ORIGINAL ARTICLE

Myxomatous mitral valve disease: comparison of different echocardiography methods and protocols. A transesophageal echocardiography study

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Abstract: Echocardiography is the main method for mitral valve (MV) anatomy assessment. To establish the relative importance of different imaging modalities, we compared four echocardiographic methods for MV prolapse diagnosis: standard 2D transesophageal echocardiography (TEE), complete 2D-TEE (including additional views to properly visualise all scallops), 3D-TEE, and 3D colour coded TEE modelling. **Methods and results –** We analysed MV morphology in 137 patients (57,11+/-11 year, 57% male) by these four methods: 38 normal subjects and 99 patients with mitral regurgitation. The complete 2D-TEE reclassified as prolapsing 34 scallops considered normal by standard 2D-TEE (mainly A1 and A3 scallops). By 3D-TEE 15 segments classified as normal by complete 2D-TEE were reclassified as prolapsing, allowing a better diagnosis of A1, P3, and commissural prolapse. Based on 3D-model data 8 segments have been reclassified compared to 3D-TEE. The accuracy of the other methods compared with the gold-standard 3D-TEE was 98% for complete 2D-TEE, 93% for standard 2D-TEE, and 98% for the 3D modelling. **Conclusion –** The MV cannot be properly analysed by 2D examination without a full, careful, and experienced evaluation (A1, A3, P3, the commissures are more challenging). Therefore, 3D-echocardiography becomes an essential tool for the precise diagnosis of MV prolapse in everyday clinical practice.

Keywords: mitral valve, prolapse, myxomatous mitral valve disease, transesophageal echocardiography, three-dimensional echocardiography

Rezumat: Ecografia reprezintă principala metodă imagistică de apreciere a morfologiei valvei mitrale. Pentru a stabili importanța diferitelor modalități în diagnosticul prolapsului de valvă mitrală, am comparat patru metode: ecografia transesofagiană (ETE) 2D standard, ETE 2D protocol complet (incluzând secțiuni suplimentare pentru vizualizarea tuturor segmentelor), ETE-3D și modelul matematic 3D. **Metode și rezultate –** Am analizat morfologia valvei mitrale în cazul a 137 de pacienți (57,11+/-11 ani, 57% bărbați) prin cele patru metode, 38 de normali și 99 pacienți cu regurgitare mitrală. ETE-2D protocol complet a reclasificat drept prolaps 34 de segmente considerate normale de ETE-2D standard (mai ales din categoria segmentelor A1 și A3). ETE-3D a reclasificat drept prolaps 15 segmente considerate normale prin ETE-2D protocol complet. Modelul 3D matematic a reclasificat 8 segmente comparativ cu ETE-3D. Acuratețea metodelor comparativ cu standardul de aur ETE-3D a fost 99% pentru ETE-2D protocol complet, 93% pentru ETE-2D standard și 98% pentru modelul 3D. **Concluzii –** Morfologia valvei mitrale nu poate fi evaluată în întregime corespunzător prin ecografie 2D, aprecierea caracteristicilor segmentelor A1, A3, P3 și comisurilor fiind dificilă. Astfel ecografia 3D a devenit un instrument esențial în diagnosticul prolapsului de valvă mitrală în practica clinică de zi cu zi.

INTRODUCTION

Mitral valve repair is the surgical method of choice for patients with severe mitral regurgitation due to myxomatous mitral valve disease whenever the valve is deemed reparable by detailed imaging assessment and the required surgical expertise is available.

Therefore, precise knowledge of mitral valve morphology and function is mandatory for proper patient management. Echocardiography is the main method for the diagnosis and detailed mitral valve anatomy description in patients with mitral regurgitation. Morphologically, myxomatous mitral valve disease is characte-

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rized by fibromyxomatous changes, mucopolysaccharide accumulation and collagen alternation[1]. However, the echocardiographic definition of this pathology is still debatable and has changed in parallel with different technical developments (from M-mode echocardiography to bi-dimensional echocardiography and 3D echocardiography). In general, it is characterized by systolic displacement of abnormally thickened mitral leaflets[2] into the left atrium[3]. However, looking at the same patient by different echocardiographic modalities may sometimes lead to different conclusions regarding the mitral valve: prolapsing vs non-prolapsing. Therefore, the purpose of this study was to compare four echocardiographic methods for the diagnosis of mitral valve prolapse: standard 2D transesophageal echocardiography (TEE) (including just the four chamber, two chamber, long axis, and bi-commisural views), complete 2D TEE (including additional and modified views for the proper visualisation of all scallops and the commissures), 3D TEE, and 3D colour coded TEE modelling.

METHODS

Study population

All patients with an established diagnosis of significant mitral regurgitation (MR) due to myxomatous disease referred to our department for transesophageal echocardiography (TEE) were included. A control group - composed of patients who were sent to our echocardiography laboratory for clinically indicated TEE, but in whom no significant cardiovascular pathology was identified - were also analysed.

The exclusion criteria were: ischemic heart disease, history of rheumatic fever or rheumatic valve disease, significant calcification of the mitral annulus, significant concomitant aortic or tricuspid valve disease (>mild), left ventricular systolic dysfunction (left ventricular ejection fraction <60%), non-sinus rhythm.

The following clinical data were collected for all patients: age, gender, history of hypertension, symptoms (e.g. dyspnoea, chest pain, palpitations, syncope). The clinical status was defined according to the New York Heart Association (NYHA) classification. Physical examination and 12-lead electrocardiography were performed in all patients.

Transesophageal 2D and 3D echocardiography

All patients had complete echocardiographic examinations (EAE protocol) followed by 3D acquisitions for the mitral valve (3D and colour 3D). Electrocardiographically gated full-volume loops were acquired over 4 cardiac cycles at a frame rate of 15 to 45 frames/s. The volume for mitral valve was a multi-beat acquisition with at least 15 frames per second.

The mitral valve morphology was analysed off-line in standard 2D TEE views following a complete TEE protocol[4]. The standard TEE exam included the four basic views for mitral valve analysis: four chamber, bi-commisural, two chamber and long axis views. The complete 2D TEE exam included all views described in Figure 1, allowing the visualisation of each scallop in at least two separate views. We used the Carpentier classification to describe the components of each leaflet. The posterior mitral leaflet is formed by three scallops: P1 (anterolateral), P2 (middle), and P3 (posteromedial), while the corresponding segments of the anterior mitral leaflet are labelled A1, A2, and A3[5]. Every scallop of the mitral valve was characterized as being normal, prolapsing, or flail. The prolapse was defined as supra-annular displacement of the leaflet body, with leaflet tips pointing towards the left ventricle, while flail was defined the orientation of free margin of the mitral leaflet towards the left atrium, with the leaflet tip pointing towards the left atrium during systole. The visualisation of ruptured chordae was noted. Using 2D images we measured the following parameters of mitral annulus (MA): antero-posterior diameter in mid-esophageal long axis view, anterolateral-posteromedial diameter in mid-esophageal commissural view, and of mitral valve leaflets: the length of the anterior and posterior leaflets in the mid-esophageal long axis view.

The morphology of every scallop was also appreciated by 3D echocardiography: from the 'surgical view' and from specific cut planes used in this volumetric data set (Figure 2). Based on the number of scallops affected we subdivided the group of patients with MR in limited mitral valve disease (1-2 scallops affected by prolapse/flail) and extensive (3-6 scallops affected by prolapse/flail).

The mitral valve was reconstructed from the acquired 3D volume using a specific software (4D MV Assessment 2.0 TomTec imaging Systems). The mathematical model illustrates graphically the leaflet topology by colouring each point of the leaflet surface of the model according to its distance to the best fitting plane of the mitral annulus. This plane is defined as the plane that fits the majority of points of the mitral annulus and minimizes the distance to points that are not on the plane. Generally, this plane is located lower than the highest points of the mitral annulus and higher than the lowest points of the mitral annulus. The

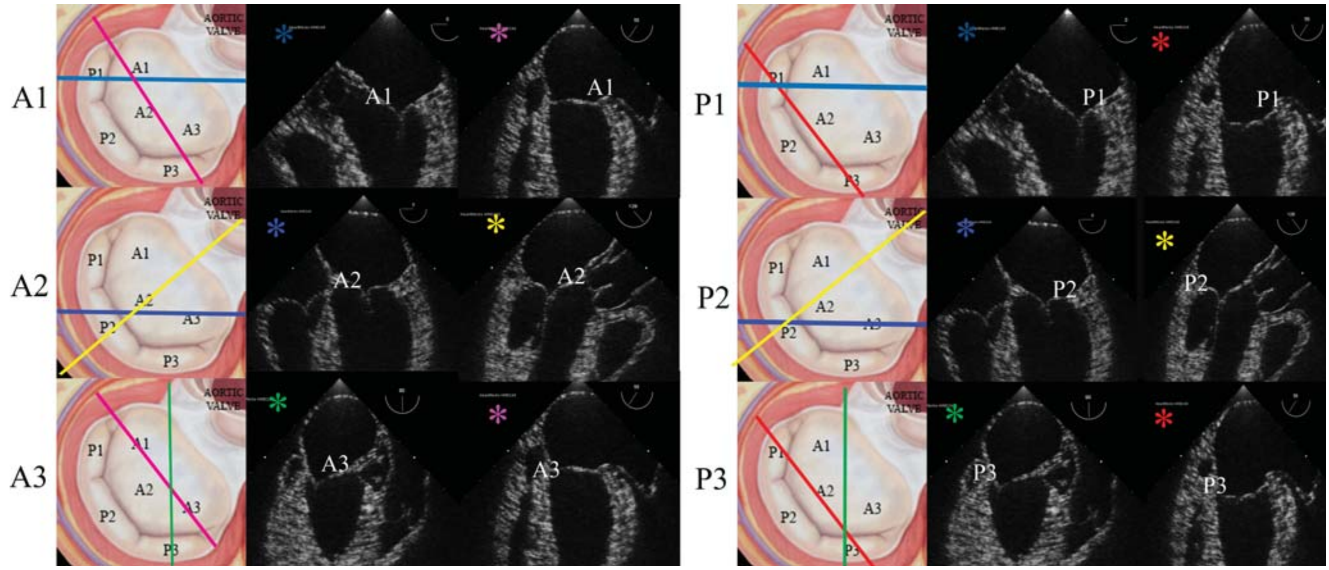

Figure 1. 2D transesophageal echocardiography complete protocol for analysing the mitral valve morphology (mid-systole still images): A1 visualisation in mid-esophageal five chamber view (light blue plane) and modified bi-commisural view (probe rotated to right for the visualisation of the entire anterior leaflet A1-A2-A3) (pink plane); A2 visualisation in mid-esophageal four chamber view (blue plane) and long-axis view (yellow plane); A3 visualisation in the modified two-chamber view (probe rotated to the right for the visualisation of A3 and P3 scallops) (green plane), and modified bi-commisural view mentioned previously (pink plane); P1 visualisation in five chamber view (light blue plane) and bi-commisural view (red plane); P2 visualisation in mid-esophageal four chamber view (blue plane) and long axis view (yellow plane); P3 visualisation in modified two chamber view mentioned previously (green plane) and bi-commsiural view (red plane). Every scallop is analysed in at least two different views and prolapse is defined as the systolic movement of that segments into the left atrium during systole, above the mitral annulus.

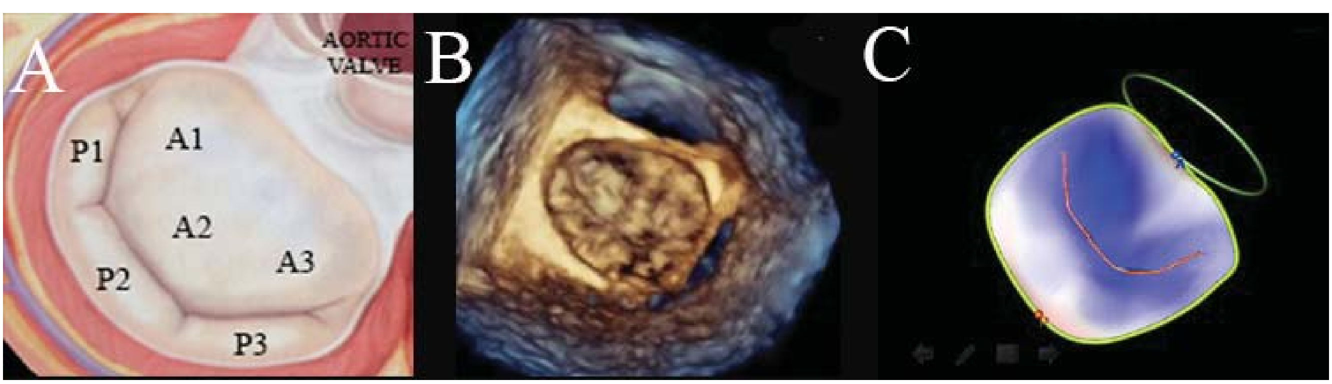

Figure 2. Mitral valve scallops based on Carpentier's classification: three scallops at the level of the posterior leaflet, separated by incisures noted P1-P2-P3, P1 being adjacent to the left atrium appendage and antero-lateral commissure, and P3 being adjacent to the postero-medial commissure and the tricuspid valve; and three corresponding anterior mitral leaflet scallops: A1-A2-A3 (A). The mitral valve can be analysed by 3D TEE using the 'surgical view'. Looking from left atrium down to the mitral valve all the above-mentioned scallops can be easily visualized; note the normal closure and the lack of prolapsing segments in a normal subject (B). The mathematical 3D model is a colour coded model showing non-prolapsing scallops coloured in blue, and prolapsing scallops coloured in red; note the blue appearance in a normal subject (C).

points of mitral valve leaflets located above this plane, in the left atrium, are coded in red, the points located below this plane, towards the left ventricle, are coded in blue, while the points located in this plane are coded in white (Figure 3). Therefore, the part of mitral valve leaflets displayed in red is considered prolapsing. The antero-posterior and anterolateral-posteromedial mitral annulus diameters, as well as the anterior and posterior leaflet areas, were automatically calculated by the software.

Figure 3. The graphic representation of the best fitted plane for a saddle shape structure (A). The mathematical 3D model reconstructs the mitral valve annulus (yellow line), the mitral valve leaflets (green), and the coaptation line (red line) (B). The colour coded model allows the possibility to appreciate mitral valve prolapse: the points of MV leaflets located above the best fitted plane are coloured in blue, the points of MV leaflets located below the best fitted plane are coloured in red, while the points located at the best fitted plane level are coloured in white (C). The colour intensity (i.e. blue and red) is proportional with the distance from the best fitted plane.

The data obtained by 3D TEE analysis were considered the gold standard method[6]. The MV assessment by standard 2D TEE, complete 2D TEE, 3D TEE, and 3D mathematical model was performed remotely, blinded, by an experienced echocardiographer, holding EACVI certification in TEE (MMG).

Statistical Analysis

Continuous data are presented as mean +/- SD and nonparametric data as median and ranges.

For testing the differences between two groups we used Student's *t*-test and between three groups we used one-way ANOVA. The relationships between different parameters were assessed by correlation analysis: Pearson's method or Spearman's r method, as appropriate. Reproducibility of the 3D parameters measurements was assessed in a randomly chosen group of 15 patients. Intraobserver variability was assessed using repeated measurements performed by the same observer one month apart, while interobserver variability was evaluated by repeating the analysis by a second independent observer, blinded to the results of all prior measurements. The intraobserver variability was 96% for standard 2D TEE, 94% for complete 2D TEE, 98% for 3D TEE and 98% for 3D model TEE, while interobserver variability was 84% for standard 2D TEE, 84% for complete 2D TEE, 84% for 3D TEE and 96% for 3D model TEE. Statistical analyses were performed using SPSS version 21.0 (SPSS, Inc., Chicago, IL). P values <0.05 were considered significant.

RESULTS

One hundred and fifty patients were included: 110 patients with organic mitral regurgitation due to myxomatous mitral valve disease, and 40 normal subjects. Thirteen patients were excluded after the echo analysis due to poor image quality and inadequate temporal resolution. Therefore, 137 patients were included in the final study group: 38 normal subjects and 99 patients with mitral regurgitation (MR).

The mean age (54.9+/-10.6 vs 58.3+/-11.7, p=0.12) and gender distribution (57% men vs 57% men, p=0.9) were similar in the group of patients with mitral regurgitation and in the normal group. The normal subjects had no symptoms, while in the MR group there were 52 patients in NYHA I class, 37 patients NYHA II class and 10 patients NYHA III class.

Using the 3D TEE protocol in the MR group 28 patients (28%) had just one scallop affected by prolapse, 22 patients (22%) had two scallops, 12 patients (12%) had three scallops, 9 patients (9%) had four scallops, 5 patients (5%) had five scallops and 21 patients (21%) had all scallops affected. Two patients with severe mitral regurgitation had an isolated lesion of the posterior commissure, with no evidence for prolapse. In 6 patients (6%) the pathology was seen only at the level of the anterior mitral leaflet, in 49 patients (49%) the pathology was seen only at the level of the posterior mitral leaflet, while in 44 patients (44%) both mitral leaflets were affected. The patients' classification based

Table 1

Number of segments with prolapse	2D TEE standard	2D TEE complete	3D TEE	3D model TEE
No prolapsing scallops	41	39	40	40
1	38	32	28	29
2	22	25	22	19
3	9	9	12	15
4	10	6	9	7
5	3	6	5	7
6	14	20	21	20

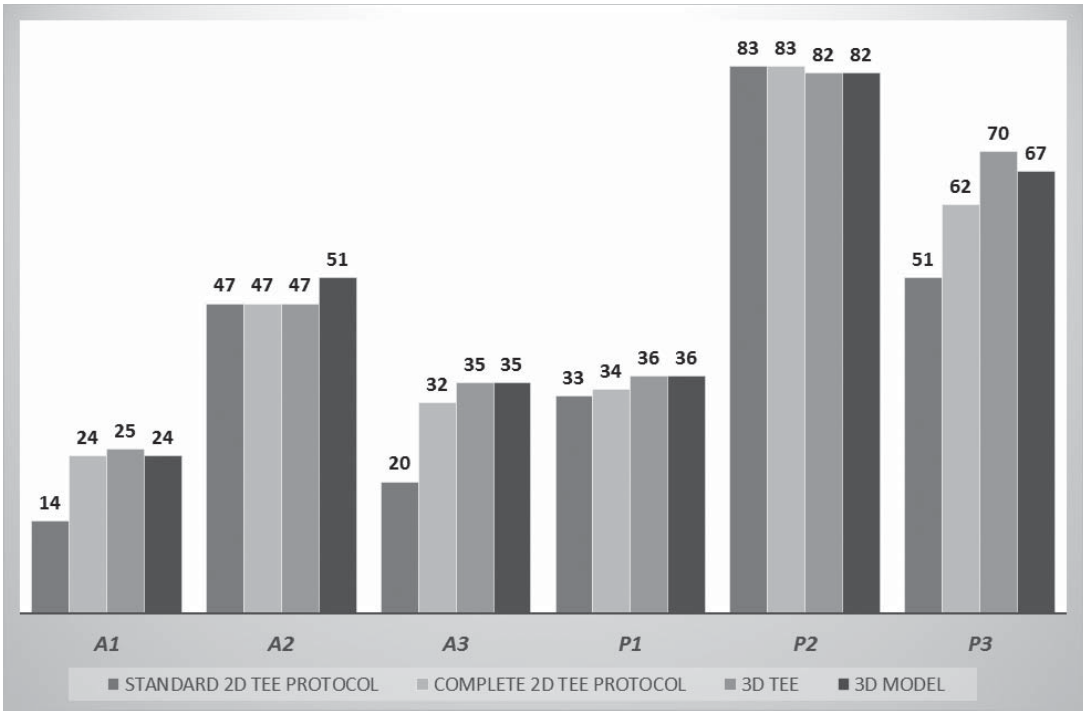

Figure 4. The graphic representation of number of affected scallops by the four methods: standard 2D TEE, complete 2D TEE, 3D TEE and 3D TEE model. The main difference relates to the A1, A3 and P3 scallops.

on the extension of mitral valve prolapse by the four methods is presented in Table 1.

We overall analysed 137 segments of each type (A1, A2, A3, P1, P2, P3) by the four methods: standard 2D TEE, complete 2D TEE, 3D TEE, and 3D model TEE. The results are presented in Figure 4 and Table 2.

The advantages of complete 2D TEE compared to standard 2D TEE are demonstrated by the high number of segments classified as normal by standard 2D TEE and reclassified as prolapsing by complete 2D TEE (34 segments: 4,1% of all the scallops analysed). In fact, 29% of prolapsing A1 scallops, 37% of prolapsing A3 scallops and 17% of prolapsing P3 scallops were not detected by sole analysis of standard 2D TEE views.

3D TEE provides new incremental information and 15 segments classified as normal by complete 2D TEE were reclassified as prolapsing by 3D TEE, while one scallop considered prolapsing by complete 2D TEE was considered normal by 3D TEE. Of note, 8 P3 scallops considered normal by complete 2D TEE were considered prolapsing after 3D TEE analysis (i.e. 5% of all P3 scallops analysed). Compared to complete 2D TEE, 3D modelling reclassified as prolapsing 4 A2 scallops, 3 A3 scallops and 5 P3 scallops. Comparing 3D TEE data with 3D model TEE data 8 segments from 822 have been reclassified based on 3D model (4 A2 scallops were considered prolapsing and 3P3 scallops were considered non-prolapsing by 3D model TEE) (Figure 5).

Table 2

	Number of pts in which this scallop was prolapsing by 3D TEE	Number of prolapsing segments reclassified by 3D TEE comparing to standard 2D TEE	Number of prolapsing segments reclassified by 3D TEE comparing to complete 2D TEE	Number of prolapsing segments reclassified by 3D TEE comparing to 3D model TEE
A1	25	11	1	1
A2	47	0	0	4
A3	35	15	3	0
P1	36	3	2	0
P2	82	1	1	0
P3	70	19	8	3
overall		**49**	**15**	**8**

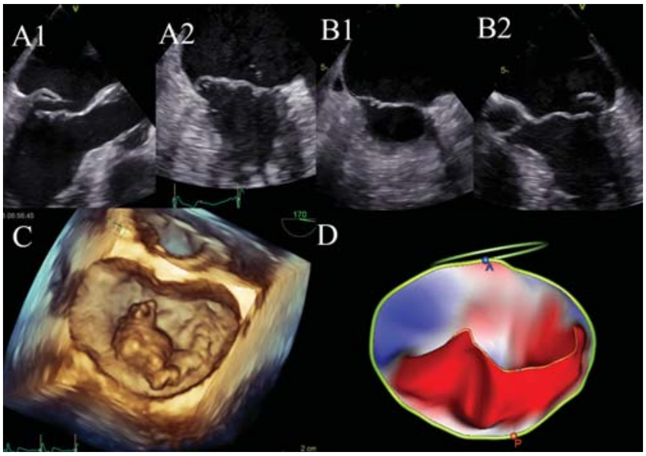

Figure 5. Mitral valve analysis in a patient with myxomatous mitral valve disease. The 2D standard TEE showed P2 prolapse visualised in long axis view (A1) and P3 prolapse visualised in bicommisural view (A2); The 2D TEE complete examination proved also A3 prolapse visualised in modified bicommisural view (B1) and P1 prolapse visualised in five chamber view (B2). The 3D TEE surgical view of the mitral valve suggests prolapsing of P2, P3 and A3 scallops (C), while the 3D mathematical model shows that the body of A2 is above the mitral annulus as well (D).

The accuracy of the other methods compared with gold standard 3D TEE is: 98% for complete 2D TEE, 93% for standard 2D TEE, and 98% for 3D modelling.

Patients with scallops reclassified from non-prolapsing to prolapsing by complete vs standard 2D TEE had more often severe mitral regurgitation (73.1% of reclassified patients vs 40.3% of non-reclassified patients have severe mitral regurgitation, p<0.001) and extensive mitral valve disease (61.5% of reclassified patients vs 51.4% of non-reclassified patients have more than 3 scallops affected, p<0.001). Patients with scallops reclassified from non-prolapsing to prolapsing by 3D vs complete 2D TEE have more frequent severe mitral regurgitation (53.2% from reclassified patients vs 45.1 % from non-reclassified patients have severe mitral regurgitation, p<0.001) and limited mitral valve disease (92.3 % from reclassified patients vs 43.4 % from non-reclassified patients have less than 2 scallops affected).

Table 3

Accuracy comparing to gold standard 3D TEE	**Standard 2D TEE**	**Complete 2D TEE**	**3D model TEE**
A1	68%	99%	99%
A2	100%	100%	91%
A3	54%	93%	93%
P1	89%	92%	97%
P2	100%	99%	99%
P3	70%	88%	96%

Based on complete 2D TEE exam, 20 patients have the anterior commissure affected, and 38 patients have the posterior commissure affected. The anterior commissure was generally affected in patients with extensive mitral valve disease (just in one case less than two scallops were affected) and the posterior commissure was affected in 11 cases with limited mitral valve disease and 27 cases with extensive mitral valve disease. Using 3D echocardiography one case with anterior commissure involvement and three more cases with posterior commissure involvement were detected (Figure 6). 3D TEE was useful for the detection of one case with P1-P2 and P2-P3 pseudo-commissures, and one case with posterior mitral valve cleft (Figure 7).

Mitral valve flail was detected by complete 2D TEE for 55 scallops (four A2 scallops, one A3 scallop, one P1 scallop, 46 P2 scallops and 3 P3 scallops). Using standard 2D TEE we detected flail in 44 cases (2 A2 scallops and 42 P2 scallops) while using 3D TEE flail was observed in 40 segments (4A2 scallops, 4P3 scallops, and 32 P2 scallops).

The length of the anterior and the posterior mitral leaflets measured by 2D echocardiography in the long axis view had a weak correlation with the area of the anterior and respectively posterior mitral leaflet, mea-

Figure 6. Severe mitral regurgitation visualised in the bi-commisural view, the origin of mitral regurgitation jet being adjacent to the P3 scallop (A). The 3D surgical view (B) and the 3D model (C) proved that the P3 scallop is prolapsing and the posterior commissure is also affected.

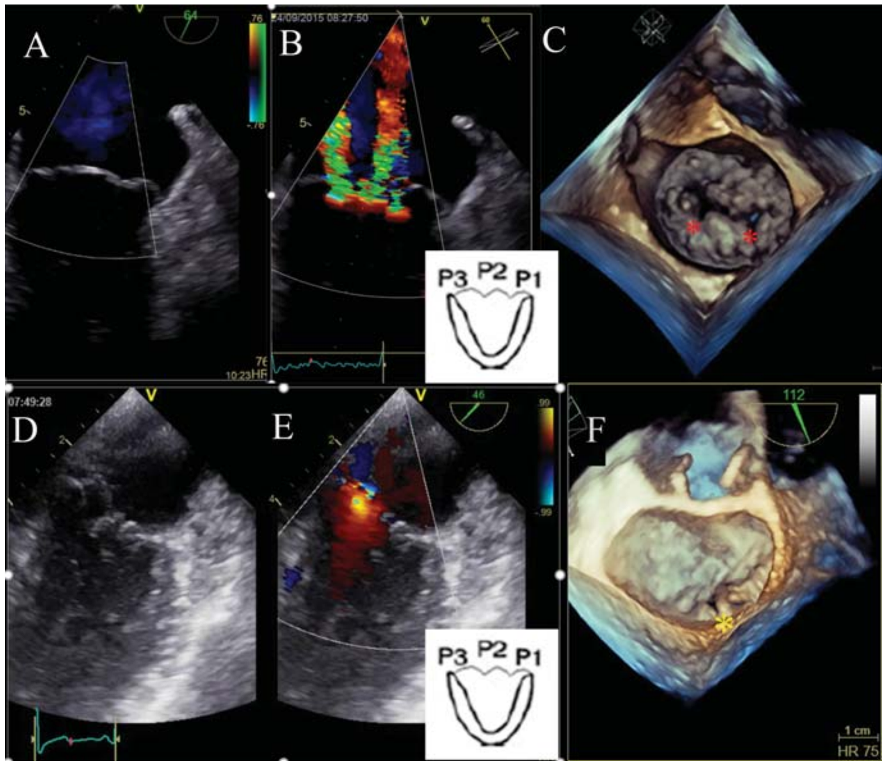

Figure 7. 2D color Doppler TEE in a patient with mixomatous mitral valve disease: in the standard bi-commisural view (A) there is no mitral regurgitation jet, while in the modified bi-commisural view at P1-P2-P3 level there are three jets of mitral regurgitation (B). The 3D atrial view of the mitral valve is very helpful for establishing the diagnosis: one jet is central at the level of A2-P2 that are prolapsing, and the other two jets are located at the level of pseudo-commisures between P1-P2 and P3-P2 (C). In another case of mitral regurgitation,the modified bi-commisural view at P1-P2-P3 level suggests mitral valve prolapse and mitral regurgitation jet at the level of P2 scallop (D, E); the 3D surgical view of the mitral valve is very helpful for establishing the diagnosis: P1-P2 cleft (F).

sured by 3D echocardiography ($r=0.27$, $p=0.01$ and $r=0.17$, $p=0.05$, respectively).

The antero-posterior MA diameter measured by 2D TEE in the long axis view, and the anterolateral-posteromedial MA diameter measured by 2D TEE in bi-commissural view had moderate correlations with the values of these diameters obtained by 3D geometrical reconstruction ($r=0.39$, $p<0.001$ and $r=0.53$, $p<0.001$). However, the values obtained by 2D versus 3D echocardiography are significantly different for the antero-posterior diameter of the mitral annulus: 3.4+/-0.54 cm vs 3.5+/-0.61 cm, $p=0.002$.

DISCUSSION

Mitral valve prolapse was described by John Brereton Barlow[7] already 50 years ago, based on clinical auscultation and cine-angiographic exam. However, even after five decades, it remains a difficult to define entity[8].

Table 4

Study	Patients	Methods	Results
Pepi et al[6]	112 pts	2D TTE, 3D TTE, 2D TEE, 3D TEE and surgical inspection	3D TEE has the best accuracy comparing to surgical inspection (95%)
Grewal et al[21]	42 pts	2D vs 3D TEE vs surgical inspection	Three-dimensional TEE imaging was superior to 2D TEE imaging in the diagnosis of P1, A2, A3, and bileaflet disease
Tamborini et al[22]	200pts	3D TEE vs surgical inspection	Three-dimensional TTE allowed an accurate identification (95% accuracy) of all MV lesions.
La-Canna et al[23]	222pts	2D TTE, 3D TTE, 2D TEE, 3D TEE and surgical inspection	RT3D-TEE correctly identified 58 (96.5%) compared to 42 (70%), 31 (52%), and 21 (35%) detected by 2D-TEE, RT3D-TTE, and 2D-TTE ($p < 0.0001$).
Gracia-Orta et al[24]	81 pts	2D vs 3D TEE vs surgical inspection	The 2D study incorrectly classified 22 segments, mainly corresponding to complex disease. The 3D study incorrectly classified 14 segments, unrelated to complex disease.

It was initially recognized as a clinical entity, the most important auscultatory element being the late systolic click, with or without a late systolic murmur[9]. The first echocardiographic features described by M mode echo (late systolic negative flow)[10] had low sensitivity and specificity compared to clinical and angiographic data[11]. Bi-dimensional echocardiography defined mitral valve prolapse as the superior systolic movement of mitral valve leaflet in relation to the mitral annulus[12]. Therefore, the early studies reported a high incidence of mitral valve prolapse[13,14], considering abnormal the superior displacement of mitral valve leaflets even in the four-chamber view. The description of the 3D saddle shape of the mitral annulus[15] changed the understanding and assessment of mitral valve prolapse. This new information suggested that mitral valve prolapse should be diagnosed only in the long-axis view, but in this view only the A2 and P2 scallops can be analysed. The current agreement is that diagnosis of mitral valve prolapse can be made in any view as long as billowing of the anterior mitral leaflet of less than 5 mm is not considered[16]. The 3D reconstruction of the mitral valve offers the possibility to overcome these problems and to diagnose and localise accurately the mitral valve prolapse[17].

The usefulness of 3D TEE in the correct identification of prolapsing scallops has been proved previously[18,19], with an accuracy of this method compared to intraoperative results of >95%[6]. The advantages of 3D TEE over 2D TEE in localisation of mitral valve prolapse are even more important for inexperienced echocardiographers, compared to expert echocardiographers[20]. In our study, the accuracy of 2D vs 3D TEE in the diagnosis of MV prolapse was 98%, higher than previously reported, probably due to multiple views utilised for MV examination. The advantage of 3D TEE vs complete 2D TEE was important mainly for the diagnosis of A3, P1 and P3 prolapse. The detection of mitral valve flail and cordal rupture was higher for complete 2D TEE comparing to 2D TEE probable due to the higher temporal resolution. Therefore, a complete 2D TEE exam of the MV remains of great value for the diagnosis of prolapse[25]. Conversely, the standard 2D TEE examination has a low sensitivity for MV prolapse diagnosis, mainly concerning the A3 and P3 scallops.

The new method analysed in our study was the identification of prolapsing scallops based on colour coded mathematical modelling. The differences between 3D TEE and the mathematical model are mainly explained by the model considering the distance from every point of MV leaflets to the best fitting plane, and not to the mitral annulus plane. The accuracy of 3D TEE model vs 3D TEE is 98%. Of note, this difference is mainly related to the A2 scallop: the basal part of A2 may be superior to the best fitted plane, but still inferior to the highest point of the mitral annulus (the anterior point). The use of this colour coded mathematical model may overcome some of the difficulties in making the diagnosis of MV prolapse[15,26,27] and may be very useful in everyday clinical practice[28], especially for interpreters with limited experience[29]. The method needs further validation against intraoperative findings.

Three-dimensional TEE is superior in the diagnosis of MV indentations (i.e. grooves separating the posterior mitral leaflets <50% of leaflet length), or clefts indentations (i.e. grooves separating the posterior mitral leaflets less than 50% of leaflet length)[30].

STUDY LIMITATIONS

The main limitation of our study was that the mitral valve was evaluated only by echocardiography and no surgical or anatomical information was available for comparison.

CONCLUSION

Three-dimensional echocardiography becomes an essential tool for the precise diagnosis of mitral valve prolapse in everyday clinical practice because certain areas of the mitral valve cannot be seen completely without a full, careful and experienced evaluation (A1, A3, P3, commissurres). The 3D colour-coded mathematical model generated semi-automatically may be very useful for less experienced echocardiographers. Two-dimensional TEE remains an important diagnostic tool in experienced hands, able to perform a complete mitral valve examination. The standard 2D TEE exam has a low sensitivity for the diagnosis of mitral valve prolapse and should not be recommended as the only method for mitral valve morphology analysis.

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