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ORIGINAL PAPER

The role of experience in echocardiographic identification of location and extent of mitral valve prolapse with 2D and 3D echocardiography

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Abstract Contradiction exists on the incremental value of two-dimensional (2D) and 3D transoesophageal echocardiography (TOE) over 2D transthoracic echocardiography (TTE) for the detection of mitral valve (MV) prolapse in readers with different echocardiographic experience. Twenty patients and five healthy persons were retrospectively identified who had undergone 2D-TTE, 2D-TOE and 3D-TOE. Fifteen (75 %) patients had surgical evidence of prolapse of the posterior MV leaflet and five patients (25 %) had a dilated MV annulus without prolapse. Three reader groups with different echocardiographic expertise (novice, trainees, cardiologists) scored thus in total 675 posterior scallops. Overall there was an improvement in agreement and Kappa values from novice to trainees to cardiologists. Diagnostic accuracies of 2D-TOE were higher than those of 2D-TTE mainly in novice readers. The incremental value of 3D-TOE over 2D-TOE was mainly seen in specificities. Time to diagnosis was dramatically reduced from 2D to 3D-TEE in all reader groups (all $P<0.001$). 3D-TOE also improved the agreement (+12 to +16 %) and Kappa values (+0.14 to +0.21) in all reader groups for the exact description of P2 prolapse. Differences between readers with variable experience in determining the precise localization and extent of the prolapsing posterior MV scallops exist in particular in 2D-TTE analysis. 3D-TOE analysis was extremely fast compared to the 2D analysis methods and showed the best diagnostic accuracy (mainly driven by specificity) with identification of P1 and P3 prolapse still improving from novice to trainees to cardiologists and provided optimal description of P2 prolapse extent.

Keywords Mitral valve prolapse · Two-dimensional echocardiography · Three-dimensional echocardiography

Introduction

Mitral valve (MV) prolapse is the leading cause of mitral regurgitation and the most frequent reason for MV surgery in the industrialized world [1]. Localisation of the prolapse is crucial for planning surgical management [2]. Two-dimensional (2D) transthoracic and transoesophageal echocardiography (TTE and TOE) are at this moment in most hospitals still the imaging modality of choice for assessment of the MV scallop(s). It is well recognized that a high level of expertise is required for accurate acquisition and interpretation of the 2D images. More recently, in several studies it has been demonstrated that 3D-TOE may be more easy and accurate to identify the locations of MV prolapse [3–6]. However, the generalizability of 3D-TOE publications has been questioned since the observers were usually highly experienced experts working in academic referral centers. Reproducibility is crucial for validation of the general concept that 3D-TOE is the superior imaging

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technique in non-experts. Currently, sparse data are available on this topic with contradictory results [7, 8]. The current study was undertaken to assess the value of 2D-TTE, 2D-TOE and 3D-TOE in three groups of readers with different experience in TOE for the identification of posterior MV scallop prolapse.

Methods

Patients population

Twenty patients who had undergone 2D-TTE, 2D-TOE and 3D-TOE before MV repair were retrospectively identified. Also five persons with suspected cardiac embolic source but normal MV anatomy who had undergone the same echocardiographic research were identified. The localization and extent of MV pathology (prolapse) in the 20 patients was defined by surgical exploration: isolated P1 in 0 patients, P1–P2 in 2 patients, P2 in 12 patients, P2–P3 in 2 patients, and isolated P3 in 4 patients.

Image acquisition and analysis

All TTE and TOE studies were performed by one single expert echocardiographer (JMcG and MLG respectively) using a Philips iE 33 ultrasound system (Philips Medical Systems, Best, The Netherlands), equipped with a S5-1 transducer for TTE and X7-2t matrix array transducer for TOE. 2D-TTE imaging included at least all the standard MV cross-sections as published by Monin et al. [9], 2D-TOE imaging included at least all the standard MV cross-sections as published by Foster et al. [10].

The 3D-TOE images were acquired in the zoomed mode, with a pyramidal volume allowing the highest temporal and spatial resolution, apart from a few patients in whom only a full volume dataset was available. The 3D loops were presented to the observers as the surgical intraoperative "en-face" left atrial view of the MV, with the aortic valve rotated to the 12 o'clock position (Video 1; Fig. 1a).

Observers

Nine readers with different echocardiographic expertise scored all the 2D-TTE, 2D-TOE and 3D-TOE images in a random order. For all cases the observers noted the location of MV prolapse according to the Carpentier nomenclature: P1, P2 and P3 for the lateral, middle and medial scallops, respectively [11]. In addition, in case of identified P2 prolapse it was noted whether only the central part of P2 was prolapsing (small central P2 prolapse) or also the centro-medial and/or centro-lateral parts (broad P2 prolapse or asymmetric P2 prolapse). The time for scoring the study was also noted in seconds.

Group 1 (novice) consisted of three medical students with no experience in echocardiography. These students were given a lecture on the anatomy of the MV scallops, in particular discussing schematic images of the MV anatomy displaying the scallops in standard recordings in 2D-TTE [9], 2D-TOE [10], and 3D-TOE (see Fig. 1b).

Group 2 (trainees) consisted of three cardiologists in training with basic knowledge of 2D-TTE and 2D-TOE (but

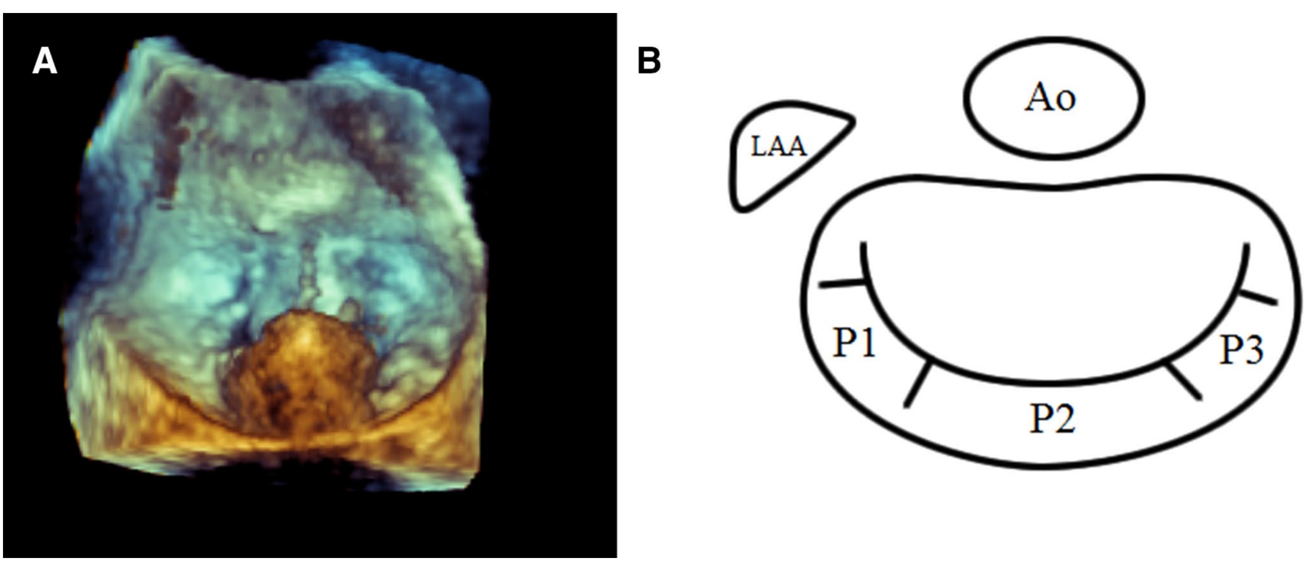

Fig. 1 **a** En-face view of the mitral valve with 3D echocardiography with a broad P2 prolapse, **b** schematic representation of the posterior mitral valve scallops

not 3D-TOE) echocardiography (number of 2D-TOE studies <75). These trainees received no formal lecture but the same schematic images as mentioned above of the 2D and 3D MV anatomy were provided.

Group 3 (cardiologists) consisted of three cardiologists with advanced knowledge of 2D-TTE, 2D-TOE and 3D-TOE echocardiography (number of independent 2D/3D-TOE studies >75).

Statistical analysis

Statistical analysis was performed using SPSS version 21.0.0.1 (SPSS, IBM, Armonk, NY). Categorical data are presented as numbers and percentages, whereas continuous data are summarized as mean ± standard deviation (SD) or median value with range. Comparisons of proportions (sensitivities, specificities, accuracies) were done with a one-sided Z test. A Wilcoxon signed ranks test was done for comparisons of time. P values <0.05 were considered significant.

Results

The study population of 20 patients and five normal subjects consisted of 15 men and 10 woman with mean age 60 ± 14 years. Six persons (including five normal MV) were in NYHA class I, 7 persons in NYHA class II and 11 and 1 person in NYHA class III and class IV, respectively. Six patients had also significant coronary artery disease.

Diagnostic accuracies of the different readers

The diagnostic sensitivities, specificities, accuracies (or agreement) and Kappa values are all displayed in Table 1. Overall (when all individual scallops were summated) there was an improvement in agreement and Kappa values from novice to trainees to cardiologists. This was most clearly seen for 2D-TTE and least clearly for 2D-TOE. With 2D-TTE sensitivity improved from novice to experts from 58 to 82 % (P < 0.005), specificity from 78 to 90 % (P < 0.005) and diagnostic accuracy from 72 to 88 % (P < 0.001). With 3D-TOE specificity increased from 89 to 95 % (P < 0.05) and diagnostic accuracy from 86 to 92 % (P < 0.05). The diagnostic improvement seen in more experienced readers was in particular caused by better identification of P3 prolapse (Kappa values increased from 0.19 to 0.47 to 0.73 for 2D-TTE, from 0.45 to 0.65 to 0.70 for 2D-TOE and from 0.52 to 0.72 to 0.85 for 3D-TOE). With 2D-TTE sensitivity increased from 33 to 72 % (P < 0.05), specificity from 84 to 96 % (P < 0.05) and diagnostic accuracy from 81 to 95 % (P < 0.005). With 3D-TOE specificity increased from 84 to 96 % (P < 0.05) and diagnostic accuracy from 81 to 95 % (P < 0.01). For the other scallops results were more ambiguous, apart from a better diagnostic accuracy in P1 scallop prolapse detection with 3D-TOE (Kappa values increased from 0.53 and 0.41 to 0.71).

Table 1 Diagnostic accuracy (agreement) and Kappa values for the detection of mitral valve scallop prolapse localization

	Sensitivity			Specificity			Accuracy			Kappa		
	N	T	C	N	T	C	N	T	C	N	T	C
P1												
2D-TTE	67	33	67	77	86	91	75	81	89	0.21	0.13	0.44
2D-TOE	67	50	50	83	88	91	81	85	88	0.28	0.28	0.34
3D-TOE	67	50	67	94	94	99	92	91	96	0.53	0.41	0.71
P2												
2D-TTE	67	88	88	70	74	74	68	83	83	0.35	0.62	0.62
2D-TOE	94	79	79	63	74	74	83	81	77	0.60	0.60	0.52
3D-TOE	85	85	85	85	96	85	85	88	85	0.69	0.75	0.69
P3												
2D-TTE	33	72	72	84	89	96	72	81	91	0.19	0.47	0.73
2D-TOE	44	89	89	95	89	88	83	87	88	0.45	0.65	0.70
3D-TOE	72	89	89	84	91	96	81	89	95	0.52	0.72	0.85
All												
2D-TTE	58	75	82	78	85	90	72	82	88	0.36	0.59	0.72
2D-TOE	79	81	79	84	86	87	82	84	84	0.61	0.65	0.65
3D-TOE	81	81	85	89	93	95	86	89	92	0.69	0.75	0.81

C cardiologist, *N* novice, *T* trainee

Value of 2D-TOE over 2D-TTE in the different observer groups

The incremental value of 2D-TOE over 2D-TTE can also be appreciated from Table 1. Sensitivities, specificities and accuracies of 2D-TOE were higher than those of 2D-TTE in novice readers. The increments in these readers were 21 % (P < 0.01), 6 % (P = NS), and 10 % (P < 0.01), respectively. Kappa values increased from 0.36 to 0.61. The increment in sensitivity was driven by better detection of both P2 (increment 27 %, P < 0.001) and P3 (increment 11 %, P = NS) scallop prolapse, the increment in specificity was driven by better exclusion of both P3 (increment 11 %, P < 0.05) and P1 (increment 6 %, P = NS) scallop prolapse. The respective increments in intermediate readers were 6, 1, and 2 % (all P = NS). The non-significant increment in sensitivity was driven by better detection of P1 and P3 scallop prolapse (all P = NS). In cardiologists no incremental value was seen.

Value of 3D-TOE over 2D-TOE in the different observer groups

The incremental value of 3D-TOE over 2D-TOE can also be appreciated from Table 1. Kappa values increased from 0.61 to 0.69 in novice, from 0.59 to 0.65 in trainees and from 0.65

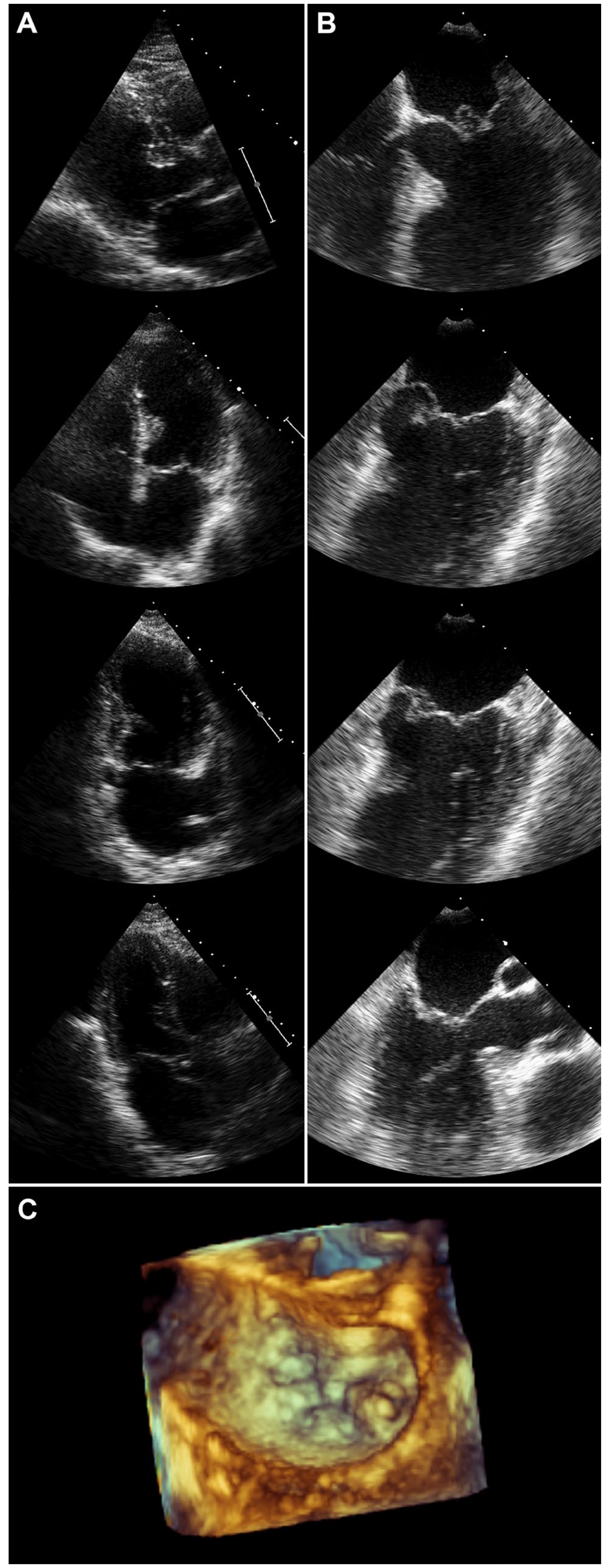

Fig. 2 Visualization of mitral valve prolapse with the three different echocardiographic techniques. **a** Two-dimensional TTE with the mitral valve in the four standard views: parasternal long-axis, four chamber, two chamber and three chamber views. **b** Two-dimensional TOE with the mitral valve in three standard views: four chamber, bi-commissural (tilted more posterior in the first image) and long-axis views. **c** Three-dimensional TOE en-face view of the mitral valve with clear visualisation of the P3 prolapse

to 0.81 in cardiologists. Minor non-significant improvements were seen in sensitivity to detect scallop prolapse [a significant effect on sensitivity was only seen in the novice group for P3 prolapse (increment 28 %, $P<0.05$)]. The respective increments in specificity were: for novice readers 5 % ($P<0.10$), for intermediate readers 7 % ($P<0.05$) and for cardiologists 8 % ($P<0.01$). The increments in specificity were in all groups driven by better exclusion of P1 and P2 scallop prolapse (it was only in cardiologists also driven by better exclusion of P3 scallop prolapse). In Fig. 2 the standard views of all three echocardiographic techniques in a patient are shown. In the 2D-TTE views it was difficult to see the prolapse. The P3 prolapse was clearly visualized with 2D-TOE (Fig. 2b) and optimal with 3D-TOE (Fig. 2c).

Value of 3D-TOE over 2D-TOE in identification of exact P2 prolapse localization and extent

In the 16 patients with P2 prolapse the prolapse was defined by the surgeon as small centrally located in three patients, a broad (involving the centro-medial and central and centro-lateral parts) in six patients and asymmetric (involving the centro-medial or centro-lateral part with or without central location) in seven patients. As seen in Table 2, 3D-TOE improved the agreement and Kappa values in all reader groups. An example of improved identification of the P2 prolapse localization and extent is given in Fig. 3.

Analysis time

As seen in Table 3, students needed more time to diagnose the lesion for both 2D-TTE (107 ± 57 vs. 65 ± 33 ms in trainees, $P<0.001$ and 86 ± 62 ms in cardiologists, $P<0.02$) and 2D-TEE (99 ± 64 vs 62 ± 26 ms in trainees, $P<0.001$ and 82 ± 57 ms in cardiologists, $P<0.10$). The time to diagnosis was dramatically reduced from 2D to 3D-TEE in all reader groups (all $P<0.001$). No differences in time to diagnosis existed for 3D-TEE between the reader groups (students 15 ± 11 ms, trainees 16 ± 12 ms and cardiologists 17 ± 13 ms).

Discussion

In this study we sought to assess the advantage of 2D and 3D-TOE over 2D-TTE to determine the precise localization and extent of the prolapsing segments of the posterior MV leaflet in readers with different levels of experience in echocardiography. The main findings of the present study were (1) the diagnostic accuracy of 2D-TTE for the iden-

Table 2 Identification of P2 prolapse according to the precise localization or extent (broad, small central, or eccentric)

Readers	2D agreement (%)	3D agreement (%)	2D Kappa	3D Kappa
Novice	47	59 (+12)	0.28	0.42 (+0.14)
Trainees	55	67 (+12)	0.36	0.53 (+0.17)
Cardiologists	48	64 (+16)	0.29	0.50 (+0.21)

Table 3 Time in seconds to diagnosis for the different observer groups

Readers	Novice	Trainee	Cardiologist
2D-TTE	107 ± 57	65 ± 33	86 ± 62
2D-TOE	99 ± 64	62 ± 26	82 ± 57
3D-TOE	15 ± 11	16 ± 12	17 ± 13

tification of posterior MV scallop prolapse increased from novice to trainees to cardiologists, (2) the diagnostic accuracy of 2D-TOE was higher than that of 2D-TTE for novice readers only, (3) with 3D-TOE time to diagnosis was much shorter and best diagnostic accuracy (mainly driven by specificity) was seen, and (4) identification of P1 and P3 prolapse with 3D-TOE still improved from novice to trainees to cardiologists.

The presence, location and extent of prolapse is of crucial importance in defining the likelihood of successful

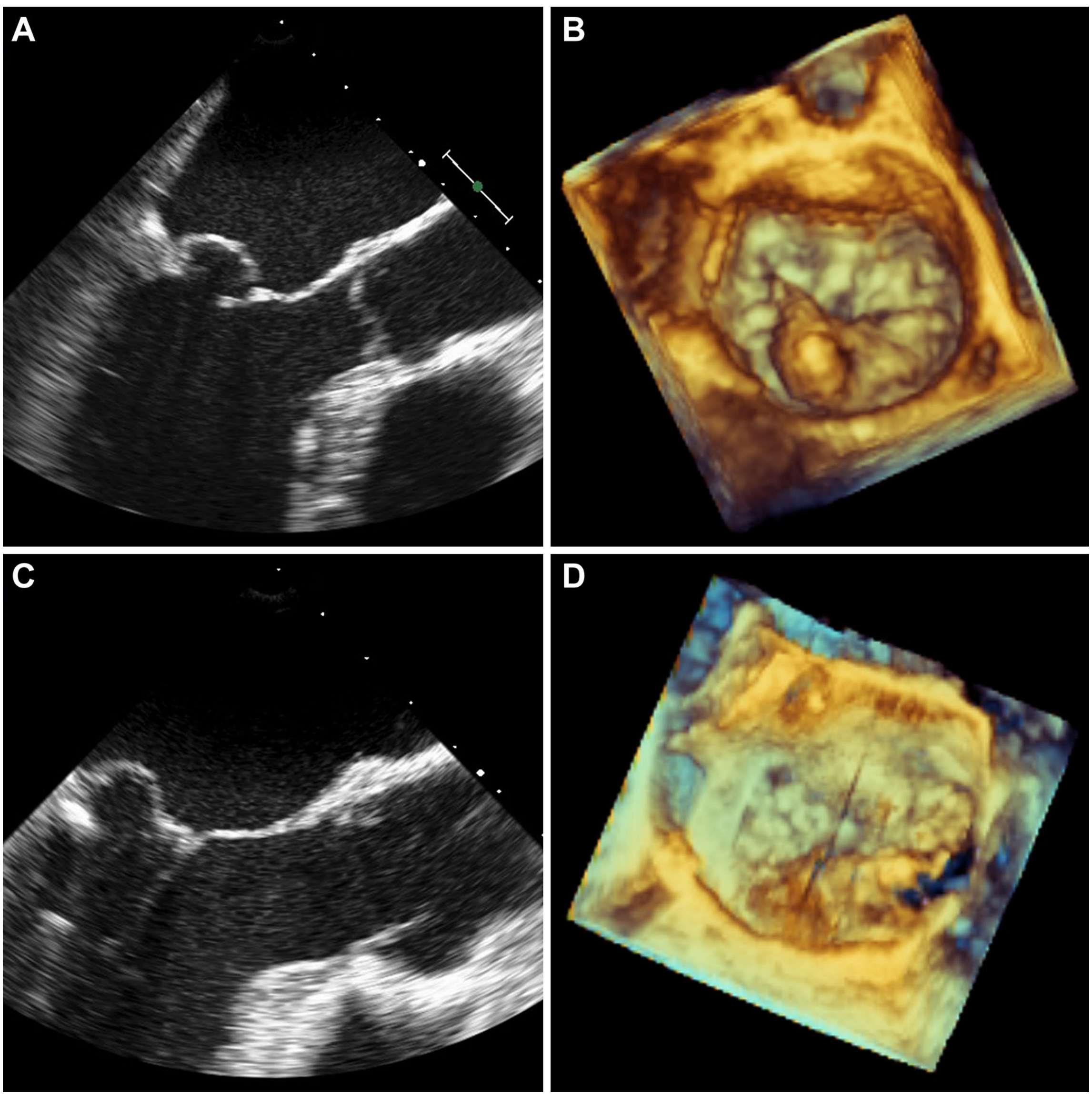

Fig. 3 Two-dimensional TOE with prolapse of the posterior mitral valve leaflet (**a, c**). Three-dimensional TOE with different prolapse of the posterior mitral valve leaflet: broad P2 prolapse (**b**) and asymmetric P2 (centro-medial) in addition to a P3 prolapse (**d**)

MV repair [2, 12]. As seen in this study, more experienced observers—but not less experienced—may identify the prolapsing MV scallops quite satisfactorily with 2D-TTE. Others and us also have shown that experts, certainly in patients with good transthoracic windows, with current transducer technology and standardized acquisition and analysis of planes may have an excellent diagnostic accuracy in assessment of posterior MV leaflet prolapse [9, 13]. Traditionally, however, 2D-TOE has been regarded as the gold standard to define MV anatomy. However, it should be recognized that multiplane 2D-TOE is highly operator dependent since it requires manual manipulation of the transducer in the esophagus to acquire views of all parts of the MV leaflets. This process may even be complicated by factors such as distortion of left ventricular geometry, mitral annular dilatation, and aortic root enlargement that can change all of the orientation of the ultrasound plane in relation to MV anatomy, resulting in scallop misidentification. More important, identification of the prolapsed segment is also highly operator dependent, because it requires the operator to be skilled at mentally reconstructing the MV in three dimensions from multiple 2D-TOE images to understand the underlying MV anatomy. This mental reconstruction often requires information obtained through live probe manipulation that is not permanently recorded. Thus, once the TOE study is completed, this information is not available to another reviewer at a later time as only limited views are saved. The importance of this limitation is difficult to assess but it should be noticed that in our study even novice readers showed good diagnostic results with 2D-TOE, albeit not optimal. With 3D-TOE, the entire MV can be visualized in a single image, making it possible to examine both leaflets from the left atrial (surgical) perspective, allowing more definitive identification of prolapse of individual scallops and segments. Thus, mental reconstruction is no longer critical for localization of MV pathology.

Compared with 2D-TOE, 3D-TOE is less operator dependent and does not require the finesse of probe manipulation to delineate MV pathology. Good quality 3D-TOE "en-face" views of the MV obviate the need for the process of mentally reconstructing the MV and therefore such images may be very helpful, in particular, in less-experienced observers.

However, interpretation of 3D echocardiographic images also requires a learning curve and even with 3D images false identification of segmental lesions may occur, in particular in the commissural regions [14]. The generalizability of 3D-TOE publications has also been questioned since the observers (usually only a single one) were highly experienced experts working in academic referral centers. Reproducibility is crucial for validation of the general concept that 3D-TOE is superior to 2D-TOE in non-experts. Unfortunately, conflicting data were reported for the incremental value of 3D "en-face" analysis of MV scallops. In the study of Hien et al. six patient cases were analyzed by 21 physicians without clinical experience in TOE and 15 physicians certified at an expert level. Significant benefits were seen for 3D-TOE in both novice persons without experience with TOE and experts [7]. In contrast, in a study by Tsang et al. 50 patient cases were scored by ten readers with different experience in echocardiography but sensitivity nor specificity for the detection of MV scallop prolapse improved, actually the observers had even greater difficulty with 3D-TOE compared with 2D-TOE data (in their study only 3D parametric maps made by experts improved diagnostic accuracy) [8]. In our study small improvements were seen in all reader groups, mainly based on improvements in diagnostic specificity. Importantly, 3D-TOE also improved the agreement and Kappa values in all reader groups for the exact description of P2 prolapse.

Limitations

The images used for this study were acquired by expert TTE and TOE echocardiographers resulting in high-quality images. This may have influenced both the lack of additional value of 2D-TOE over 2D-TTE in the more-experienced readers, as reported also by others [9], and the relatively high diagnostic accuracy of the less-experienced observers. Also, only posterior scallop prolapse was analyzed in this study. This was done because such lesions constitute the most common localized form of prolapse and most importantly a scallop subdivision of the anterior MV leaflet is artificial since this leaflet has no indentations. The study population was composed of persons without any MV disorder and patients who were referred for MV repair, which give a bias of including pathology that is severe and also more amenable to surgical repair. However, this cannot be avoided when an independent gold standard is necessary. It should also be recognized that a surgical gold standard may overcall prolapse because when the MV is inspected and the heart volume is small. However, the results of this study in comparing different expertise would still be valid.

3D-TTE images were not included in the present study because it is well agreed that even in the hand of experts 3D-TTE has limited accuracy in prolapse identification [3, 13–15]. Finally, each reader group consisted of only a small number of readers. However, the total number of analyses scallops was with 675 analyses not small.

Conclusion

Differences between readers with variable experience in determining the precise localization and extent of the prolapsing posterior MV scallops exist in particular in 2D-TTE analysis. 3D-TOE analysis was extremely fast compared to the 2D analysis methods and showed the best diagnostic accuracy (mainly driven by specificity) with identification of P1 and P3 prolapse still improving from novice to trainees to cardiologists and provided optimal description of P2 prolapse extent.

Compliance with ethical standards

Conflict of interest None declared.

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