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Original Research Article

Assessment of Left Atrial Function by Tissue Doppler Strain Imaging in Mitral Stenosis before and after Balloon Mitral Valvotomy

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Abstract:

Aim: The aim of the present study was to assess the LA function with tissue doppler velocities, strain imaging and variation of left atrial lateral wall, interatrial septum and global longitudinal la stain in severe mitral stenosis.

Methods: A prospective case study performed over 18 months in the Department of Cardiology, Patients were recruited from outpatient department and those admitted with severe Mitral Stenosis. Twenty five patients with severe Mitral Stenosis in sinus rhythm and 25 ages matched Controls were enrolled in the study.

Results: Left ventricular systolic and diastolic dimensions and Left Ventricular Ejection Fraction were comparable in both the groups and there was no significant difference seen in M mode parameter of LV in both groups. LA ejection fraction as calculated by modified Simpson's method was lower in Mitral Stenosis patients when compared to controls. Tissue Doppler Imaging parameter of Left Atrial function like E' and A' Diastolic velocities showed significant lower value in Mitral Stenosis when compared to controls. Severe Mitral stenosis showed a lower ventricular end Systolic Strain as measured at Atrial Septum and Left Atrial Lateral Wall Global LA Strain. Post BMV LA volumes (maximum and minimum) and M mode LA dimensions reduced significantly as compared to pre BMV. All patients of Mitral Stenosis included in the study underwent successful BMV with post BMV 2D mean Mitral Valve area of 1.94 ± 0.25 cm2 by palnimetry which was more than 50% of initial MVA. Post BMV Tissue Doppler velocity remained unchanged as measured at interatrial septum however E' velocity at lateral wall improved significantly. A significant inverse correlation was found between Left atrial Systolic Strain as measured at atrial septum ($p<0.001$) and left atrial maximum volume.

Conclusion: Left Atrial function as assessed by Tissue Doppler velocities and Tissue Doppler derived Strain is lower in patients with severe Mitral Stenosis. Left atrial reservoir function assessed by Strain imaging improves within 24 hours after Balloon Mitral Volvotomy.

Keywords: Tissue Doppler Velocities, Strain Imaging, Variation Of Left Atrial Lateral Wall, Interatrial Septum, Severe Mitral Stenosis.

Introduction

Mitral stenosis (MS) is characterized by narrowing of the mitral valve orifice. It is the most commonly involved valve in rheumatic heart disease which usually presents with exertional dyspnea, palpitations and in late stages chronic heart failure. Dilation of left atrium leads to disorganization of the atrial muscle fibres and fibrosis of the left atrium (LA).[1,2] Left Atrium acts as a conduit in diastole, when the Mitral leaflets open and allow blood to enter the left ventricle. At the end-diastole, the left atrium contracts, and the pump function occurs.[3]

Rheumatic mitral stenosis (MS) causes left atrial (LA) geometrical changes, due to an increase in LA pressure and volume, and consequently deterioration of its systolic function. Due to inflow obstruction, the atrial booster pump contributes less to LV filling in mitral stenosis even during sinus rhythm, despite a proportional increase, with increasing severity, in the LA preload. These novel technologies have been validated for the assessment of both global and regional LV function and have recently been applied to the evaluation of regional LA function. From an electromechanical perspective, echocardiographic parameters that assess LA mechanical function may provide a greater understanding of atrial performance and its relationship with ventricular function.[4,5] Strain parameters are relatively independent of tethering effects and is less load dependent compared to traditional parameters of LA function. Additionally, strain and strain rate parameters permit evaluation of phasic atrial function throughout the cardiac cycle. [6] Many methods have been used previously to assess atrial function, both invasive and non-invasive.

Treatment for mitral stenosis involves medical therapy, percutaneous mitral valvuloplasty and surgical therapy. [7,8] Development of Tissue Doppler imaging has enabled to accurately evaluate myocardial properties in a load independent and reproducible manner. Tissue Doppler derived Strain Rate and Strain imaging has the advantage of being not affected by translational movements thus reflects actually the myocardial deformation. [9] Its Initial use has been for quantifying regional myocardial deformation in ventricles. [10,11] It has also been used to evaluate Left Atrial function in conditions like Hypertension, [12] Diabetes, [13] and post Cardiac Resynchronization Therapy. [14] Assessment of left atrial function in severe Mitral Stenosis using Strain and Strain Rate imaging has not been done earlier.

The aim of the present study was to assess the LA function with tissue doppler velocities, strain imaging and variation of left atrial lateral wall, interatrial septum and global longitudinal la stain in severe mitral stenosis.

Materials and Methods

A prospective case study performed over 18 months in the Department of Cardiology, Ruban Memorial Hospital, Patna, Bihar, India. Patients were recruited from outpatient department and those admitted with severe Mitral Stenosis. Twenty five patients with severe Mitral Stenosis in sinus rhythm and 25 ages matched Controls were enrolled in the study.

Inclusion Criteria

Control Group: Patients with no cardiovascular risks factors, no any cardiac disease and not on any cardiac medications.

Mitral Stenosis Group: Patients with isolated severe Mitral Stenosis (with no other significant valvular lesions) in sinus rhythm, planned for Balloon Mitral Valvotomy.

Exclusion Criteria

1. Patients of Mitral Stenosis not suitable for Balloon Mitral Valvotomy.
2. Patients with Atrial Fibrillation.
3. Patients with more than mild Aortic or Mitral regurgitation (pre or post Balloon Mitral Valvotomy).
4. Patients undergoing Balloon Mitral Valvotomy as an emergency procedure.
5. Patients who had undergone Closed Mitral Valvotomy or Balloon Mitral Valvotomy or any form of cardiac surgery in the past.
6. Patients with Coronary Artery Disease, Hypertension & Diabetes Mellitus.
7. Patients with poor echo windows or incomplete study.

Clinical Assessment

All patients were subjected to thorough history taking, full clinical examination, 12 lead ECG, full 2D, M mode & Doppler transthoracic echocardiographic study in standard precordial views. Left Atrial regional function and deformation properties were studied using Tissue Doppler Velocities, Strain imaging, before and after 24 hrs of balloon mitral vulvotomy and all details were plotted in tables and statistically analysed.

Echocardiographic and Doppler Studies: For All 2-D, M-mode, conventional Doppler echocardiographic measurements and strain parameter were performed under ECG gated echocardiography, according to guidelines of American Society of Echocardiography. All measurements were repeated thrice and mean values were taken. Each individual included in the study underwent standard transthoracic echocardiogram and Tissue Doppler imaging in left lateral decubitus position in expiratory apnea by 5 Hz probe. PHILIPS EPIQ 7c Diagnostic ultrasound system with help of Automated cardiac motion quantification (ACMQ) Software. All the measurements of ventricular parameters were recorded using the leading edge technique and in accordance with the recommendations of American Society of Echocardiography. [14,15] Following parameters were obtained from the M mode guided pictures in parasternal long axis view ; Left Atrial dimensions in mm, Left Ventricular internal dimensions in both systole and diastole (LVIDDs and LVIDDd) in mm, thickness of interventricular septum (IVSd) and posterior wall (PWTd) at end diastole in mm. LVEF was calculated by modified Simpson's method52. MVA was calculated by planimetry and Pressure Half Time. Color flow Doppler was used to detect presence of valvular regurgitation. Left atrial volume and size was measured by 2D echocardiogram in apical 4 chamber view and Ejection Fraction was calculated using modified Simpson's method. [14] Maximum Left Atrial volume was measured during ventricular systole when mitral valve was closed and smallest Left Atrial volume during ventricular late diastole with pulmonary veins and mitral apparatus excluded from volume measurement. [16]

Various LA volumes have been used to describe LA phasic function: 1. Reservoir volume,. 2. Conduit volume, 3. Contractile volume

The relative contribution of LA phasic function to LV filling is dependent upon the diastolic properties of LV. In subjects with normal diastolic function, the relative contribution of the reservoir, conduit and contractile function of the LA to the filling of LV is approximately 40%, 35% and 25% respectively. As LV relaxation gradually worsens, the relative contribution of LA reservoir and contractile function increases while conduit function decreases. But with advanced diastolic dysfunction the LA serves predominantly as a conduit.

Pulse Waved Tissue Doppler Imaging: Tissue Doppler imaging was performed in apical four chamber view by placing the sample volume at midpoint of Interatrial Septum and Lateral left atrial wall. Peak early diastolic velocity (E') and late diastolic velocity (A') were recorded. A high frame rate (>110 frame/sec) was selected for the study. Special case was taken for correct alignment of the Doppler beam parallel to Interatrial septum. Doppler measurements were obtained during end expiration. An appropriate velocity scale was chosen to avoid data aliasing.

Atrial Strain and Strain Rate Imaging: Color Doppler myocardial images were acquired using a narrow sector (usually < 30 degree) to attain a frame rate >110 frames/sec. Attempts were made to align the atrial wall parallel to the Doppler beam. Because of the thin atrial walls, a narrow (10X2.5mm) sample volume was selected 57. Images were acquired followed by offline strain and strain rate evaluation using QLAB software. Sample volume was placed at mid Interatrial septum and mid Lateral wall of Left atrium in apical four chamber view.[17] Mean Strain (Strain and Strain Rate) parameters were recorded at end diastole defined as peak of R wave in ECG and end systole defined as the end of T wave in ECG. [18]

Balloon Mitral Valvotomy and Follow Up

All patients of Mitral Stenosis underwent Balloon Mitral Valvotomy through trans-septal single balloon technique. Balloon Mitral Valvotomy was considered successful when post procedure echo revealed mitral valve area > 1.5cm^2 by echo with less then 2+ Mitral Regurgitation. [19] Tissue Doppler velocities, Strain and Strain Rate parameters were measured 24 hours after Balloon Mitral Valvotomy in manner similar to pre procedure evaluation.

Statistical Analysis: All statistical analysis were performed by SPSS for Windows 16.0 (Chicago, USA) and RGui 2.8.0. Numerical results were expressed as Mean ± SD. Comparisons between Cases and Controls were done using the student's t test and Mann- Whitney U test for independent samples. Pre and Post Balloon Mitral Valvotomy analysis were done using the Paired Sample t test and Wilcoxon Signed Rank test. The level of significance is 5% (p value< 0.05). Pearson Correlation coefficient is used to find the correlation between the two variables.

Results

Table 1: Baseline Characteristics

Variable	Controls (n=25)	Mitral stenosis (n=25)	p value
Age of the Subject	31.7 ± 9.9	29.7 ± 6.9	p = 0.37
M mode LV dimensions in Diastole (mm)	42.9 ± 3.7	38.7 ± 5.6	p = 0.15
M mode LV dimensions in Systole (mm)	28.9 ± 2.4	27.8± 3.8	p = 0.31
M mode Posterior wall Dimensions (mm)	9.1 ± 1.2	9.1± 1.1	p = 0.87
M mode Interrventricular Septum Dimensions (mm)	9.2 ± 1.1	9.3± 1.2	p = 0.77
LV EF by Simpson's method (%)	60.2 ± 3.2	61.4± 3.8	p = 0.16
Peak TR Gradient (mm Hg)	18.2 ± 4.8(n=19)	4.0± 31.5(n=25)	p = <0.002
M Mode Right Ventricular Dimension (mm)	9.3±1.2	10.1± 1.2	p = 0.76

During the period of 18 months, 50 patients were included in the study of which 25 were of severe Mitral Stenosis (2D MVA < 1.5 cm2) and 25 were age matched Controls (31.7 ± 9.9 vs 29.7 ± 6.9 years; p= 0.37: MS vs Control).Female were more than Two third in both controls and Mitral stenosis groups. MVA of 25 mitral stenosis patient was (2DMVA=0.78 ± 0.12 cm2). Left ventricular systolic and diastolic dimensions and Left Ventricular Ejection Fraction were comparable in both the groups and there was no significant difference seen in M mode parameter of LV in both groups.

Table 2: Left Atrial Echo parameters

Variable	Controls (n=25)	Mitral Stenosis (n=25)	p value
M Mode Left Atrial Dimensions (mm)	30.1 ± 4.2	41.4± 7.6	p < 0.001
Maximum LA size in A4C (mm)	44.6 ± 4.7	65.4± 7.1	p < 0.001
2 D Left Atrial Maximum Volume (ml)	34.4±10.8	91.6 ± 31.1	p < 0.001
2 D Left Atrial Minimum Volume (ml)	14.7 ± 4.8	69.8± 28.3	p < 0.001
Left Atrial EF by Simpson's Method (%)	59.4 ± 6.9	24.3± 7.6	p < 0.001

2D Left Atrial parameters like, M mode LA dimensions, maximum LA size in A4C, maximum and minimum LA volumes were significantly higher in patients with mitral stenosis in comparison to controls. LA ejection fraction as calculated by modified Simpson's method was lower in Mitral Stenosis patients when compared to controls (24.3 ± 7.6 % vs 59.4 ± 6.9 %; p<0.001; MS vs Control).

Table 3: TDI parameters

Variable	Controls (n=25)	Mitral Stenosis (n=25)	p value
IAS Pulse Wave E' Velocity (cm/sec)	10.8 ± 3.7	7.8 ± 3.4	p = 0.003
IAS Pulse Wave A' Velocity (cm/sec)	10.2 ± 3.9	7.2 ± 2.8	p = 0.02
Left Atrial Lateral Wall Pulse Wave E' Velocity (cm/sec)	16.9 ± 3.4	7.7 ± 1.8	p <0.001
Left Atrial Lateral Wall Pulse Wave A' Velocity (cm/sec)	14.2 ± 3.8	7.5 ± 3.8	p <0.001

Tissue Doppler Imaging parameter of Left Atrial function like E' and A' Diastolic velocities showed significant lower value in Mitral Stenosis when compared to controls.

Table 4: Left atrial Strain parameters in MS as compared to controls

Variable	Controls (n=25)	Mitral Stenosis (n=25)	p value
IAS Strain at Ventricular End Systole (%)	30.9 ± 9.6	12.3± 7.1	p<0.001
IAS Strain at Ventricular Late Diastole (%)	-0.05 ± 0.31	0.04± 0.53	p = 0.36
Left Atrial Lateral Wall Strain at Ventricular End Systole (%)	29.6± 13.0	19.8± 9.2	p= 0.003
Left Atrial Lateral Wall Strain at Ventricular Late Diastole (%)	0.06± 0.71	0.02± 0.46	p = 0.6
GLA STRAIN (%)	**34.57± 3.85**	**14.54±0.85**	**P =.001**

Severe Mitral stenosis showed a lower ventricular end Systolic Strain as measured at Atrial Septum (12.3±7.1% vs 30.9±9.6%; p<0.001; MS vs Control) and Left Atrial Lateral Wall (19.8±9.2% vs 29.6±13.0%; p=0.003; MS vs Control. Global LA Strain (14.54±0.85 vs 34.57±3.85; p=001; MS vs control).

Table 5: Echo/Doppler parameters Pre and Post BMV

Variable	Pre BMV (n=25)	Post BMV (n=25)	p value
M Mode Left Atrial Dimensions (mm)	41.4 ± 7.6	38.0 ± 6.8	p=0.002
Maximum LA Size in A4C (mm)	65.4±7.1	63.3 ± 7.8	p=0.063
2 D Left Atrial Maximum Volume (ml)	91.6± 31.1	71.6±24.6	p<0.001
2 D Left Atrial Minimum Volume (ml)	69.8±28.3	48.3±18.7	p<0.001
Left Atrial EF by Simpson's Method (%)	23.3±6.8	32.9±9.8	p<0.001

Post BMV LA volumes (maximum and minimum) and M mode LA dimensions reduced significantly as compared to pre BMV. However LA size as measured in A4C remained unchanged (65.4 ± 7.1 vs 63.3 ± 7.8 mm; p =0.063: pre BMV vs post BMV) post procedure.

Table 6: Echo/Doppler parameters Pre and Post BMV

Variable	Pre BMV	Post-BMV	P value
Mitral Valve Areaby 2D (cm2)	0.78±0.12	1.93±0.24	p<0.001
Mitral Valve Areaby Doppler (cm2)	0.85±0.15	1.98±0.24	p<0.001
Mean mitral gradient (mm ofHG)	15.86± 6.56	7.24 ± 3.23	P < 0.001
Doppler Peak TRGradient (mmHg)	54.0±31.5	31.7 ±14.3	p<0.001

All patients of Mitral Stenosis included in the study underwent successful BMV with post BMV 2D mean Mitral Valve area of 1.94 ± 0.25 cm^2 by palnimetry which was more than 50% of initial MVA.

Table 7: Tissue Doppler Velocities Pre and Post BMV

Variables	Pre BMV (n=25)	Post BMV (n=25)	p value
IAS Pulse wave E' Velocity (cm/sec)	7.8 ± 3.4	6.8 ± 2.9	p=0.82
IAS Pulse wave A' Velocity (cm/sec)	7.2 ± 2.8	6.7 ± 2.3	p=0.48
Left Atrial Lateral Wall Pulse Wave E' Velocity (cm/sec)	7.7 ± 1.8	9.6 ± 2.2	p<0.001
Left Atrial Lateral Wall Pulse Wave A' Velocity (cm/sec)	7.5 ± 3.8	7.6 ± 2.3	p=0.82

Post BMV Tissue Doppler velocity remained unchanged as measured at interatrial septum however E' velocity at lateral wall improved significantly (7.7 ± 1.8 vs 9.6 ± 2.2; p<0.001: Pre BMV vs Post BMV).

Table 8: Left atrial Strain parameters Pre and Post BMV

Variables	Pre BMV (n=25)	Post BMV (n=25)	p value
IAS Strain at Ventricular End Systole (%)	12.3 ± 7.1	19.0 ± 9.8	p=0.01
IAS Strain at Ventricular Late Diastole (%)	0.04 ± 0.53	0.14 ± 0.74	p=0.55
Left Atrial Lateral Wall Strain at VentricularEnd Systole (%)	19.8 ± 9.2	24.6 ± 9.6	p=0.07
Left Atrial Lateral Wall Strain at VentricularLate Diastole (%)	0.02 ± 0.46	-0.14 ± 1.09	p=0.48
GLA STRAIN (%)	14.54±0.85	19.47±5.75	p = 0.01

A significant inverse correlation was found between Left atrial Systolic Strain as measured at atrial septum (p<0.001) and left atrial maximum volume. A similar correlation was also found between left atrial Lateral wall Systolic Strain and maximum LA volume (p<0.001).

Discussion

The left atrium (LA) acts as a reservoir, conduit, and pump.[20,21] It acts as a reservoir during left ventricular systole (LV) when the mitral valve is closed, LA is relaxed, and its annulus is temporarily displaced toward the apex.[22] It acts as a conduit in diastole when blood moves forward through the open mitral valve and as a pump to augment left ventricular preload at the end of the diastole.[23] It is known that Left Atrial function is influenced by both atrial and ventricular factors. The atrial factors affecting Left Atrial function include Left Atrial contractility & relaxation, Left Atrial pressure & compliance and rhythm abnormalities. Ventricular factors include Mitral annular displacement, Left Ventricular compliance & relaxation.

Mitral stenosis is one of the many conditions associated with Left Atrial dilatation and remodeling. The atrium enlarges in response to two broad conditions: pressure and volume overload. [24,25] A wide range of Left Atrial pressure exists in rheumatic Mitral Stenosis despite similar Mitral valve area because an important determinant of Left Atrial pressure is LA compliance.[26] In the present study, females constituted about two-third the population. This was similar to the findings seen in the study conducted by Rohani et al. which also showed a high prevalence of female population in the study. In terms of the age, the mean age of the study subjects was 29.70 ± 6.90 years which was in concordance with a study conducted by Roushady et al. which reported the mean age of patients with MS as 31.9 ± 6.3 years. [27]

In our study left atrial size as determined by Left Atrial dimensions in M mode and 2D echo in A4C, Left Atrial maximum and minimum volumes were significantly higher in patients with Mitral Stenosis as compared to Control group. In Mitral Stenosis because of increased resistance at the level of mitral valve there is marked increase in Left Atrial pressure leading to its enlargement. In addition, there is increased atrial afterload (at mitral valve level) during atrial contraction, which may lead to decreased Left Atrial pump function as evident in our study by lower Left Atrial ejection fraction in Mitral Stenosis group. After successful Balloon Mitral Valvotomy with increase in mitral valve area, afterload at mitral valve level decreases leading to improvement in Left Atrial ejection fraction. This was evident as early as 24 hours after Balloon Mitral Valvotomy in our study.

Regarding reservoir function, which was assessed in our study by mean Strain at the end systole, as measured at end of T wave was found to be significantly reduced in patients with severe Mitral Stenosis. This was true for both as measured at mid interatrial septum and mid lateral LA wall. There was a significant improvement in Inter Atrial Septal strain within 24 hours after Balloon Mitral Valvotomy and a trend towards improved systolic Strain as measured at lateral LA wall. However, Left Atrial size as assessed in A4C remained unchanged at 24 hours after Balloon Mitral Valvotomy. This would suggest that these abnormalities are not related to structural abnormality of left atrial wall per se, if so, should have taken longer time to resolve, but are functional abnormality related to degree of Mitral Stenosis.

Rohani A et al [1] (2017) showed that peak atrial longitudinal strain (PALS) is used to evaluate left atrium (LA) function in patients with mitral stenosis (MS), before and after percutaneous transmitral commissurotomy (PTMC) and mitral valve replacement (MVR). The peak systolic global LA strain improved post-PTMC (P < 0.001) and post-MVR (P = 0.012). PALS is impaired in patients with severe symptomatic MS and improved acutely after treatment and may be a good indicator of LA function and may predict the right time for intervention on mitral valve. The LA strain in this study showed a significant improvement from pre-BMV to post- BMV by 14.54 ± 0.85 to 19.47 ± 5.75 respectively with a statistical significance of p<0.001. Various other studies also investigated the acute effect on LA pre-BMV and post-BMV, the findings of which were commensurate with this study. Another study conducted by Reddy et al. reported a significant difference in the improvement of LA strain with p<0.001 which was in concordance with the presentstudy. [28]

Ahmed MI et al [29] (2014) conducted a prospective study that enrolled 54 patients who undergone successful BMV. Longitudinal Left atrial function was evaluated by speckle tracking derived strain. Left atrial volumes were measured before valvotomy, after the procedure and after 12 months during follow-up. The percent improvement of left atrial longitudinal strain correlated significantly with mean trans- mitral pressure gradient drop. Also left atrial mean peak left atrial longitudinal strain correlated significantly with left atrial volumes reductions after 12 months. Successful BMV results in reduction of mean left atrial volumes after 12 months which is well correlated with PALS percent change after BMV. This study also in favour of the longitudinal atrial stain is predictor of successful BMV. Atrial strain parameter measured during diastole were not significantly different in patients with Mitral Stenosis when compared to normal individuals in our study. It may due to the fact that during diastole Mitral valve is wide open and left atrial function is also influenced by LV compliance. This has also been suggested by Di Salvo et al [30] who demonstrated a strong correlation between early diastolic Strain and Strain Rate values and LV global diastolic function indices and between peak early diastolic Strain and peak Systolic annular excursion. In our study even the velocities assessed at septum were lower in Mitral Stenosis group. This probably may be related to severity of Mitral Stenosis in patients included in the study. Mi Seung Shin et al [31] in their study included patients with moderate to severe stenosis, whereas in our study all patients has severe Mitral Stenosis which could have resulted in more severe left atrial dysfunction and thus abnormal septal Tissue Doppler velocities. Post Balloon Mitral Valvotomy early diastolic Tissue Doppler velocity of Lateral LA wall improved whereas that of Interatrial Septum remained unchanged in our study. This may be attributed to, interatrial septum being more as compared to lateral LA wall. Sudden decrease in left atrial after load after BMV improves Lateral wall velocity within 24 hours after BMV which is a relatively free structure.

Conclusion

Left Atrial function as assessed by Tissue Doppler velocities and Tissue Doppler derived Strain is lower in patients with severe Mitral Stenosis. Left atrial reservoir function assessed by Strain imaging improves within 24 hours after Balloon Mitral Volvotomy. Global Longitudinal LA strain can be taken as an indicator of left atrial function, and its improvement following valvotomy may be taken as a good indicator of successful BMV.

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