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Original Research Article

Mitral Valve Deformation Evaluated as a Determinant of Ischemic MR Severity Using Transesophageal Echocardiography in Subjects Undergoing Surgical Myocardial Revascularization with or without concomitant Mitral Valve Procedure

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ABSTRACT

Background: Ischemic Mitral Regurgitation (iMR) is a result of functional imbalance between mitral valve leaflets tethering and closing forces caused by left ventricular remodeling following myocardial infarction. This mechanistic mitral valve deformation can be a predictor of ischemic MR severity. Present study was aimed at evaluating mitral valve deformation in different grades of ischemic MR in subjects with varying grades of MR undergoing myocardial revascularization surgery with or without concomitant mitral valve procedure.

Material and methods: 196 subjects undergoing surgical myocardial revascularization with or without concomitant mitral valve procedure were evaluated for presence of ischemic MR and mitral valve deformation. MR was quantified using echo indices like vena contracta width (VCW), Effective regurgitant orifice area (EROA), Regurgitant volume (RVol) & Regurgitant fraction (RF) into either “No” or “Mild,” “Moderate” and “Severe” ischemic mitral regurgitation (iMR) groups. The degree of mitral valve deformation was evaluated using systolic indices of deformation like tenting area, tenting height, and posterior leaflet angle. Systolic and diastolic mitral annular diameters, areas and annular height to commissural width ratio also were compared in different grades of ischemic MR.

Results: Mean MV systolic tenting area (TA) (1.87±0.42, 2.15±0.46 & 3.65± 0.26 vs. 1.34±0.44) (cm^2) ($p<0.001$), Tenting height (Th) (1.19±0.25 , 1.33±0.27 & 2.13±0.19 vs. 0.88±0.27) (cm) ($p<0.001$) and posterior mitral leaflet angle (PMLAβ) (50.96±8.85, 53.74±8.53 & 62.66±8.76 *vs.* 35.52 ±6.82) (^{0}) ($p<0.001$) were significantly higher in mild, moderate & severe groups *vs.* no iMR group respectively. The degree of MV deformation increased with increasing grade of MR in a linear manner.

Conclusion: Higher degree of MV deformation was seen with higher grades of ischemic MR. Both systolic and diastolic mitral valve deformation indices predicted ischemic MR severity in patients undergoing myocardial revascularization surgery with or without the concomitant mitral valve procedure. Ischemic mitral regurgitation, Vena contracta width, Effective regurgitant orifice area, Mitral valve deformation, Tenting area, Tenting height, Posterior leaflet angle.

Keywords: Ischemic mitral regurgitation, Vena contracta width, Effective regurgitant orifice area, Mitral valve deformation, Tenting area, Tenting height, Mitral valve posterior leaflet angle.

INTRODUCTION

The mitral valve or left Atrio-ventricular valve (also known as bicuspid valve) is situated between the Left atrium and left ventricle and allows a unidirectional passage of oxygenated blood from left atrium to left ventricle in a normal human heart.[1] The “Mitral valve apparatus” is a 3-Dimensional functional unit comprising of 1. fibro-collagenous, elastic “anterior and posterior mitral valve leaflets”, 2. a fibrous ring at the atrioventricular junction called “annulus” where these leaflets are attached, 3. “chordae tendineae”, ligamentous structures which provide attachments of the MV leaflets to 4. muscular structures arising from LV wall called anterolateral and posteromedial “papillary muscles” and 5. the “supporting left ventricular myocardial wall” from where the papillary muscles arise. [2,3,4] The mitral valve has a specific non- planar geometry designed to maintain leaflet coaptation and thereby prevent regurgitation of blood into the left atrium (LA) during ventricular systole. [2,3,4,5] (figure-1)

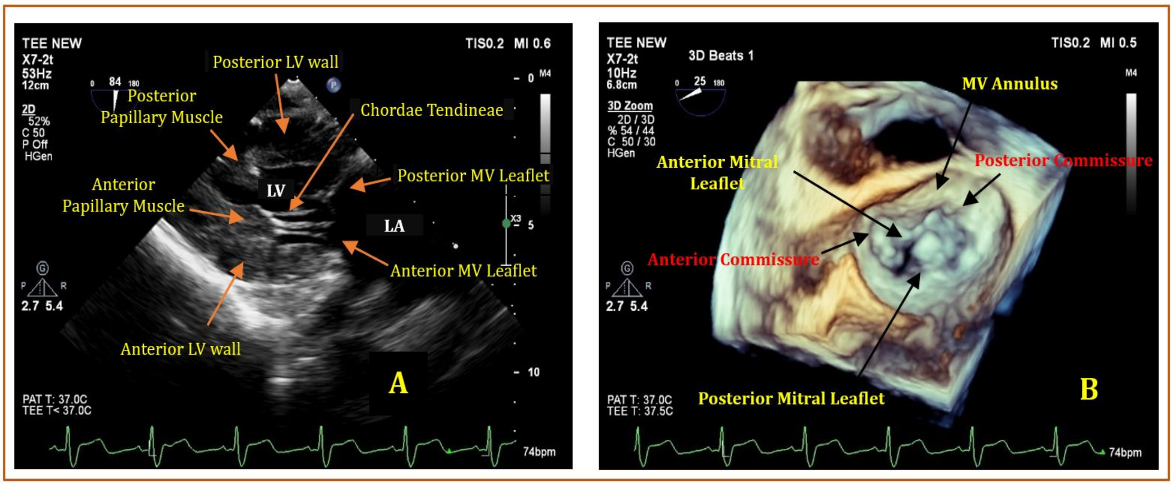


Figure 1: 2D & 3D Transesophageal echocardiography to demonstrate components of “Mitral valve apparatus”. Image A) Trans Gastric 2 Chamber View (TG-2CV) obtained at (80-90^0) showing mitral valve leaflets, chordae tendineae, papillary muscles and supporting left ventricular walls. B) 3D full volume single beat acquisition of mitral valve from LA perspective at midesophageal probe position and multiplane angle at (20-30^0). Showing saddle shaped non-planer mitral valve annulus, anterior and posterior mitral leaflets, and commissures.

While the mechanisms responsible for primary mitral regurgitation are structural abnormalities in mitral valve leaflets and sub valvular apparatus (chordae tendineae & papillary muscles), secondary (functional) MR is a result of global or regional myocardial dysfunction resulting into an inadequate closure of mitral valve leaflets due to reduced closing forces and increased tethering forces on mitral valve leaflets. [6,7,8,9] Ischemic mitral regurgitation (iMR) is a type of secondary MR, a complication of myocardial infarction (MI), and not the fortuitous association of coronary artery disease with intrinsic (rheumatic or degenerative) valvular heart disease. [10,11,12] iMR represents the valvular consequences of increased tethering forces i.e. [apical and lateral displacement of papillary muscles] and reduced closing forces i.e. [reduced contractility, desynchrony of the papillary muscles] due to LV dysfunction, annular dilation, and changes in annular geometry. [10, 11,12,13] The diagnostic criteria of chronic IMR can be summarized as, MR occurring more than 16 days after myocardial infarction (MI) with one or more LV segmental wall motion abnormalities; significant coronary disease in a territory supplying the wall motion abnormalities and structurally normal MV leaflets and chordae tendineae. The third criterion is important to exclude patients with organic MR and associated CAD. [12,13,14] This mechanistic change in mitral valve is a result of either an isolated posterior leaflet tethering (in case of a previous inferior myocardial infarction) or bi-leaflet (anterior and posterior) tethering (in case of previous anterior myocardial infarction). Increased leaflet tethering results in low level leaflet coaptation in relation to mitral annular plane, creating a systolic tenting. [10,11,12,13] The area created by "tenting" of the leaflets with mitral annular plane as a base is called as "tenting area" and the height of coaptation zone from the annulus is called as "tenting height". The angle intercepted by the posterior mitral leaflet to mitral annular plane is called as "posterior mitral leaflet tenting angle (PMLA)(β^0)." [13,14,15,16,17] (Figure 2)

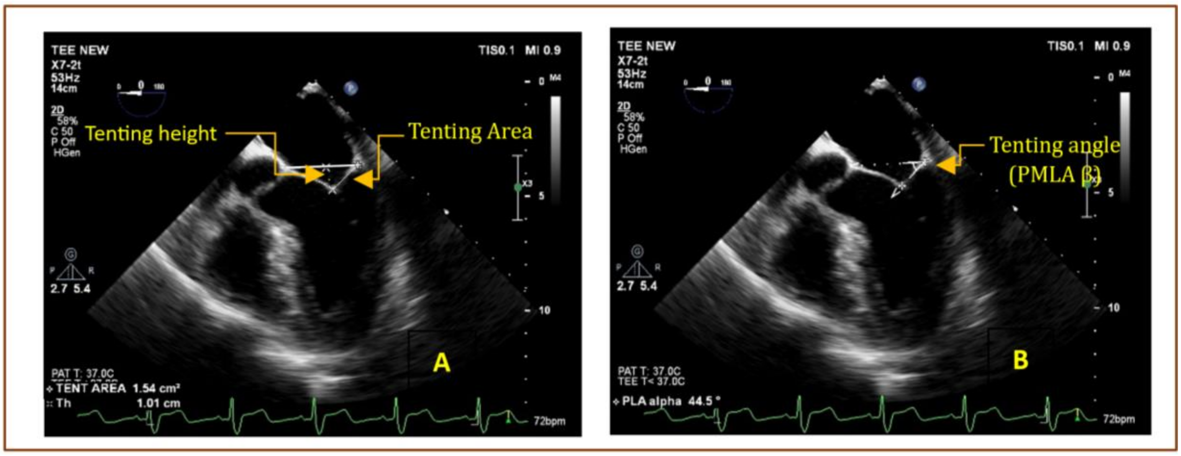


Figure 2: Midesophageal 4 chamber view ME4cv (0-20^0) showing Systolic MV deformation indices viz. A) Tenting area (TA) (a triangular area bound by mitral annular plane at the base, anterior and posterior leaflets as its two sides) and tenting height (Th) (A perpendicular distance of the MV leaflets coaptation point from the mitral annular plane) B) Posterior mitral leaflet tenting angle (PLAβ) (An acute angle intercepted by the posterior mitral leaflet with the mitral annular plane.

Presence of iMR is a marker of poor outcome and has major prognostic and therapeutic implications. [18] The incidence of iMR is up to 40% of patients after myocardial infarction. [18,19] 7 to 31% of patients undergoing coronary angiography have evidence of iMR. [19] Nearly 41% candidates undergoing surgical myocardial revascularization (CABG) may have associated iMR. [18,19,20] Importantly, an uncorrected iMR even a milder one poses an increased risk for death and heart-failure hospitalization; hence, consideration for surgical repair or more aggressive perioperative medical management is needed to improve surgical outcome. [20,21,22] In-hospital mortality rates for isolated CABG is 3% and 7- 20% for concomitant mitral procedure along with CABG respectively. [23,24,25] This significant difference in clinical outcomes makes preoperative evaluation of ischemic MR and its determinants using 2D and 3D echocardiography a necessity to plan surgery and perioperative medical management. Transesophageal echocardiography provides an excellent opportunity to evaluate iMR in anaesthetized subjects undergoing coronary bypass grafting surgery.[26] So, the present study was aimed at transesophageal echocardiographic evaluation of mitral valve deformation as a predictor of severity of ischemic MR. Echocardiographic indices of mitral valve deformation viz. diastolic mitral annular diameter and area (MADd & MAAd), systolic mitral annular diameter and area (MADs & MAAs) , systolic tenting area (TA), tenting height (Th) and posterior leaflet tethering angle(PLAβ) were studied in subjects undergoing elective surgical myocardial revascularization with or without concomitant mitral valve repair/replacement procedure.[16,17,27,28] . (figure 2,3)

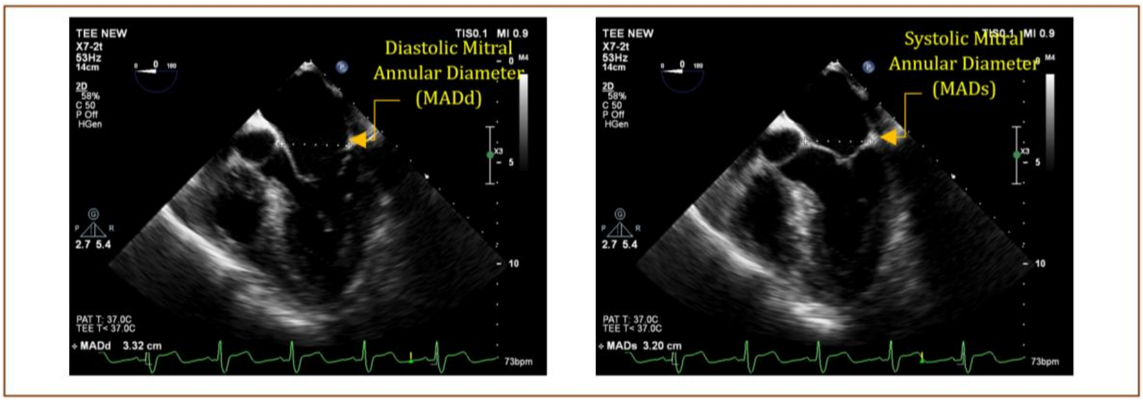


Figure 3: Midesophageal 4 chamber view ME4cv (0-20^0) showing MV deformation indices viz. A) Diastolic mitral annular diameter (MADd) (A transverse distance between medial and lateral annular planes in end diastole) and B) Systolic mitral annular diameter (MADs) (A transverse distance between medial and lateral annular planes in end systole)

MATERIALS & METHODS

This prospective observational study involved transesophageal echocardiographic evaluation of 204 subjects undergoing elective myocardial revascularization surgery for an angiographically diagnosed significant coronary artery disease in cardiovascular thoracic surgical unit of a tertiary care hospital in northern Karnataka, India. Transesophageal echocardiography (TEE) was performed after induction of anaesthesia and sternotomy before the surgical myocardial revascularization. Patients with history of myocardial infarction within 16 days before surgery (n=3), patients having contraindications for transesophageal Echocardiographic probe insertion (n=2) and ssubjects with pre-operative pharmacological or mechanical cardiovascular support [inotropes or Intra-aortic balloon counter pulsation (IABP) dependent subjects] (n=3) were excluded from the study. 2D transesophageal echocardiography was performed in 196 subjects fulfilling inclusion criteria to diagnose and quantify ischemic MR and to measure the indices of mitral deformation using X-matrix phased array transducer probe (X7-2T) mounted on Philips healthcare® Epic7c ultrasound workstation. The handling of the TEE probe was gentle and principle of ALARA was followed to avoid excessive heating of the TEE probe.[29]

Echocardiographic assessment of ischemic MR severity:

Guidelines of the American Society of Echocardiography were used to grade iMR severity. Using AHA/ACC updated guidelines for valvular heart diseases, the degree of severity of ischemic MR was graded and grouped into a “No iMR”, “Mild iMR", “Moderate iMR" & “Severe iMR” groups as follows:

“No iMR” was defined as absence of any mitral regurgitation. “Mild iMR” was defined as MR regurgitant volume (RVol) <30 (ml/beat), regurgitant fraction (RF) <30%, effective regurgitant orifice area (EROA) <0.2 cm^2 and a vena contracta width of < 0.3 cm. “Moderate iMR” was defined as MR regurgitant volume (RVol) between 30 - 59 (ml/beat), regurgitant fraction (RF) between 30-49%, effective regurgitant orifice area (EROA) between 0.2-0.39 cm^2 and vena contracta width of 0.3 to 0.69cm. “Severe iMR” was defined as a regurgitant volume (RV) ≥60 (ml/beat), regurgitant fraction (RF) ≥50 %, effective regurgitant orifice area (EROA) ≥0.4 cm^2 and vena contracta width of ≥0.7 cm. [30,31,32] Patients with organic (non-ischemic) MR were excluded from the present study. [30,31]

All the subjects were subjected to assessment of mitral valve deformation using transesophageal echocardiographic indices as 1. Systolic leaflet deformation, 1. Mitral valve tenting area (TA) were measured at midsystole as the area enclosed between the annular plane and mitral leaflets. 2. Tenting height (Th) which represents extent of displacement of mitral coaptation toward the LV apex was measured as the distance between leaflet coaptation and the mitral annuls plane. 3. The posterior leaflet angle (PLAβ) was calculated according to formula: - PLA= $\sin^{-1}$(TD/ PLL), where “β” is the posterior leaflet angle. 4. Mitral annulus diameter (MADd) was measured at end diastole and at mid systole (MADs). 5. The end-diastolic & mid systolic mitral annular (MAAd & MAAs) areas were obtained from its dimensions in the midesophageal 4 chamber and 2 chamber views using an ellipsoid assumption: MA area = ¼ π x d1x d2. Where d1 and d2 ware anteroposterior and transverse MV diameters measured at end diastole & mid systole respectively. [28,34,35]

STATISTICAL ANALYSIS

Data obtained from 196 subjects was tabulated and analyzed using Microsoft office Excel version 2016, Microsoft Corporation® One Microsoft Way, Redmond, Washington 98052-6399 USA and IBM SPSS Statistics for Windows®, Version 20.0. Armonk, NY, USA. The Inter group comparison of quantitative data was Analysed with Z- score test statistics. Pearson’s chi square test statistics was used for intergroup comparison of qualitative data. Analysis of variance (ANOVA) was used to analyse significance in different grades of iMR. The significance was mentioned in terms of *p*-values. *P*-value more than 0.05 was considered non-significant (NS) while *p*-value of 0.05 and less was considered significant (S). *P*-value of less than 0.001 was considered highly significant (HS).

RESULTS

The comparison of demographic, clinical and laboratory characteristics of the subjects in different groups of ischemic MR severity are shown in table. No. 1. The demographic study variables viz. age *(p=0.29)*, sex *(p=0.9)*, body surface area (BSA) *(p=1.94)*, associated comorbidities viz. hypertension *(p=0.1)*, diabetes mellites (DM) *(p=0.47)*, chronic obstructive pulmonary disease (COPD) *(p=0.28)*, smoking *(p=0.5)*, medication viz. β-blockers *(p=0.86)*, prior percutaneous coronary intervention *(p=0.122)*, and biochemistry viz. HbA_1C *(p=0.061)* and CK-MB levels *(p=0.277)* did not show any statistically significant difference in different groups of iMR grades. There was a statistically significant difference observed in variables like angiographic grade of coronary artery disease *(p=0.043)*, type of myocardial infarction*(p=0.0001)*, history of post MI thrombolytic therapy *(p=0.0001)*, pharmacotherapy with angiotensin II receptor blocker *(p=0.0001)*, diuretics therapy *(p=0.012)* and nitrates *(p=0.025)* and preoperative serum creatinine levels *(p=0.001)* in different iMR groups.

The comparison of transesophageal echocardiographic mitral valve deformation indices in different grades of mitral regurgitation are shown in table No.2. There was a highly significant difference noted in transesophageal echocardiographic indices of systolic mitral valve deformation viz.

Tenting area ($p=0001$), Tenting height ($p=0.0001$), tenting angle of posterior mitral leaflet (β) ($p=0.0001$), systolic MV annular diameter ($p=0.0001$) and area ($p=0.001$). There was a significant increase in MV deformation with increasing grade of iMR. Diastolic MV annular diameter ($p=0.0001$) and area ($p=0.001$), MV annular height to commissural width ratio (AHCWR) ($p=0.001$) also were significantly higher in increased grades of iMR. (Graph No.1)

Table No.1: - Comparison of demographic, clinical and biochemical characteristics of the subjects in different groups of ischemic MR severity

Study Variable		**Grade of IMR (n=196)**				**P Value (Significance)**
		No iMR (n=39) (Mean ±SD) / (%)	**Mild iMR (n=67) Mean ±SD) / (%)**	**Moderate iMR (n=73) Mean ±SD) / (%)**	**Severe iMR (n=17) Mean ±SD)/ (%)**	
Age (Years)		60.18±9.92	59.93±8.99	59.96±8.7	54.24±12.63	0.29(NS)
Sex	Male	27(19%)	50(34%)	55(38%)	13(9%)	0.9 (NS)
	Female	12 (24%)	17(33%)	18(35%)	4(8%)	
BSA (kg/m^2)		1.69±0.14	1.68±0.16	1.71±0.15	1.72±0.15	1.94 (NS)
Hypertension	Yes	30 (20%)	51(34%)	56(37%)	13(9%)	0.1 (NS)
	No	9 (20%)	16 (35%)	17 (37%)	4 (8%)	
Diabetes Mellites	Yes	26(22%)	42(36%)	41(35%)	8(7%)	0.47 (NS)
	No	13(16%)	25(32%)	32(41%)	9(11%)	
COPD	Yes	10(24%)	12(29%)	18(45%)	1(2%)	0.28 (NS)
	No	29 (19%)	55(35%)	55(35%)	16(11%)	
Smoking	Yes	14(25%)	17(31%)	21(38%)	3(5%)	0.50 (NS)
	No	25(18%)	50(35%)	52(37%)	14(10%)	
Angiographic Grade of CAD	CAD-RAD Grade 4A	14(19.1%)	24(32.9%)	20(27.4%)	15(20.6%)	0.043 (S)
	CAD-RAD Grade 4B	14(25.5%)	20(36.4%)	19(34.5%)	2(3.6%)	
	CAD-RAD Grade 5	21(18.3%)	40(34.8%)	45(39.1%)	9(7.8%)	
Preop β-Blockers	Yes	33(20%)	57(34%)	65(38%)	14(8%)	0.86 (NS)
	No	6(22%)	10(37%)	8(30%)	3(11%)	
Preop AT II RB	Yes	18(17%)	28(26%)	49(45%)	13(12%)	0.0001(HS)
	No	21(24%)	39(44%)	24(27%)	4(5%)	
Preop Nitrates	Yes	29(19%)	52(34%)	60(39%)	13(8%)	0.025 (S)
	No	10(24%)	15(36%)	13(30%)	4(10%)	
Preop Diuretics	Yes	12(12%)	30(32%)	44(45%)	11(11%)	0.012(S)
	No	27(26.5%)	37(37%)	29(29.5%)	6(7%)	
Type of MI	Non-ST Elevation MI	17(63%)	5(19%)	2(7%)	3(11%)	0.0001(HS)
	Ant Wall MI	14(20%)	27(38%)	23(32%)	7(10%)	
	Ant Wall MI + Lat Extension	3(15%)	8(40%)	8(40%)	1(5%)	
	Ant Wall MI + Inf Wall MI	1(13%)	2(25%)	4(50%)	1(13%)	
	Inf Wall MI	4(6%)	25(36%)	36(51%)	5(7%)	

Prior PCI	Yes	10(37%)	7(26%)	8(30%)	2(7%)	0.122(NS)
	No	29(17%)	60(36%)	65(38%)	15(9%)	
Thrombolysis	Yes	10(37%)	7(26%)	8(30%)	2(7%)	0.0001(HS)
	No	29(17%)	60(36%)	65(38%)	15(9%)	
HbA1C (gm/dl)		8.46±2.54	7.62±2.00	7.48±2.19	6.97±1.86	0.061 (NS)
Sr. Creatinine(mg/dl)		1.08±0.25	1.04±0,22	1.14±0.30	1.37±0.55	0.001 (HS)
CK-MB (IU/Lit)		29.33±10.71	30.21±13.96	26.51±9.71	29.24±10.24	0.277(NS)

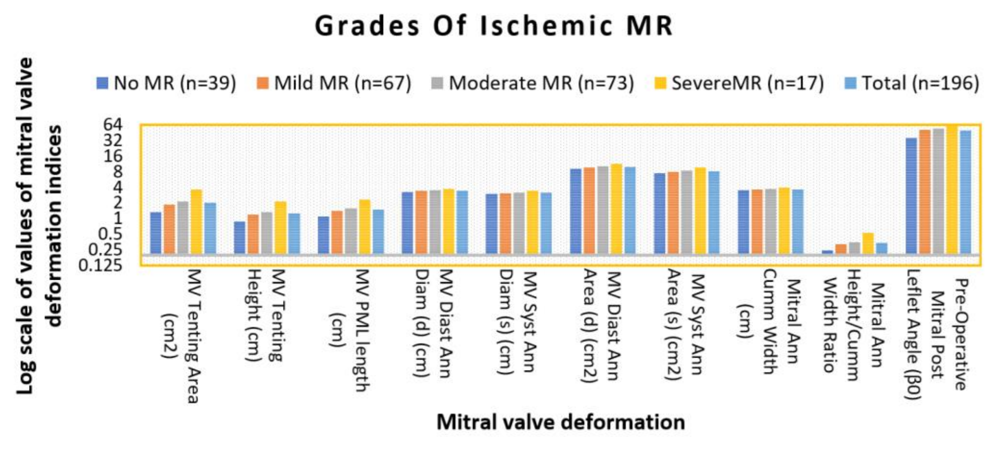
(BSA: - Body Surface Area, COPD: - Chronic Obstructive Pulmonary Disease, CAD: - Coronary Artery Disease, AT II RB: - Angiotensin II Receptor Blocker, MI: - Myocardial Infarction, PCI: - Percutaneous Coronary Intervention. CK-MB: - Creatine Kinase – Muscle & Brain)

Table 2: - Comparison of Transesophageal Echocardiographic Mitral valve deformation indices in different grades of Ischemic mitral regurgitation

Echocardiographic MV Deformation Indices	Grade Of Ischemic Mitral Regurgitation					
	No iMR (n=39) Mean±SD	Mild iMR (n=67) Mean±SD	Moderate iMR (N=73) Mean±SD	Severe iMR (n=17) Mean±SD	Total (n=196) Mean±SD	P Value & Significance
MV Tenting Area (TA) (cm^2)	1.34±0.44	1.87±0.42	2.15±0.46	3.65±0.26	2.02±0.72	0.0001(HS)
MV Tenting Height (Th) (cm^2)	0.88±0.27	1.19±0.25	1.33±0.27	2.13±0.19	1.26±0.40	0.0001(HS)
MV PML length (cm)	1.11±0.27	1.42±0.25	1.56±0.27	2.36±0.19	1.49±0.40	0.0001(HS)
Diastolic Mitral Ann Diam (MADd) (cm)	3.30±0.18	3.40±0.15	3.50±0.21	3.74±0.19	3.45±0.22	0.0001(HS)
Systolic Mitral Ann Diam (MADs) (cm)	3.02±0.16	3.11±0.14	3.20±0.19	3.42±0.17	3.15±0.20	0.0001(HS)
Diastolic Mitral Ann Area (MAAd) (cm^2)	9.01±0.94	9.57±0.81	10.11±1.24	11.48±1.11	9.83±1.22	0.001(HS)
Systolic Mitral Ann Area (MAAs) (cm^2)	7.56±0.79	8.03±0.69	8.49±1.03	9.65±0.91	8.25±1.02	0.001(HS)
Mitral Ann Cumm Width (MaCw)(cm)	3.50±0.18	3.60±0.15	3.70±0.21	3.94±0.19	3.65±0.22	0.001(HS)
Mitral Ann Height/Width Ratio (AhCwR)	0.25±0.07	0.33±0.07	0.36±0.07	0.54±0.07	0.34±0.10	0.0001(HS)
MV Post Leaflet Angle (PMLA) (β^0)	35.51±6.82	50.96±8.85	53.74±8.53	62.66±8.76	49.93±11.41	0.0001(HS)

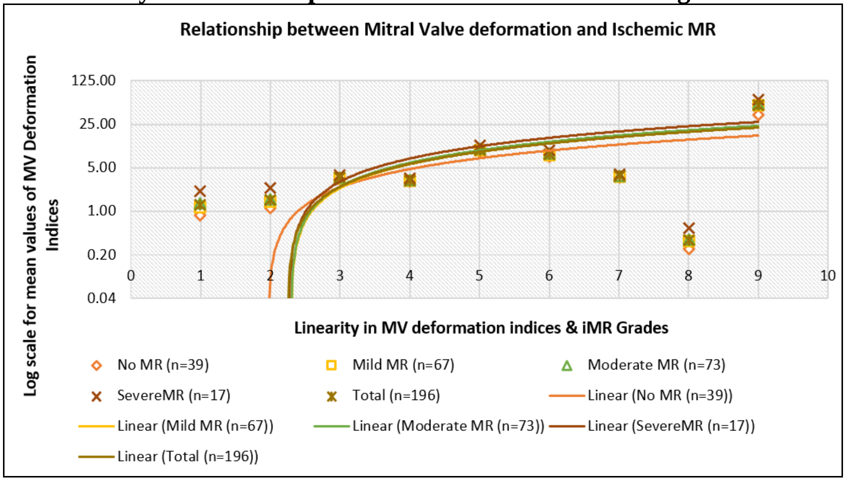
(MV: - Mitral Valve, PML: - Posterior Mitral Leaflet, Ann: - Annular, Cumm: - Commissural)

Graph 1: - Degree of Mitral valve deformation in different grades of ischemic MR



Graph 1. The MV deformation indices showed higher values with increasing grades of iMR. Higher grades of MR had higher degree of MV deformation.

Graph 2: - Linearity in relationship between MV deformation and grade of ischemic MR



Graph 2: - Horizontal axis: - 1. Tenting Area (cm^2) 2. Tenting Height (cm) 3.PML length (cm) 4. Diastolic Mitral Ann Diam (d) (cm) 5. Systolic Mitral Ann Diam (s)(cm) 6. Diastolic Mitral Ann Area (d) (cm2) 7. Systolic Mitral Ann Area (s) (cm2) 8. Mitral Ann Cum Width (cm) 9. Mitral Ann Height/Width Ratio 10. Mitral valve Post Leaflet Angle (β^0). There was a linear increase in MV deformation with severity of iMR.

DISCUSSION

In present study, transesophageal echocardiographic evaluation of 196 subjects undergoing elective surgical myocardial revascularization (CABG) were evaluated for presence of ischemic mitral regurgitation (iMR) and were grouped according to their grades of severity into "No", "Mild", "Moderate" and "Severe" iMR. Baseline demographic, clinical and relevant biochemical characteristics and echocardiographic indices of mitral valve deformation were recorded in different grades of iMR and compared for statistical significance. The degree (extent) of mitral valve deformation was evaluated using systolic and diastolic MV deformation indices viz. tenting area (TA), tenting height (Th), posterior mitral leaflet length (PML length), tenting angle of posterior mitral leaflet (PMLAβ), mid systolic MV annular diameter (MADs)and area (MAAs), mitral valve commissural width (MVCW), mitral valve annular height to commissural width ratio (MAhCwR) and MV annular diastolic diameter (MADd) and area (MAAd). Demographic characteristics, age *($p=0.29$)*, sex *($p=0.9$)*, body surface area (BSA) *($p=1.94$)*, associated clinical comorbidities like hypertension *($p=0.1$)*, diabetes mellites (DM) *($p=0.47$)*, chronic obstructive pulmonary disease (COPD) *($p=0.28$)*, smoking *($p=0.5$)*, pharmacotherapy with β-blockers *($p=0.86$)*, history of prior percutaneous coronary intervention *($p=0.122$)*, and biochemical indicator of diabetic control, HbA1c levels *($p=0.061$)* and myocardial injury, CK-MB levels *($p=0.277$)* were distributed evenly in all the grades of ischemic MR and did not determine its severity. Valuckiene Z et al found similar results except increasing age and female sex determined severity of iMR.[39] In our study, higher angiographic grade of coronary artery disease (CAD-RAD Grade 4B and 5) determined higher grades of iMR *($p=0.043$)*. Non-ST segment elevation MI determined lower grades of iMR while anterior, inferior and combine anterior+inferior wall MI determined higher grades of iMR *($p=0.0001$)*. Subjects who received post MI thrombolytic therapy, had lower grades of iMR *($p=0.0001$)*. Valuckiene Z et al observed similar results in their study. [39] Subjects with ischemic MR were more often on angiotensin II receptor blockers *($p=0.0001$)* This pharmacotherapeutic strategy reduces the iMR severity as documented by Kang DH et al (PRIME study) and Lee S et al. [40,41] pre operative use of diuretics *(p=0.012)* and nitrates (vasodilators) *(p=0.025)* also reduces the severity of iMR as evaluated by Stevenson LW et al. [42] Sr. creatinine levels were significantly higher in higher grades of iMR *(p=0.001),* a similar observation was made by Seghatol FF et al in subjects with ischemic MR following acute myocardial infarction.[43] In present study, higher grades of iMR were associated with higher tenting area *(p=0001),* tenting height *(p=0.0001),* tenting angle of posterior mitral leaflet (β) *(p=0.0001),* systolic and diastolic MV annular diameter *(p=0.0001)* and area *(p=0.001)* respectively. similar observations were noted by Dudzinski, DM et al. [34]. There was a significant increase in degree of MV deformation with increasing grade of iMR.[34] Basically, Ischemic MR is a result of geometric change in left ventricle and the imbalance between the tethering and closing forces on mitral valve leaflets leading to papillary muscle displacement and subsequent leaflet tethering. [36] Tethering patterns are “symmetric” (in cases of LV remodeling secondary to anterior or anterolateral or multiple myocardial infarctions) and “asymmetric” (in cases of LV remodeling secondary to inferior or posterior wall infarcts). [36,37] Asymmetric iMR intercepts higher tenting area and posterior leaflet angles compared to the symmetric phenotype Dudzinski, DM et al [45,46] In Allen carpentier’s classification, ischemic MR is categorized as “type I” (central MR) in cases of symmetric tethering and “type IIIb” (eccentric MR) in cases of asymmetric tethering.[36] We found significantly lower degree of MV deformation in No iMR category.

In present study evaluation of ischemic MR and mitral valve deformation was done using transesophageal echocardiography (TEE). TEE provides an excellent opportunity to evaluate the ischemic MR and mitral valve deformation in operating room prior to surgical myocardial revascularization under general anesthesia with endotracheal tube in situ. Performing transesophageal echocardiography and analyzing mitral valve deformation becomes more feasible However, because of vasodilating effects of anesthesia, iMR severity may be underestimated by intraoperative TEE. One proposed tactic to ensure appropriate severity grading is to administer vasopressor or assessing the MR just after the sternotomy when the effect of anaesthesia on afterload is balanced by surgical stimulus. Both these methods to mitigate effect of anaesthesia on afterload were used in our study to minimize underreporting of iMR. Present study has considered both quantitative as well as semi quantitative parameters of MR assessment 2D vena contracta width (VCW), Effective regurgitant orifice area (EROA), Regurgitant volume (RVol) and Regurgitant fraction (RF). Also, the indices of systolic as well as diastolic MV deformation were considered for analysis which makes this study novel as such comprehensive evaluation using transesophageal echo (TEE) has not been done before. Tethering and tenting of the mitral leaflets is the final common pathway mediating leaflet maladaptation and incomplete closure in iMR. The average of abnormal vector forces on the mitral leaflets echocardiographically manifest as tenting and iMR. Mid esophageal 4 chamber view was considered for measurement of tenting as it resembles best with apical 4 chamber view of TTE. [26,27] This counterpart of 2D TTE properly appreciates incomplete mitral leaflet closure pattern because the mitral annular plane is very well defined in this view. Tenting height, the maximal mid-systolic distance from mitral leaflet tips to the annular plane – reflects the abnormal apical shift of the coaptation zone was longer in higher grades of ischemic MR in present study. [34] Similar observations were noted in review done by Daduzinski et al. [34] The tethering angles define the relationship of the base of the leaflets to the annulus: β represents the angle between annular plane and anterior mitral leaflet and β the angle between annular plane and posterior mitral leaflet.[34]

Though the exact values depend on methodology and imaging plane selected, higher ratios of posterior angle to anterior angle characterize the asymmetric tenting phenotypes, and predicts increased MR severity. [34] In present study we could see increasing angle degree in increased tethering and iMR severity. Tenting area, measured in midsystole (to a fullest extent), provides a more integrative and less angle dependent measure of annular plane and entire leaflets geometry and not just the annular attachment of the leaflets like tenting angle. [34] In present study it was a main parameter of evaluation. Daduzinski h et al and Agricola E et al have shown that in cases of type I iMR jets (symmetric phenotype) , anterior and posterior mitral leaflets intersect almost equal tenting angles to mitral annular plane while type IIIb (asymmetric phenotype) jet there was excessively increased tenting angle of posterior mitral leaflet ($PMLA_{\beta}$) and the ratio of posterior to anterior leaflet angle (PLA_{β}/ALA_{α}) was more than 1 in case of asymmetric tethering.[34,46] In present study, the analysis of MV deformation based on Agricola E et al’s tethering phenotypes (symmetric vs. asymmetric) was not considered which would have thrown insight into characteristics of deformation in different LV remodeling scenarios. This was a limitation of our study. As the iMR grade increased, the MV commissural width *(p=0.001)* and annular height to commissural width ratio (AhCwR) *(p=0.001)* also were significantly higher in increased grades of iMR. Ryan LP et al evaluated AhCwR in patients following myocardial infraction in evolving phases till 8 weeks post infraction and noted a consistent decrease in AhCwR as MR grade decreased. [47]

In present study transesophageal echocardiography was performed after general anaesthesia with endotracheal tube (GA+ETT). The effect of anaesthesia on loading conditions were not taken in account while performing echocardiography and grading of iMR.

Ischemic MR has two distinct phenotypes, symmetric and asymmetric (Allen carpentier’s type I and IIIb respectively). The subgrouping of each iMR grades into these subcategories was not considered in present study. It could have given a better insight into the association of MV deformation with pathophysiology of iMR. This can form a basis for future research on this topic.

Though care was taken to avoid foreshortening of midesophageal echo images, there can be a variation in 2D plane for measurements of echo indices like MV tenting area (TA), tenting height (Th) and angle (PLAβ).

The mitral valve annular areas were obtained using anteroposterior and transverse diameters of mitral valve annulus. As MV annulus is a non-planer structure, the 2D planar measurements considered in present study may not be very accurate. A study involving 3D measurement (tenting volume) may be helpful and will have better weightage against 2D parameter (tenting area).

CONCLUSION

Degree of mitral valve deformation increased linearly with severity of ischemic mitral regurgitation. Transesophageal echocardiographic indices of mitral valve deformation significantly predicted severity of ischemic MR in subjects undergoing myocardial revascularization surgery with or without concomitant mitral valve procedure. Not only the systolic tenting area (TA), but also the tenting height (Th) and posterior leaflet angle (PLAβ) significantly correlated linearly with increasing grade of ischemic MR. Anterior and inferior wall myocardial infarction alone or in combination and higher angiographic grades of coronary artery disease CAD-RAD 4B & 5 were associated with higher grades of ischemic MR. Lower grades of ischemic MR were associated with non-ST segment elevation MI and reception of timely thrombolysis. Authors recommend regular transesophageal echo assessment of subjects undergoing surgical myocardial revascularization with or without concomitant mitral valve repair/replacement to evaluate ischemic MR and assess the mitral valve deformation.

Declaration by Authors

Ethical Approval: Present study is a part of a research project ethically approved by Institutional "Ethics Committee on Human Subject" (KAHER/ETHIC/2018-19/D-119).

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