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Original Article

Role of three dimensional transesophageal echocardiography in predicting mitral regurgitation after percutaneous balloon mitral valvuloplasty

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ABSTRACT

Background: Percutaneous balloon mitral valvuloplasty (PBMV) can be complicated with significant mitral regurgitation (MR). We performed a pilot, prospective study to evaluate the role of three dimensional transesophageal echocardiography (3D-TEE) in the prediction of MR after PBMV through mitral valve quantification (MVQ).

Methods: Between October 2014 and October 2016, 37 patients with rheumatic, moderate-to-severe mitral stenosis, referred to the Cath lab of Bab Alshearia University hospitals for PBMV, were divided into two age and sex matched groups. Group I included 25 patients without significant MR following PBMV [vena contract area (VCA) $<0.4\,cm^2$], while group II included 12 patients with significant MR after PBMV [VCA $\geq 0.4\,cm^2$]. Both groups were comparable in terms of TEE data, Wilkins score for favorability of PBMV and baseline hemodynamics.

Results: Data from MVQ showed that both groups were comparable ($p > 0.05$) in terms of MV annulus quantification (Anteroposterior diameter, annular sphericity, 3D area and height), MV scallops (A1, A2, A3, P1, P2 and P3) areas, as well as A1 and A2 tenting volumes. However, we recorded significant differences between the two groups as regard total MV, A2, P2 and P3 tenting volumes ($p < 0.05$) and tenting height ($p = 0.03$), as well as A2, A3 and P2 prolapse volumes ($p < 0.05$). Moreover, our data showed a significant difference between both groups in terms of MV coaptation heights ($p = 0.01$), but not in anterior coaptation length ($p = 0.13$).

Conclusion: Mitral valve quantification through 3D-TEE is a simple automated method, easily applicable to patients before PBMV. Moreover, MVQ-derived data, such as MV scallops' tenting and prolapse volumes, coaptation heights, and exposed and total A2 lengths may predict the possibility of significant MR after PBMV.

1. Introduction

Rheumatic mitral stenosis (MS) remains an important public health concern, particularly in developing countries.[1] The transcatheter approach gas developed to replace surgery in several cardiac procedures.[2] Surgical commissurotomy, first described in 1923, became the standard treatment for patients with MS in the late 1940s.[3] However, following the introduction of the Inoue balloon catheter in 1984, percutaneous mitral balloon valvuloplasty (PMBV) emerged as a safe and effective treatment for MS, eventually becoming the preferred treatment option for selected symptomatic MS patients.[4,5]

Two-dimensional echocardiography is used to evaluate MV morphological features including leaflet mobility, flexibility, thickness, and calcification, as well as subvalvular fusion, commissural fusion, and calcification.[6] These morphological features are used by different scoring systems to describe the extent of MV disease, to evaluate the suitability for PMBV, and to predict the success or even contraindication to PMBV as Wilkins score.[7] However, some patients develop significant MR post-PBMV in spite of having accepted scores before the procedure. The risk of significant MR is defined as an increase of $\geq$2/4 grade in MR severity[8] and new guidelines define it by a vena contracta area (VCA) measurement of $\geq 0.4\,cm^2$ on three-dimensional transesophageal echocardiography (3D-TEE).[9] Therefore, studying the predictors of MR after PBMV remains an important task in hand.

Abbreviations: 3D, Three Dimensional; ECG, Electrocardiography; ESPAP, Estimated Systolic Pulmonary Artery Pressure; MR, Mitral Regurgitation; MVQ, Mitral Valve Quantification; MV, Mitral Valve; PBMV, Percutaneous Balloon Mitral Valvuloplasty; VCA, Vena Contracta Area.

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Mitral valve quantification (MVQ) using 3D-TEE is a new modality, which is less dependent on the operator's variability and provides data on several parameters that are not assessed by other modalities.[10] We performed this pilot, prospective study to evaluate the role of 3D-TEE in the prediction of significant MR after PBMV through MVQ.

2. Materials and methods

2.1. Patient selection

Between October 2014 and October 2016, 37 patients with rheumatic, moderate-to-severe MS, referred to the Cath lab of Bab Alshearia University hospitals for PBMV, were divided into two age and sex matched groups. Group I included 25 patients without significant MR following PBMV (VCA $<0.4\,cm^2$), while group II included 12 patients with significant MR after PBMV (VCA $\geq 0.4\,cm^2$). All patients gave oral consent after understanding the objective and procedures of the study.

Patients were excluded if they were ineligible for PBMV (Wilkins score >9, MR severity >II grade, or left-ventricular (LV) ejection fraction <50%), had a contraindication for TEE, or had a clinical/lab/angiographic evidence of active rheumatic disease, coronary artery disease, severe aortic valve disease, organic tricuspid valve (TV) involvement, and chronic obstructive/restrictive lung disease. All patients in the study were subjected to full history taking, complete general and local examination, laboratory investigation (complete blood count, liver and renal function tests, and viral markers), and 12-lead electrocardiography.

2.2. Transthoracic echocardiography

An ECG-gated examination was performed with the patient lying on his left side and routine views were acquired, using a Philips iE X Matrix ultrasound machine and an S5-1 matrix array transducer (Philips medical system, Andover, USA). The following measures were recorded according to the recommendations of the American Society of Echocardiography (ASE): LV dimensions and systolic function, left atrium dimensions and volume, MV area by planimetry and pressure half time, transmitral mean pressure gradient, PBMV feasibility by Wilkins score, TV regurgitation and estimated systolic pulmonary artery pressure (ESPAP) by applying the modified Bernoulli equation to peak velocity, represented by the tricuspid regurgitation Doppler signal.

2.3. Transesophageal echocardiography

TEE done routinely before PBMV to exclude LAA thrombus,

Single heartbeat or multiple beats protocols 3D Full volume or 3D zoom were acquired several times,

- Step 1 (Cine Loop Opening): The data were acquired from the specific offline folder on the main page of the software (Full Volume Cine Loop or Zoomed 3D-TEE cine ECG-gated loop for the MV) (Fig. 1A).
- Step 2 (Frame selection and confirmation): Validation of the right frame was chosen. The correct frame is the early diastolic frame, just before opening of the MV (Fig. 1B).
- Step 3 (Image alignment): The images were presented in four quadrants, including three orthogonal planes, each representing an anatomic plane derived from the 3D data and a volume-rendered view. By rotating the volumes and moving the middle point to the locations (shown in the right lower box), the tool gets information about the location of different needed structures (Fig. 1C).
- Step 4 (annulus point identification): Initial points are needed to make an atlas-based estimation of the annulus, which is performed by moving the indicator points to the annulus. Furthermore, the nadir (coaptation point) and the lower aortic annulus must be marked to calculate different parameters (Fig. 1D).
- Step 5 (Annulus Editing) After the estimation is finished, the annulus points must be manually checked and, if needed, adapted to their right location by defining intermediate reference points in 18 radial planes (i.e. 36 reference points), rotated around the long axis (Fig. 1E).
- Step 6 (Commissure Editing): The two commissure points have to be manually placed. This can be done best using the 3D volume projection in the lower right box (Fig. 1F).
- Step 7 (Leaflet Editing) To determine the leaflets' areas, their location and curvature must be known. First, the leaflet's contour is estimated, which can be altered by clicking with the mouse on another location. With the right mouse button, the border between the two leaflets is selected and is used to distinate the leaflet area to the anteromedial or posteromedial areas (Fig. 1G).
- Step 8 (Border Editing) The border between the valvular segments can be assigned by dragging the diamond to their right locations. When this is not done properly, the area and lengths of each leaflet segment is not accurate and cannot be used (Fig. 1H).[11]

2.3.1. Quantitative assessment of mitral morphology

The reconstructed valve was displayed as a color-coded, 3D-rendered surface representing a topographical map. Measurements[10,12–14] of the key parameters (Figs. 2 and 3) were automatically generated (Supplementary file 1).

2.3.2. Vena contracta area (VCA) quantification

Three-dimensional color Doppler acquisitions were performed with excellent quality ECG tracing,[15] using either a four-chambers or a long-axis view. The acquisition sector angle, the color sector size and the imaging depth were adjusted to increase the temporal resolution, including the flow convergence zone, the vena contracta, and at least a proximal part of the regurgitant jet.[16] Tissue gain settings and color gain were kept in the same ranges as in the 2D color imaging to optimize the volume imaging rate (temporal resolution); however, single heartbeat or multiple beat protocols were used.[15]

Using the 2D long-axis images (systolic phase) that were automatically generated from the 3D volume by post-processing software, the longitudinal planes were adjusted to bisect the regurgitant jet in both images**.** Each systolic frame was examined to identify the frame in which the MR jet is the largest and best visualized.[17] Once this systolic frame is identified, the short-axis plane was moved up and down orthogonal to the regurgitant jet and tilted (in the jet direction) until the cross-sectional area of the VC can be visualized[18] (Fig. 4).

3. Results

3.1. Baseline data

We enrolled 37 patients, who underwent PBMV, divided into two groups: group I ($n = 25$, VCA $< 0.4\,cm^2$) and group II ($n = 12$, VCA $> 0.4\,cm^2$). Both groups were comparable in terms of age ($p = 0.47$), gender, BMI, clinical characteristics ($p > 0.05$), and echocardiographic measurements including mitral valve area ($p = 0.41$), mean pressure gradient ($p = 0.81$), and other preprocedural hemodynamic data (Table 1).

3.2. II. Hemodynamic data before and after PBMV

We recorded statistically significant differences ($p < 0.001$) between pre- and post-PBMV recordings, such as MV area,

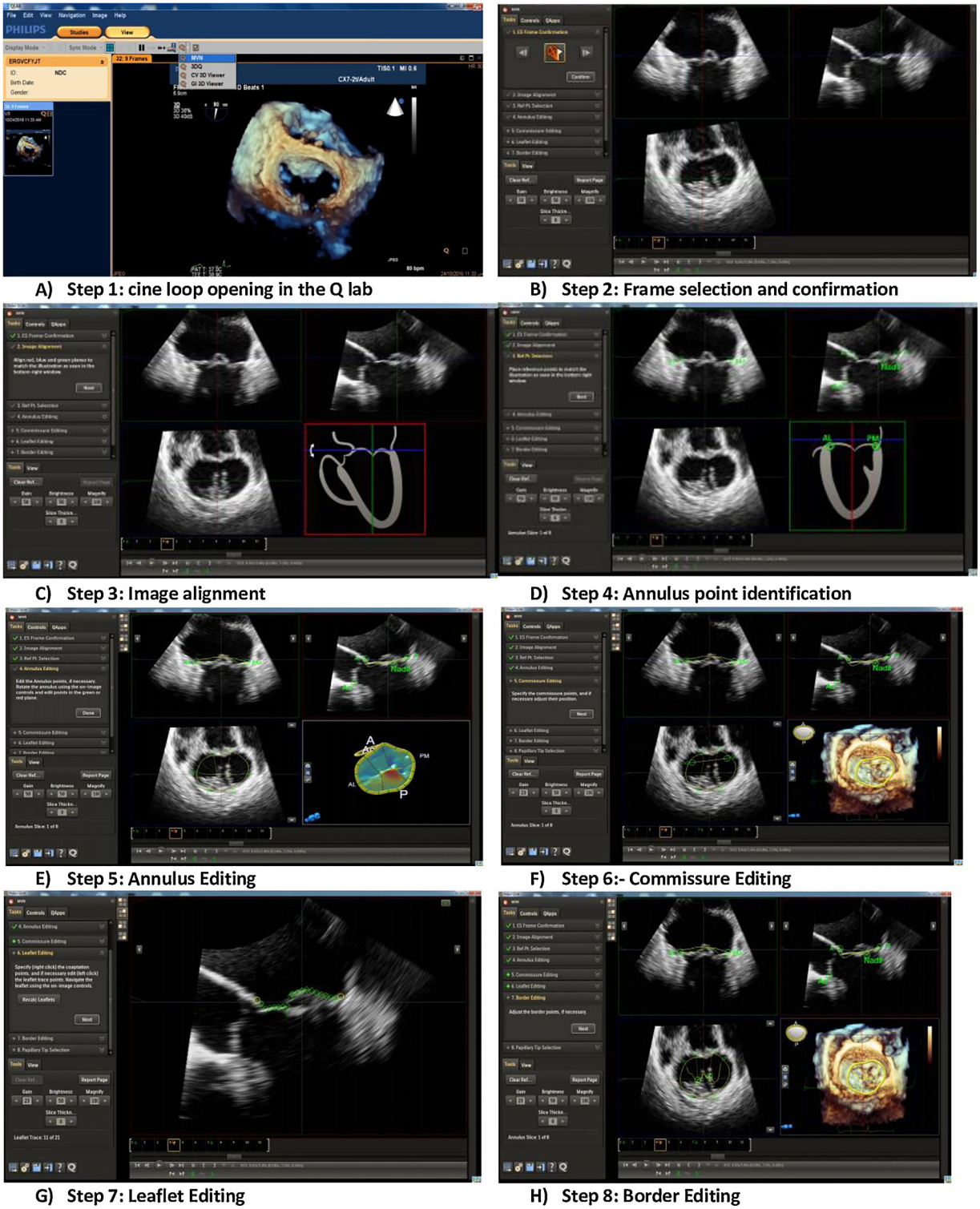

Fig. 1. A-Step 1: cine loop opening in the Q lab, B-Step 2: Frame selection and confirmation, C-Step 3: image alignment, D-Step 4: annulus point identification, E-Step 5: Annulus Editing, F-Step 6: Commissure Editing, G-Step 7: leaflet editing, and H-Step 8: border editing (Bruggink R et al., 2015).

ESPAP, left atrial pressure, and MV peak and mean pressure gradients (Table 2). No major complications, such as mortality, cerebrovascular accidents, severe MR necessitating surgery, and cardiac tamponade occurred during and after PBMV.

3.3. III. Mitral valve quantification data

3.3.1. Annular and leaflet MVQ

There were no significant differences between the two groups regarding MV annulus quantification parameters,

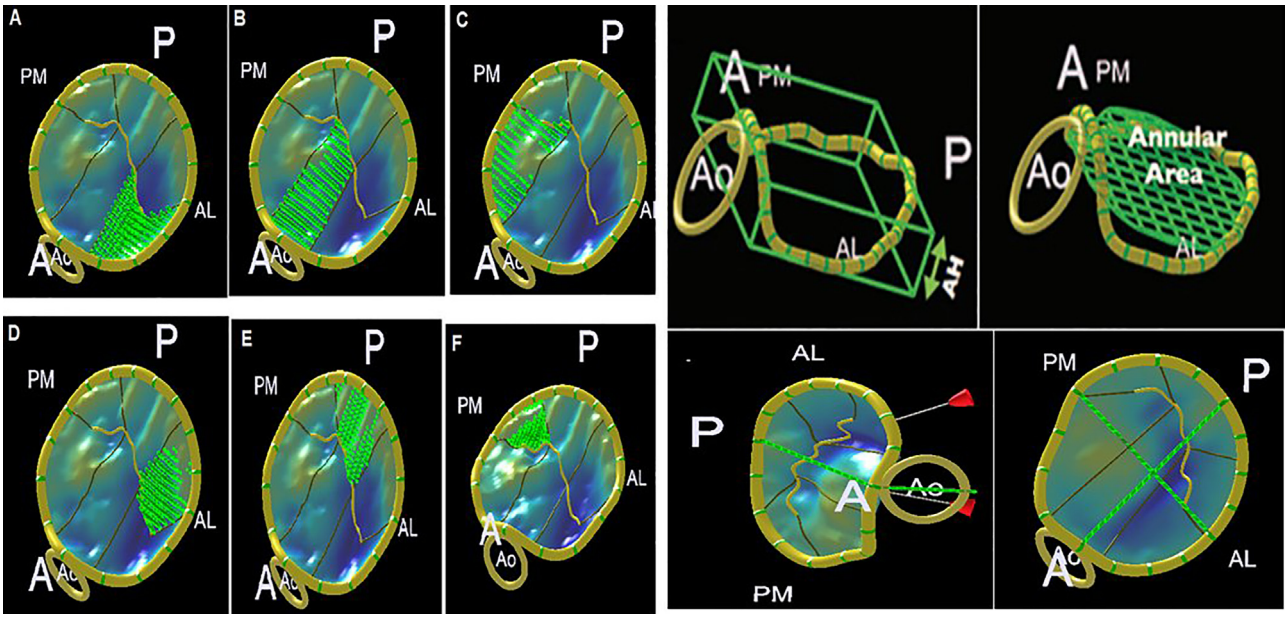

Fig. 2. Mitral valve quantification parameters, exported from the Q lab (MV scallops tenting volumes and some MV annulus quantification) (Sugeng L et al., 2012).

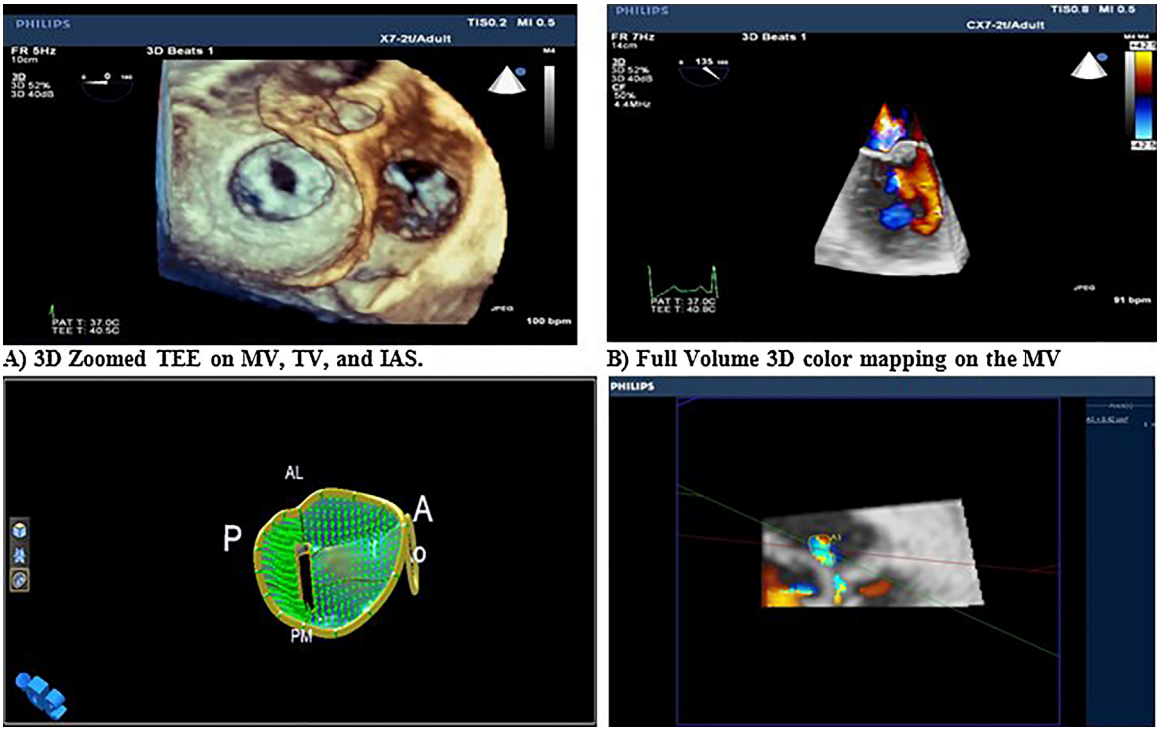

Fig. 3. A) 3D Zoomed TEE on MV, tricuspid valve, and interatrial septum, B) Full Volume 3D color mapping on the MV. C) Total MV tenting volume of patient in group II. D) Vena Contracta Area of patients in group II > 0.4 cm^2.

including anteroposterior (p = 0.64) and anterolateral-posteromedial (p = 0.53) diameters, annular 3D circumference (p = 0.23), height (p = 0.09) and ellipsicity (p = 0.79). Moreover, there were no significant differences between both groups as regard MV scallops' 3D-areas (p > 0.05), as well as total anterior (p = 0.55) and posterior (p = 0.71) leaflets' areas. Regarding MV scallops length, both groups were comparable in all measures, except for A2 (p = 0.04), P2 (p = 0.007), and total A2 length (p = 0.002) (Table 3).

3.3.2. Tenting volumes

Regarding the MV scallops tenting volumes; we detected statistically significant differences (p < 0.05) between the two groups in terms of the tenting volumes of A2, A3, P2, and P3, as well as the total MV tenting volume and height. However, both groups were comparable as regard A1 (p = 0.63) and P1 (p = 0.06) tenting volumes (Table 3).

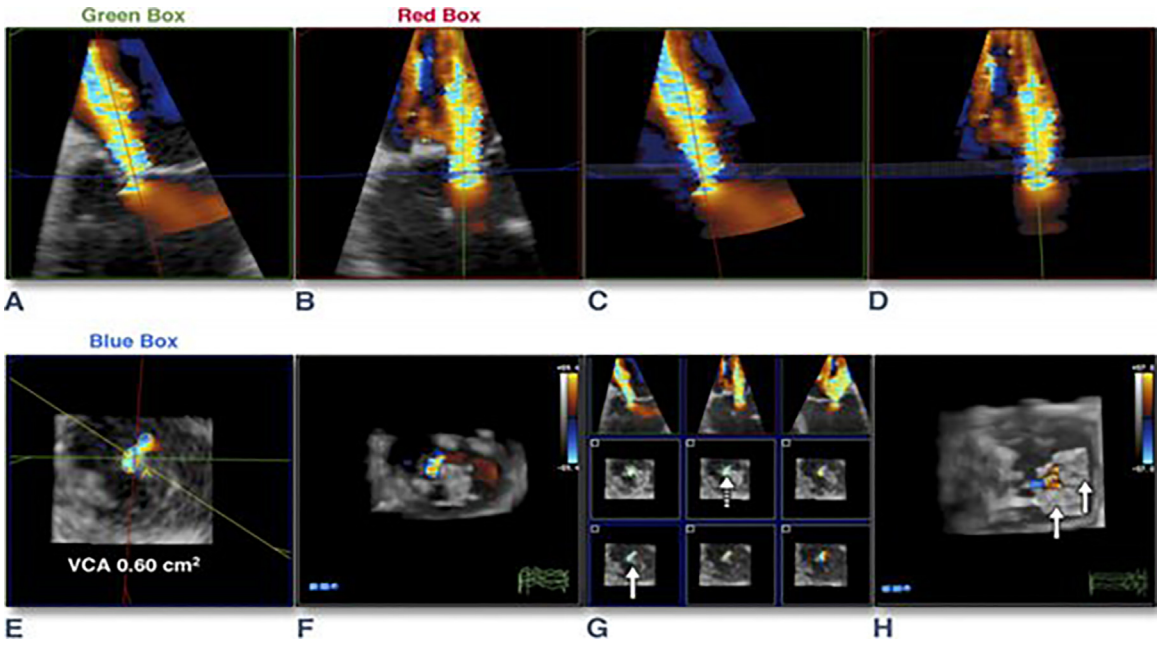

Fig. 4. Vena Contracta Area measurement with multiplanar reformat of the 3D TEE (Paaladinesh T et al., 2012).

3.3.3. Prolapse volumes

We recorded significant differences ($p < 0.05$) between the two groups as regard A2, A3, P2, and total MV prolapse volumes. However, there was no significant difference between both groups in terms of A1 ($p = 0.05$), P1 ($p = 0.47$) and P2 ($p = 0.13$) prolapse volumes (Table 3).

3.3.4. Coaptation parameters

Our analysis revealed a significant difference between the two groups as regard anterior and posterior coaptation heights ($p = 0.01$); however both groups were comparable ($p > 0.05$) as regard other MV coaptation parameter, as well as aortomitral angle (Table 4).

Table 1
Baseline Demographic and Echocardiographic Characteristics in both groups.

Demographic Criteria		Group I	Group II	P value
Age		29.476 ± 6.728	31.125 ± 7.228	>0.05
Gender	Male	5 (13%)	5 (13%)	>0.05
	Female	20 (56%)	7 (18%)	
BMI		27.2 ± 3.5	29.0 ± 3.2	>0.05
DM		1(2.7%)	0(0.0%)	>0.05
HTN		2(5.4%)	1(2.7%)	>0.05
Smoking		4 (11%)	2 (5%)	>0.05
Prior PMC		5 (20%)	2 (16.7)	>0.05
NYHA Class		2.6 ± 0.7	2.6 ± 0.7	>0.05
Echocardiographic Criteria				
Ejection fraction (%)		65.048 ± '3.471	65.563 ± 4.718	0.7042
Wilkins score		8.00 ± 0.97	8.64 ± 1.36	0.060
Wilkins score components				
Mobility		2.01 ± 0.47	2.04 ± 0.4	0.573
Valve Calcification		1.03 ± 0.53	1.50 ± 0.51	0.548
Thickness		2.05 ± 0.41	2.07 ± 0.51	0.893
Subvalvular Apparatus Thickening		2.27 ± 0.46	2.45 ± 0.54	0.215
Mitral valve area (cm2)		0.86 ± 0.23	0.93 ± 0.18	0.418
ESPAP (mmHg)		44.00 ± 9.91	47.06 ± 10.18	0.249
Left atrial pressure (mmHg)		26.55 ± 4.91	26.15 ± 4.27	0.729
MV peak gradient (mmHg)		22.44 ± 4.24	21.20 ± 4.82	0.848
MV mean gradient (mmHg)		13.33 ± 3.72	14.56 ± 3.80	0.818

4. Discussion

The present study validates a novel echocardiographic assessment score. Along with Wilkins score, application of MVQ scoring system during routine TEE examination before PBMV may improve patient selection for PBMV technique (suboptimal inflations) or MV replacement. In our study, no baseline clinical or preprocedural hemodynamic characteristics could predict the risk of significant MR following PBMV. These results are in agreement with several previous studies in the literature.[19,20] Regarding transthoracic echocardiographic data; none of them had a predictive value for MR development in our study.

The following parameters could significantly predict the risk of MR following PBMV: 1) A2 scallop morphology (A2 tenting volume, prolapse volume, and length), 2) MV leaflets prolapse, and 3) the coaptation height between anterior and posterior MV leaflets. On the other hand, the annulus shape, leaflets areas by 2D and 3D-TEE, and coaptation length of both MV leaflets had no predictive value in the prediction of MR. In contradiction to our results, smaller MV area and greater LA dimensions were proposed by Mailer et al and Cho et al as predictors for the development of significant MR following PBMV.[21,22]

Using 2D ultrasound has three main drawbacks that make it harder to perform a precise measurement: 1) lack of total structural overview, increasing the risk of misdiagnosis, 2) the use of assumptions and mental visualization in calculating volumes because they are depend on 2D measurements in two orthogonal views, and 3) the difficult reoperability in follow up measurements because the slice must be on the same location and angle as the previous measurements.[23] All these disadvantages are

Table 2
Hemodynamic and echocardiographic characteristics before and after BMV.

	Pre PBMV	Post PBMV	P value
Mitral valve area (cm^2)	0.89 ± 0.49	1.90 ± 0.22	<0.001
Pulmonary artery peak systolic pressure (mmHg)	61.07 ± 10.22	36.90 ± 6.23	<0.001
Left atrial pressure (mmHg)	26.21 ± 4.62	16.26 ± 4.18	<0.001
Mitral valve peak gradient (mmHg)	21.34 ± 4.75	9.62 ± 2.78	<0.001
Mitral valve mean gradient (mmHg)	13.60 ± 3.76	5.89 ± 2.32	<0.001

Table 3
Comparison between the two groups regarding MVQ parameter (Leaflets areas-tenting and prolapsing volume).

	Group I	Group II	P value
MV A1 3D area	474.25 ± 144.27	508.01 ± 128.35	0.2265
MV A2 3D area	579.91 ± 180.75	532.18 ± 197.61	0.1126
MV A3 3D area	513.63 ± 153.73	424.46 ± 104.06	0.1307
MV P1 3D area	306.05 ± 45.123	371.81 ± 114.91	0.2125
MV P2 3D area	525.14 ± 148.10	582.63 ± 70.897	0.4051
MV P3 3D area	303.72 ± 112.18	316.68 ± 53.842	0.2591
Total A Leaf 3 D Area	2335.3 ± 483.87	2043.1 ± 513.23	0.5517
Total P Leaf 3 D Area	1196.3 ± 153.16	1217.8 ± 151.66	0.7124
Total MV Leaflets 3 D Area	2597.1 ± 587.56	2752.0 ± 548.50	0.5874
A1 Tenting Volume	1.640 ± 0.7639	1.744 ± 0.5031	0.6395
A2 Tenting Volume	1.397 ± 0.5618	1.754 ± 0.3805	0.0356
A3 Tenting Volume	1.187 ± 0.4587	1.561 ± 0.3954	0.0134
P1 Tenting Volume	0.9924 ± 0.1358	1.049 ± 0.1771	0.0671
P2 Tenting Volume	0.7752 ± 0.4195	1.630 ± 0.4394	<0.0001
P3 Tenting Volume	0.7829 ± 0.2797	1.528 ± 0.4240	<0.0001
MV Tenting volume	6.857 ± 3.179	9.751 ± 2.013	0.0031
A1 Prolapse Volume	0.01281 ± 0.01390	0.01688 ± 0.01740	0.0551
A2 Prolapse Volume	0.006667 ± 0.01065	0.02188 ± 0.02880	0.0319
A3 Prolapse Volume	0.03286 ± 0.04797	0.07688 ± 0.07171	0.0318

Table 4
Comparison of between the two groups regarding MVQ parameter (annulus quantification – MV leaflets scallops lengths and MV coaptation parameters).

	Group I	Group II	P value
A1 length	27.564 ± 4.165	27.148 ± 2.579	0.7273
A2 length	35.813 ± 4.575	41.623 ± 4.284	0.0431
A3 length	30.814 ± 4.244	29.202 ± 2.253	0.1777
P1 length	19.557 ± 2.976	21.129 ± 2.740	0.1087
P2 length	22.730 ± 3.435	26.309 ± 4.254	0.0076
P3 length	21.634 ± 3.592	22.664 ± 1.840	0.3032
Total A2 length	43.560 ± 5.245	51.290 ± 3.524	0.0023
Direct A2 length	32.734 ± 2.154	34.581 ± 2.444	0.3529
Direct P2 length	19.378 ± 2.775	20.641 ± 3.325	0.831
MV Tenting Height	8.598 ± 1.636	11.128 ± 2.805	0.0328
MV Ant coaptation height	7.509 ± 1.589	5.777 ± 2.687	0.0194
MV post coaptation height	7.509 ± 1.589	5.777 ± 2.687	0.0194
MV Ant coaptation	42.151 ± 4.504	38.793 ± 5.422	0.1312
MV annulus AP diameter	49.074 ± 4.082	48.420 ± 4.228	0.6436
MV AL-PM diameter	50.004 ± 3.898	49.082 ± 5.102	0.5368
MV Ann height	9.802 ± 0.7013	10.409 ± 0.8099	0.0954
MV Ann3D Circ	168.44 ± 13.655	162.05 ± 19.766	0.2303
MV Ann2D Area	2110.9 ± 445.67	2023.6 ± 470.77	0.5715
MV Ann3D Min Area	2165.9 ± 448.57	2067.9 ± 484.83	0.5334
MV Ann ellipsicity	102.40 ± 9.906	101.53 ± 10.473	0.7979

avoided with 3D ultrasound; therefore, its use to predict the outcomes of PBMV may have additional practical implications.

4.1. Recommendations

1-Use of MVQ for patients with moderate-to-severe MS is recommended for better choice of the appropriate method of treatment either PBMV or surgical replacement, 2-Integrate the Q Lab software on the echo machine to be applied online for rapid evaluation and reporting, 3-Further studies with a larger sample size are required to confirm and validate our findings.

4.2. Conclusion

Mitral valve quantification through 3D-TEE is a simple automated method, easily applicable to patients before PBMV. Moreover, MVQ-derived data, such as MV tenting scallops, MV scallops prolapse, MV coaptation height, MV-exposed A2 length and total A2 length may predict the possibility of significant MR after PBMV.

Conflicts of interest

None to Declare.

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