loading conditions. Zito et al. [20] reported that delayed untwisting in MR patients can be explained, as the LV volume continued to decrease beyond AVC in MR patients owing to ongoing flow to LA. There was no significant difference regarding time to peak untwist pre versus early versus late, which can be explained by high resistance developed after correction of MR and relatively low pressure flow through LA which may prolong untwist after correction of volume overload preoperatively. Candan et al. [18] showed that untwist decreased significantly in the replacement group (−120.4 ±47.8 vs. −79.2 ±39.5; $P = 0.002$), which is discordant with our study, which may be explained by that new surgical maneuver and experience developed to preserve geometry and papillary preservation help to maintain both systolic and diastolic functions to be normalized postoperatively.

## 5-Conclusion

Speckle tracking is a useful technique for assessing LV deformation mechanics and detect subtle affection before conventional echocardiography. GLS and twist are increased preoperatively owing to MR and then normalized at 3-month follow-up. We will follow up our patients and update our results.

## 6-Study limitation

The study was done on a small number of patients, with mainly two-dimensional echocardiography being used, which excluded some patients in the early postoperative period owing to poor window. Three-dimensional echocardiography can help solve this problem in future studies with a larger sample size.

## 7-Financial support and sponsorship

Nil.

## 8-Conflicts of interest

There are no conflicts of interest.

## 9-References

1. El Sabbagh A, Reddy YNV, Nishimura RA. Mitral valve regurgitation in the contemporary era: insights into diagnosis, management, and future directions. JACC Cardiovasc Imaging 2018; 11:628–643.
2. Andell P, Li X, Martinsson A, Andersson C, Stagmo M, Zoller B, et al. Epidemiology of valvular heart disease in a Swedish nationwide hospital-based register study. Heart 2017; 103:1696–1703.
3. Ahmed MI, Gladden JD, Litovsky SH, Lloyd SG, Gupta H, Inusah S, et al. Increased oxidative stress and cardiomyocyte myofibrillar degeneration in patients with chronic isolated mitral

regurgitation and ejection fraction >60%. J Am Coll Cardiol 2010; 55:671–679.
4. Bansal M, Kasliwal RR. How do I do it? Speckle-tracking echocardiography. Indian Heart J 2013; 65:117–123.
5. Candan O, Hatipoglu Akpinar S, Dogan C, Demirkiran A, Dindar B, Bayram Z, et al. Twist deformation for predicting postoperative left ventricular function in patients with mitral regurgitation: a speckle tracking echocardiography study. Echocardiography 2017; 34:422–428.
6. Shafii AE, Gillinov AM, Mihaljevic T, Stewart W, Batizy LH, Blackstone EH. Changes in left ventricular morphology and function after mitral valve surgery. Am J Cardiol 2012; 110:403–408.
7. Dilip D, Chandra A, Rajashekhar D, Padmanabhan M. Early beneficial effect of preservation of papillo-annular continuity in mitral valve replacement on left ventricular function. J Heart Valve Dis 2001; 10:294–300. discussion 300-291.
8. Coutinho GF, Bihun V, Correia PE, Antunes PE, Antunes MJ. Preservation of the subvalvular apparatus during mitral valve replacement of rheumatic valves does not affect long-term survival. Eur J Cardiothorac Surg 2015; 48:861–867. discussion 867.
9. Gercek M, Faber L, Rudolph V, Fox H, Puehler T, Omran H, et al. Myocardial adaptation as assessed by speckle tracking echocardiography after isolated mitral valve surgery for primary mitral regurgitation. Int J Cardiovasc Imaging 2021; 37:913–920.
10. Singh V, Kumar S, Bhandari M, Devenraj V, Singh SK. Global longitudinal strain: is it a superior assessment method for left ventricular function in patients with chronic mitral regurgitation undergoing mitral valve replacement?. Indian J Thorac Cardiovasc Surg 2020; 36:119–126.
11. Cho EJ, Park SJ, Yun HR, Jeong DS, Lee SC, Park SW, et al. Predicting left ventricular dysfunction after surgery in patients with chronic mitral regurgitation: assessment of myocardial deformation by 2-dimensional multilayer speckle tracking echocardiography. Korean Circ J 2016; 46:213–221.
12. Kim HM, Cho GY, Hwang IC, Choi HM, Park JB, Yoon YE, et al. Myocardial strain in prediction of outcomes after surgery for severe mitral regurgitation. JACC Cardiovasc Imaging 2018; 11:1235–1244.
13. Pastore MC, Mandoli GE, Dokollari A, Bisleri G, D’Ascenzi F, Santoro C, et al. Speckle tracking echocardiography in primary mitral regurgitation: should we reconsider the time for intervention?. Heart Fail Rev 2022; 27:1247–1260.
14. Witkowski TG, Thomas JD, Debonnaire PJ, Delgado V, Hoke U, Ewe SH, et al. Global longitudinal strain predicts left ventricular dysfunction after mitral valve repair. Eur Heart J Cardiovasc Imaging 2013; 14:69–76.
15. Choi JO, Shin DH, Cho SW, Song YB, Kim JH, Kim YG, et al. Effect of preload on left ventricular longitudinal strain by 2D speckle tracking. Echocardiography 2008; 25:873–879.
16. Alashi A, Khullar T, Mentias A, Marc Gillinov A, Roselli EE, Svensson LG, et al. Long-term outcomes after aortic valve surgery in patients with asymptomatic chronic aortic regurgitation and preserved LVEF: impact of baseline and follow-up global longitudinal strain. JACC Cardiovasc Imaging 2020; 13(Part 1):12–21.
17. Kazui T, Niinuma H, Tsuboi J, Okabayashi H. Changes in left ventricular twist after mitral valve repair. J Thorac Cardiovasc Surg 2011; 141:716–724.
18. Candan O, Ozdemir N, Aung SM, Bakal RB, Gecmen C, Akpinar SH, et al. Effect of mitral valve repair versus replacement on left ventricular rotational deformation: a study with speckle tracking echocardiography. J Heart Valve Dis 2013; 22:651–659.
19. Verseckaite R, Mizariene V, Montvilaite A, Auguste I, Bieseviciene M, Laukaitiene J, et al. The predictive value of left ventricular myocardium mechanics evaluation in asymptomatic patients with aortic regurgitation and preserved left ventricular ejection fraction. A long-term speckle-tracking echocardiographic study. Echocardiography 2018; 35:1277–1288.
20. Zito C, Carerj S, Todaro MC, Cusma-Piccione M, Caprino A, Di Bella G, et al. Myocardial deformation and rotational profiles in mitral valve prolapse. Am J Cardiol 2013; 112:984–990.