



Original Article

Left and right ventricular deformation in patients with severe mitral stenosis and pulmonary hypertension undergoing percutaneous balloon mitral valvuloplasty: A two dimensional speckle-tracking echocardiographic study

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ABSTRACT

Seventy-five patients with isolated severe MS (mitral valve area: $1.10 \pm 0.15 \text{ cm}^2$) and pulmonary hypertension underwent regional and global longitudinal strain (GLS) measurements of left (LV) and right ventricle (RV) at baseline and within 48 h after percutaneous balloon mitral valvuloplasty (PBMV). PBMV resulted in significant improvement in LV GLS ($-16.35 \pm 1.67\%$ vs $-19.98 \pm 2.17\%$) and RV GLS ($-10.34 \pm 2.38\%$ vs $-13.83 \pm 2.04\%$), $p < 0.001$ for both. Absolute increase in strain of basal segments of LV was more compared to mid and apical segments. We also found significant positive correlation between decrease in mean LA pressure (pre PBMV $28.91 \pm 4.21 \text{ mm Hg}$ vs post PBMV $10.55 \pm 3.04 \text{ mm Hg}$, difference of 16.36 mm Hg ; $p < 0.001$) obtained invasively during PBMV for 62 patients with improvement in LV GLS ($r = 0.257$, $p = 0.048$), RV GLS ($r = 0.267$, $p = 0.043$), and fall in right ventricular systolic pressure ($r = 0.308$, $p = 0.022$) that occurred post PBMV. The LV dysfunction is predominantly because of altered hemodynamics due to restricted LV filling with additional contribution from rheumatic involvement of basal LV myocardial segments. The improvement in LV deformation after PBMV is likely due to increase in preload. RV afterload reduction because of LA pressure decrease improved RV deformation.

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1. Introduction

Mitral stenosis (MS) is the most common valve lesion in rheumatic heart disease (RHD). In long-standing MS, pulmonary hypertension (PH) develops in many patients leading to right heart failure.¹ Although in isolated MS, the left ventricle (LV) is under-filled with no hemodynamic load on LV, few studies have reported that LV systolic dysfunction may not be so uncommon in patients with MS.^{2,3} Right ventricular (RV) systolic dysfunction is common in RHD and correlates with severity of pulmonary hypertension.^{1,4,5} We aimed to assess global and regional biventricular function using two-dimensional speckle tracking echocardiography⁶ in patients with isolated severe MS with

pulmonary hypertension before and after percutaneous balloon mitral valvuloplasty (PBMV).

2. Methods

This was a prospective study of 75 consecutive patients (≥ 18 years) with isolated severe MS and PH in sinus rhythm undergoing PBMV. Patients with multi-valvular disease or other valve involvement and co-morbidities like hypertension, diabetes mellitus, coronary artery disease and overt left and right ventricle systolic dysfunction were excluded. Standard echocardiography examination was done before and after PBMV (within 48 h) in all the patients. The PBMV was done by standard technique using Inoue balloon or Accura balloon. The heart rate, aortic pressure and left atrial pressure were recorded before and after PBMV. The severity of PH was graded by Doppler echocardiography based on peak right ventricular systolic pressure (RVSP) as mild 36–45 mm Hg, moderate 46–60 mm Hg and severe if $> 60 \text{ mm Hg}$.¹ Ethics

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committee approved the study and written informed consent was taken from each participant.

Two-dimensional echocardiographic images were obtained from apical two-chamber (A2C), three-chamber (A3C) and four-chamber (A4C) views for LV and modified apical view for RV, during breath hold and stored in cine-loop format for three consecutive beats (Philips EPIQ 7C). LV myocardium was divided into six walls (anterior, anteroseptal, anterolateral, inferior, inferoseptal, inferolateral) and RV myocardium was divided into two walls (septum and free wall). All walls were then subdivided into three segments (apical, mid and basal). The peak systolic strain was calculated for each segment individually and then LV and RV global longitudinal strain (GLS) was generated automatically by the software. The speckle tracking echocardiography analysis was done offline. The longitudinal strain values were measured by a single investigator for all study subjects. The intraobserver variability in measuring LV and RV longitudinal strain was calculated for 14 randomly selected study subjects. An excellent correlation was seen for blinded measurements from the same tracings on two different occasions ($r = 0.95$; $p < 0.0001$).

Statistical analysis was done with SPSS 26.0 software. Continuous variables were presented as mean and standard deviation and were compared using the paired *t* test. Correlation was assessed by Pearson's correlation analysis. Statistical significance was set at a probability level < 0.05 .

3. Results

The mean age of patients was 31.1 ± 4.5 years with male to female ratio of 1:4. The mean MVA at baseline of $1.10 \pm 0.15 \text{ cm}^2$ increased to $1.56 \pm 0.15 \text{ cm}^2$ ($p < 0.001$) and mean transmitral diastolic gradient at baseline of $14.89 \pm 2.23 \text{ mm Hg}$ decreased to $8.79 \pm 1.84 \text{ mm Hg}$ post-PBMV ($p < 0.001$). The left ventricular ejection fraction (LVEF) was $60.44\% \pm 5.69\%$ at baseline and $60.88\% \pm 5.86\%$ after BMV ($p = 0.122$). Fifty-eight patients had moderate to severe PH, 15 patients had mild PH and 2 patients did not have PH at baseline. Baseline mean RVSP of $57.31 \pm 12.63 \text{ mm Hg}$ decreased significantly to $32.37 \pm 7.96 \text{ mm Hg}$ post-PBMV ($p < 0.001$).

The longitudinal strain in basal segments of LV was lower when compared to strain in mid and apical segments at baseline. LV

segmental strain and GLS in A3C, A4C, A2C view increased significantly post-PBMV (Fig. 1), but in absolute terms the increase in longitudinal strain was maximum in basal segments and least in the apical segments (Table 1). The improvement in LV GLS significantly correlated with increase in MVA ($r = 0.55$, $p = 0.019$), decrease in MG ($r = 0.53$, $p = 0.027$) and decrease in RVSP ($r = 0.573$, $p = 0.013$) post-PBMV.

The mean longitudinal strain of RV septum and RV GLS increased significantly post-PBMV but improvement in strain of RV free wall segments did not achieve statistical significance (Table 2). There was significant correlation between increase in RV GLS with decrease in RVSP ($r = 0.67$, $p = 0.001$) and decrease in mitral valve MG ($r = 0.69$, $p = 0.001$).

During PBMV heart rate, mean aortic pressure and mean left atrial pressure were recorded. There was a significant positive correlation between invasive mean LA pressure obtained prior to PBMV with LV GLS and RV GLS as shown in Table 3. The invasive hemodynamic data of 62 patients showed that the pre PBMV and post PBMV heart rate was 90.36 ± 9.25 beats per minute vs 89.62 ± 9.08 beats per minute ($p = 0.67$), mean aortic pressure was $90.62 \pm 6.04 \text{ mm Hg}$ vs 92.51 ± 5.45 ($p < 0.001$) and mean left atrial pressure was 28.91 ± 4.21 vs $10.55 \pm 3.04 \text{ mm Hg}$ ($p < 0.001$) respectively. We found significant positive correlation between decrease in mean LA pressure (obtained invasively) with improvement in LV GLS ($r = 0.257$, $p = 0.048$), RV GLS ($r = 0.267$, $p = 0.043$), and fall in RSVP ($r = 0.308$, $p = 0.022$) that occurred post PBMV (Table 4).

4. Discussion

We have previously shown that functional capacity significantly correlates with biventricular function after mitral valve replacement in RHD.⁴ Hence biventricular function assessment has important role in determining the prognosis beyond that of improvement in mitral valve area.⁴ LVEF is an insensitive marker for detecting subtle changes in LV systolic function, thus explaining the preserved LVEF in our study population at baseline with non-significant change post-PBMV. Our study showed reduced LV GLS in MS patients despite normal LVEF. Ozdemir et al⁷ and Bilen et al⁸ also reported similar findings. However, no correlation was found

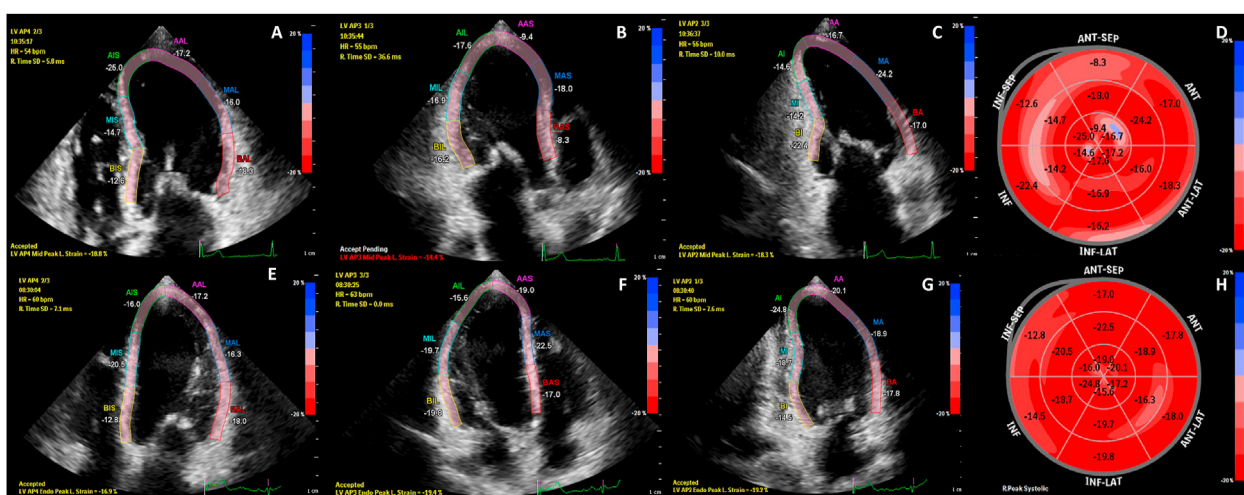


Fig. 1. Analysis of left ventricle two-dimensional (2D) echocardiographic longitudinal speckle strain in a mitral stenosis patient: A and E– 2D strain of anterolateral and inferoseptal wall of left ventricle in apical four chamber view pre and post PBMV respectively; B and F– 2D strain of anteroseptal and inferolateral wall of left ventricle in apical three chamber view pre and post PBMV respectively; C and G– 2D strain of anterior and inferior wall of left ventricle in the apical two-chamber view pre and post PBMV respectively; D and H– 2D strain analysis presented by bull's eye analysis for the whole left ventricle pre and post PBMV respectively.

Table 1
Comparison of longitudinal strain of left ventricular segments pre and post PBMV.

Left ventricular segments	Mean value pre PBMV (%)	Mean value post PBMV (%)	Mean difference	p-value
Apical three chamber view				
AAS	-18.39 ± 2.91	-19.74 ± 2.89	1.35	<0.001 ^a
MAS	-18.13 ± 2.82	-21.82 ± 3.17	3.69	<0.001 ^a
BAS	-14.18 ± 1.89	-18.09 ± 2.15	3.91	<0.001 ^a
AIL	-16.99 ± 2.34	-18.47 ± 2.60	1.48	<0.001 ^a
MIL	-17.56 ± 1.93	-21.18 ± 2.29	3.62	<0.001 ^a
BIL	-14.02 ± 4.08	-17.68 ± 4.05	3.66	<0.001 ^a
A3C	-16.41 ± 1.22	-20.75 ± 1.78	4.34	<0.001 ^a
Apical four chamber view				
AAL	-16.85 ± 2.71	-18.54 ± 1.69	1.69	<0.001 ^a
MAL	-15.96 ± 1.81	-19.35 ± 3.39	3.39	<0.001 ^a
BAL	-14.37 ± 4.28	-18.01 ± 3.64	3.64	<0.001 ^a
AIS	-19.38 ± 2.54	-21.15 ± 1.77	1.77	<0.001 ^a
MIS	-18.08 ± 1.75	-20.73 ± 2.65	2.65	<0.001 ^a
BIS	-11.57 ± 3.26	-14.28 ± 2.71	2.71	<0.001 ^a
A4C	-16.69 ± 1.71	-23.57 ± 6.88	6.88	0.005 ^a
Apical two chamber view				
AA	-16.98 ± 3.18	-18.63 ± 1.64	1.64	<0.001 ^a
MA	-15.12 ± 1.50	-18.83 ± 3.71	3.71	<0.001 ^a
BA	-12.93 ± 5.01	-18.07 ± 5.14	5.14	<0.001 ^a
AI	-21.41 ± 2.10	-23.63 ± 2.23	2.23	<0.001 ^a
MI	-21.68 ± 1.93	-25.05 ± 3.37	3.37	<0.001 ^a
BI	-15.07 ± 6.73	-20.49 ± 5.42	5.42	<0.001 ^a
A2C	-16.37 ± 1.22	-20.11 ± 3.74	3.74	<0.001 ^a
Left ventricle global longitudinal strain				
LV GLS	-16.35 ± 1.67	-19.98 ± 2.17	3.63	<0.001 ^a

Abbreviations: AA-apical anterior, AAL-apical anterolateral, AAS- apical anteroseptal, AI- apical inferior, AIL-apical inferolateral, AIS- apical inferoseptal, A2C- apical two chamber, A3C- apical three chamber, A4C- apical four chamber, BA-basal anterior, BAL-basal anterolateral, BAS- basal anteroseptal, BI- basal inferior, BIL-basal inferolateral, BIS- basal inferoseptal, MA-mid anterior, MAL-mid anterolateral, MAS- mid anteroseptal, MI- mid inferior, MIL-mid inferolateral, MIS- mid inferoseptal.

^a Significant difference.

Table 2
Comparison of longitudinal strain of right ventricular segments pre and post PBMV.

Right ventricular segments	Mean value pre PBMV (%)	Mean value post PBMV (%)	Mean difference	p-value
Right ventricular septal wall				
RV apical septum	-12.39 ± 2.52	-15.32 ± 2.34	2.93	<0.001 ^a
RV mid septum	-9.63 ± 2.46	-13.05 ± 2.52	3.42	<0.001 ^a
RV basal septum	-11.05 ± 2.54	-14.52 ± 2.54	3.46	<0.001 ^a
Right ventricular free wall				
RV apical free wall	-13.43 ± 4.38	-14.37 ± 5.90	0.94	0.082
RV mid free wall	-17.10 ± 4.64	-18.32 ± 4.62	1.22	0.102
RV basal free wall	-17.04 ± 5.15	-17.89 ± 6.87	0.85	0.224
Right ventricular global longitudinal strain				
RV GLS	-10.34 ± 2.38	-13.83 ± 2.04	3.49	<0.001 ^a

^a Significant difference.

between the MS severity and LV strain measurements in their studies in contrast to our study.

In our study, regional and global longitudinal strain of LV improved significantly post-PBMV suggesting that LV dysfunction is due to chronically reduced LV filling resulting in adverse LV remodeling which improves when LV inflow obstruction is relieved. The longitudinal strain at baseline in basal segments of LV

was much lower compared to the mid and apical segments. Although two-dimensional speckle strain increased significantly in all LV segments post-PBMV, in absolute terms the increase was maximum in basal segments and least in apical segments. This

Table 3
Correlation of invasive mean left atrial pressure with LV and RV global longitudinal strain (GLS) before PBMV.

Echocardiography derived parameters before PBMV (n = 62)	Invasive mean LA pressure before PBMV (n = 62)
LV GLS	Pearson correlation 0.702
	p-value 0.001 ^a
RV GLS	Pearson correlation 0.344
	p-value 0.010 ^a

^a Significant difference.

Table 4
Correlation of difference in mean left atrial pressure obtained invasively during PBMV with difference in various echocardiography derived parameters pre and post PBMV.

Difference in echocardiography derived parameters pre and post PBMV (n = 62)	Difference in invasive mean LA pressure pre and post PBMV (n = 62)
Difference in LV global longitudinal strain	Pearson correlation 0.257
	p value 0.048 ^a
Difference in RV global longitudinal strain	Pearson correlation 0.267
	p value 0.043 ^a
Difference in right ventricular systolic pressure	Pearson correlation 0.308
	p value 0.022 ^a

^a Significant difference.

Table 5
Comparison of our study with other similar studies in literature.

Variable	Roushdy et al ⁹	Sengupta et al ¹⁰	Mehta et al ¹²	Our study
Time period	2013–2014	2013–2014	2014–2015	2018–2019
Place of study	Egypt	Nagpur (India)	Rajasthan (India)	Delhi (India)
Type of study	Prospective	Prospective	Prospective	Prospective
Sample size	32	57	60	75
Mean age (years)	32.41 ± 11.23	28.14 ± 6.44	28.77 ± 11.02	31.1 ± 4.5
Male: Female	1: 1.6	1: 2.5	1:4	1: 4
Strain parameters studied	GLS	GLS, GCS, GRS	GLS	GLS
Significant improvement after PBMV	GLS	GLS, GCS	GLS	GLS
Correlation of baseline LV GLS with invasive left atrial pressure	Not obtained	Not obtained	Not obtained	Positive
Correlation of LV GLS/ Δ LV GLS with various parameters on echo	LV GLS positively correlated with mean mitral valve gradient, RVSP	LV GLS correlated with LA volume, mean mitral valve gradient, LVEDV Δ LV GLS with only Δ LVEDV	Not studied	Δ LV GLS correlated with Δ MVA, Δ mean mitral valve gradient, Δ RVSP
Correlation of RV GLS/ Δ RV GLS with various parameters on echo	RV GLS positively correlated with mean mitral valve gradient, RVSP	Not studied	Not studied	Δ RV GLS correlated with Δ mean mitral valve gradient, Δ RVSP

Abbreviations: GCS- global circumferential strain, GLS- global longitudinal strain, GRS- global radial strain, MVA-mitral valve area, Δ MVA-change in mitral valve area, LVEDV-left ventricle end diastolic volume, RVSP- right ventricle systolic pressure, Δ RV GLS- change in right ventricular global longitudinal strain.

suggests underlying myocardial involvement where rheumatic endocarditis and scarring extend from the mitral annulus to the surrounding basal LV segments; an effect that fades away as we go towards the apical segments. This myocardial involvement likely contributes to impaired GLS in addition to preload reduction in patients with MS.

Roushdy et al showed lower LV GLS values in MS patients with LV basal and mid-segmental strain values which increased significantly after PBMV whereas apical segments strain improved only in some LV segments.⁹ Sengupta et al reported significant improvement in LV GLS post-PBMV.¹⁰ However 14% patients in their study had atrial fibrillation (AF) but we excluded patients with AF as AF itself can result in decrease in GLS measurements.^{10,11} We also found that improvement in LV GLS significantly correlated with increase in MVA, decrease in MG across mitral valve and decrease in RVSP after PBMV. This correlation further strengthens the role of altered hemodynamics (due to LV inflow obstruction) in MS. However, because the MVA is not normal after PBMV and due to myocardial involvement, the GLS values do not normalize completely.

Our study showed impaired RV function in severe MS as seen by reduced segmental and global RV strain values at baseline with a significant improvement in global longitudinal strain of RV after PBMV. Others^{9,12,13} have also reported global RV strain and segmental RV septal strain increased significantly post-PBMV whereas no significant difference was observed in RV free wall strain. We found that the improvement in RV GLS strongly correlated with decrease in RVSP which could be explained due to decrease in the RV afterload as a result of relief of LV inflow obstruction post-PBMV. The significant increase in RV septal wall strain suggests myocardial involvement, whereby rheumatic endocarditis and scarring extend from mitral annulus to surrounding LV segments and thus reflecting changes actually occurring in LV septum and affecting the RV side.

The studies evaluating speckle tracking echocardiography in mitral stenosis are listed in Table 5. Importantly, none of the previous studies have correlated invasively recorded left atrial pressure with LV and RV speckle derived longitudinal strain. We found a significant positive correlation between invasive mean LA pressure obtained prior to PBMV with LV GLS and RV GLS suggesting the predominant role of underfilling of the left ventricle in LV dysfunction. This is further proven by our finding of significant correlation between decrease in left atrial pressure and improvement in LV GLS after PBMV.

4.1. Limitations of our study

The major limitation of our study is that we included only isolated severe mitral stenosis patients and hence our results are not applicable to patients with multi-valvular disease or other valve disease. We selected only mitral stenosis patients because regurgitant valve lesions can result in ventricular dysfunction because of chronic volume overload. In mitral stenosis the left ventricle is underfilled and hence subclinical left ventricular dysfunction was postulated at least in part to be because of rheumatic disease process, the assessment of which was the aim of this study. The other limitation is that we excluded patients with atrial fibrillation (AF) as it interferes with speckle tracking strain assessment. If we had included AF patients also, our readings might not have been accurate. Since the aim of our study was to find the factors responsible for left and right ventricular dysfunction and determine the extent of improvement post PBMV, we only included patients in sinus rhythm so as to generate accurate and reproducible data. Further we included only 75 patients in our study and hence a larger study is needed to corroborate our findings.

5. Conclusions

In this small study PBMV resulted in marked improvement in LV GLS and RV GLS with more absolute increase in strain of LV basal segments when compared to mid and apical segments. The LV and RV dysfunction is because of altered hemodynamics due to restricted LV filling and involvement of subvalvular apparatus as well as rheumatic involvement of basal LV myocardial segments. Future studies with larger sample size are required to confirm our findings.

Declaration of competing interest

None of the authors have any conflict of interest.

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