Real-time 3D transoesophageal measurement of the mitral valve area in patients with mitral stenosis

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Aims

Planimetry measured by two-dimensional transthoracic echocardiography (TTE, MVA2D) is the reference method for the evaluation of the severity of mitral stenosis (MS) but requires experienced operators and good echocardiographic windows. Real-time three-dimensional transoesophageal echocardiography (3D-TEE, MVA3D) may overcome these limitations but its accuracy has never been evaluated.

Methods and results

We prospectively enrolled 80 patients (58 ± 15 years, 86% female) referred for MS evaluation who underwent, within 1 week, a clinically indicated TTE and TEE. MVA2D was measured by experienced operators (Level III), MVA3D by one experienced and one non-experienced (Level I) operators blinded of any clinical or TTE information. MVA3D measured by the experienced operator [1.11 ± 0.32 cm²; median, 1.1 cm²; range (0.45–2.20)] did not differ from and correlated well with MVA2D [1.10 ± 0.34 cm²; median, 1.05 cm²; range (0.45–2.30)], \( P = 0.87; r = 0.79, P < 0.0001; \) ICC = 0.79 and mean difference between methods was small (± 0.004 ± 0.21 cm²). MVA3D measured by the non-experienced operator [1.08 ± 0.34 cm²; median 1.02 cm²; range (0.45–2.23)] also did not differ from and correlated well with MVA2D measured by experienced operators (\( P = 0.25; r = 0.86, P < 0.0001; \) mean difference −0.02 ± 0.18 cm²; ICC = 0.86). Intra and interobserver variability were 0.02 ± 0.25 and 0.01 ± 0.33 cm².

Conclusion

3D-TEE provides accurate and reproducible MVA measurements similar to 2D planimetry performed by experienced operators. Thus, 3D-TEE could be considered as a second-line alternative tool for the evaluation of MS severity in patients with poor echocardiographic windows or for team less accustomed to evaluate MS patients.

Keywords

Mitral stenosis • Echocardiography • Three dimensional

Introduction

Management of patients with rheumatic mitral stenosis (MS) relies on accurate echocardiographic assessment of the mitral valve area (MVA).1–3 Planimetry measured by two-dimensional transthoracic echocardiography [two-dimensional transthoracic echocardiography (2D-TTE), MVA2D] is considered as the reference method,4 but must be precisely performed at the tips of the leaflets in a well-oriented plane and therefore requires both experienced operators and good echocardiographic windows.

Three-dimensional echocardiography is an imaging modality whose technological improvement has made online real-time 3D acquisition, visualization, and analysis of heart structures possible. In a previous study, we have shown that real-time 3D-TTE provided accurate MVA measurements similar to 2D-TTE and more importantly improved accuracy of the planimetry when performed by non-experienced operators.5 However, poor echocentricity remained a limitation of transthoracic echocardiography. With recent advent of 3D-transoesophageal probe, real-time three-dimensional transoesophageal echocardiography (3D-TEE)
seemed ideally suited for the assessment of the MVA but its accuracy had never been evaluated. Thus, the aim of the study was to compare 3D-TTE and 2D-TTE measurements in a large series of patients with MS and to evaluate the impact of experience on 3D-TTE measurements.

Methods

Population

Between 2008 and 2010, we prospectively enrolled patients referred to our department for MS evaluation, who underwent, within 1 week, a clinically indicated transthoracic and transoesophageal echocardiography performed using the 3D TEE probe. Exclusion criteria were a non-feasible planimetry by 2D-TTE because of poor image quality. Patients in atrial fibrillation (AF) were not excluded.

Echocardiography

Two-dimensional transthoracic echocardiography

2D-TTE was performed using a commercial ultrasound system (SS-1 probe, IE33, Philips, Andover, MA, USA). Planimetry was performed by experienced operators (Level III, second, third and last authors) in parasternal short-axis view, adjusting the probe for an optimal mitral valve orifice in early diastole. Three to five beats were analysed and averaged. Mitral valve anatomy was classified into three groups:8,9

- flexible valves and mild subvalvular disease (chordae ≥10 mm long) (Group I),
- flexible valves and extensive subvalvular disease (chordal <10 mm long) (Group II), and
- calcified valves (Group III). MR was semi-quantitatively graded from zero to four according to jet extension and area.10 Left ventricular (LV) function and S-PAP were also measured as recommended.11

Real-time three-dimensional transoesophageal echocardiography

3D-TTE was performed after local anaesthesia and intravenous injection of midazolam or during general anaesthesia, using a matrix array transducer (X7-2t, Philips). 3D-TTE images were obtained using the zoom mode (one beat) focused on the mitral valve (Figure 1) and digitally stored. Measurements of the MVA were performed offline on a workstation using a dedicated software (QLab7, Philips), in a random order and blinded of any clinical or TTE information. MVA was measured at the best cross section of the mitral valve, defined as the most perpendicular and smallest orifice in early diastole (Figure 2). 3D-TTE measurements were performed by one experienced (Level III, last author) and one non-experienced operator (Level I, first author). In 15 randomly selected patients, MVA measurements were also performed by the same experienced and non-experienced operators and another experienced operator (Level III, second author) for intra- and inter-observer variability.

Statistics

Quantitative variables were expressed as mean ± standard deviation. Comparisons of MVA obtained by 2D-TTE (MVA2D) and 3D-TTE (MVA3D) were analysed using paired Student t-tests and Pearson’s correlation. Agreement between MVA measurements was assessed as described by Bland-Altman analysis12 and single-measure intra-class correlation coefficient (ICC). Analysis was performed overall and according to patients’ rhythm and mitral valve anatomy, which may potentially affect accuracy of MVA measurements. Inter- and intra-observer variability was calculated as mean difference ± standard deviation. All tests were two-sided. Statistical significance was defined with P < 0.05.

Results

Population

Eighty-three patients were prospectively enrolled. Three patients were excluded because of poor 3D-transoesophageal image quality and the remaining 80 patients constituted our study population. Clinical and echocardiographic characteristics of the population are presented in Table 1. Briefly, mean age was 58 ± 15 years, 86% were female and 45% were in AF. Seven patients had an LV ejection fraction <55%. Mean MVA2D was 1.10 ± 0.34 cm² [median, 1.05 cm²; range (0.45–2.30)].
TEE was performed before a scheduled percutaneous mitral commissurotomy (PMC) in 69 patients in order to exclude a contra-indication to the procedure, immediately after PMC in eight patients in whom the procedure was performed under general anaesthesia and TEE guidance (pregnant women and patients with complex anatomy) and in three patients before a planned electrical cardioversion.

Three-dimensional measurement of mitral valve area by experienced operator

MVA3D measured by the experienced operator [1.11 ± 0.32 cm²; median, 1.10 cm²; range (0.45–2.20)] did not differ from and correlated well with MVA2D (1.10 ± 0.34 cm², \(P = 0.87\), \(r = 0.79\), \(P < 0.0001\)) (Figure 3A). Mean difference between methods was 0.004 ± 0.21 cm². Bland-Altman analysis is presented in Figure 3B and shows the good agreement between methods. ICC was also good (0.79).

Similar results were observed when analyses were repeated according to patients’ rhythm (sinus rhythm, MVA2D 1.12 ± 0.36 cm² vs. MVA3D 1.08 ± 0.35 cm², \(P = 0.28\); \(r = 0.79\), \(P < 0.0001\); atrial fibrillation, MVA2D 1.08 ± 0.30 cm² vs. MVA3D 1.13 ± 0.28 cm², \(P = 0.06\); \(r = 0.82\), \(P < 0.0001\)) or anatomic group (Groups I and II, MVA2D 1.15 ± 0.36 cm² vs. MVA3D 1.16 ± 0.33 cm², \(P = 0.62\); \(r = 0.89\), \(P < 0.0001\); Group III MVA2D 1.03 ± 0.28 cm² vs. MVA3D 1.02 ± 0.29 cm², \(P = 0.86\); \(r = 0.53\), \(P = 0.003\)).

Intra- and inter-observer variability of 3D measurements of MVA were 0.02 ± 0.25 and 0.01 ± 0.33 cm² respectively. Mean time needed for offline MVA measurements was 2 ± 1 min.

Three-dimensional measurement of mitral valve area by non-experienced operator

MVA3D measured by the non-experienced operator [1.08 ± 0.34 cm²; median, 1.02 cm²; range (0.45–2.23)] also did not differ from and correlated well with MVA2D measured by experienced operators (1.10 ± 0.34 cm², \(P = 0.25\), \(r = 0.86\), \(P < 0.0001\); Figure 4A) and mean difference between methods was small (−0.02 ± 0.18 cm²). Bland-Altman analysis is presented in Figure 4B and shows the good agreement between methods. ICC was 0.86.

Intraobserver variability of 3D measurements evaluated by the non-experienced (0.01 ± 0.13 cm²) was not different from the intraobserver variability of the experienced operator (\(P = 0.80\)). Inter-observer variability of 3D measurements evaluated between the non-experienced and the experienced operators (−0.01 ± 0.21 cm²) was also not different from the inter-observer variability between experienced operators (\(P = 0.77\)).

![Figure 2](image-url) Methodology of measurement of the mitral valve area using real-time three-dimensional transoesophageal echocardiography. The three-dimensional volume (D) is sliced and oriented in order to obtain the ideal cross section of the mitral valve at the tips of the leaflets (A–C).
Discussion

In the present study, we compared MVA measurements performed using 3D-TEE to those obtained with 2D-TTE in a large cohort of patients with MS. Measurements could be performed in a few minutes and we observed a good correlation between the two methods with a low intra- and inter-observer variability.

Management of patients with MS relies on accurate echocardiographic assessment of the MVA. The planimetry, which provides a direct anatomic measurement of the mitral valve orifice, is considered as the reference method but must be performed at the tips of the leaflets with a correct plane orientation. Thus, minor changes in the depth or angle of the ultrasound beam may lead to important MVA overestimation. This requirement is a major limitation of the planimetry. 3D-TTE allows a 3D acquisition of the entire mitral valve, which can be sliced along any plane as desired. We previously demonstrated that it overcomes the plane limitation issue providing accurate MVA measurements for both experienced and non-experienced operators but a good transthoracic echocardiographic windows remained an important limitation justifying the present study.

3D-TEE combines the advantage of TEE (excellent visualization of the mitral valve) and of three-dimensional echocardiography (acquisition of a 3D volume of the entire mitral valve and reconstruction of multiple 2D planes in any desired orientation). Thus, real-time 3D-TEE seemed of interest for the evaluation of the MVA but its accuracy had yet never been evaluated. In the present study, we compared MVA measurements performed using 3D-TEE by both experienced and non-experienced operators to 2D-TTE measurements performed by experienced operators in a large cohort of patients with MS. We observed a good agreement between 2D-TTE and 3D-TEE with excellent correlations and no trend for under- or overestimation and the present study extend our previous findings with 3D-TTE to 3D-TEE. In the present study, for the purpose of research (blinded analysis), measurements were performed offline on a workstation. However, in routine practice, MVA can be directly measured on the machine using the same build-in dedicated software (Qlab). Thus MVA can be obtained immediately after the

Table 1  Clinical and echocardiographic characteristics of the 80 patients

| Age (years) | 58 ± 15 |
| Female gender | 69 (86) |
| Atrial fibrillation (%) | 36 (45) |
| Left ventricular ejection fraction (%) | 65 ± 10 |
| Anatomic group (%) | |
| I | 1 (1) |
| II | 49 (61) |
| III | 30 (38) |
| Mean transmitral gradient (mmHg) | 9 ± 4 |
| Systolic pulmonary artery pressure (mmHg) | 49 ± 15 |
| Mitral regurgitation grade (%) | |
| I | 5 (6) |
| II | 56 (70) |
| III | 18 (23) |
| IV | 1 (1) |
| MVA2D (cm²) | 1.10 ± 0.34 |
| MVA3D, experienced operator (cm²) | 1.11 ± 0.32 |
| MVA3D, non experienced operator (cm²) | 1.08 ± 0.34 |

Data presented are number of patients (percent) or mean ± SD.

2D, two-dimensional; 3D, three-dimensional; MVA, planimetry of the mitral valve.

Figure 3  (A) Correlation between mitral valve areas measured using two-dimensional transthoracic echocardiography (MVA2D) and real-time three-dimensional transoesophageal echocardiography (MVA3D) measured by the experienced operator. (B) Quality control plots using Altman and Bland analysis for the two methods. The middle line represents the mean and the upper and lower lines ± 2 standard deviation (SD).
TEE without significantly increasing the time of examination and thus patient discomfort.

Nevertheless, these measurements require the performance of TEE. In the present study all TEE were clinically indicated. Most of them were performed before PMC. We also include patients in whom TEE was performed during PMC to guide the procedure or before a planned cardioversion for the purpose of increasing MVA range. However, we certainly not implying that a 3D-TEE should be performed in all patients for MS evaluation and MVA measurements. Planimetry using TTE (either 2D or 3D) is not feasible in 5–10% of patients and 3D-TEE may represent an interesting alternative. On the other side, TEE is systematically performed before PMC in most institution to exclude a left atrial thrombus and may offer an independent way to confirm TTE measurements. Thus, from a clinical point of view, 3D-TEE measurements should be regarded as a second-line method for the assessment of the MVA in patients with poor echocardiographic windows or when the operator does not feel confident with TTE measurements. This is of particular importance because MS is a relatively rare disease in Western countries, in which few physicians have a high expertise.

The present study deserves several comments. First, it was not a feasibility study. Since our aim was to evaluate the accuracy of 3D-TEE measurements, only patients with feasible 2D-TTE measurements were enrolled and the feasibility of 2D-TTE and 3D-TEE cannot be compared. Second, availability of the 3D-TEE probe and equipment remained limited but is expected to rapidly expand in the next few years. Third, accurate measurements require appropriate settings. Excess of gain or luminosity during the 3D acquisitions can preclude the accurate delineation of the orifice. Thus, a special attention was given to decrease gain and luminosity during acquisition. In the present study, inappropriate settings lead to non-feasible measurements in three patients. It is worth noting that all 3D-TEE acquisitions were performed by one experienced operator but the two keys points, gain setting and recording of the entire mitral orifice are quite easy to master. Fourth, 2D measurements were only performed by experienced operators but we have previously shown the limited accuracy of 2D-TTE when performed by non-experienced operators. Fifth, despite excellent correlations and ICC, differences between methods are not null in some patients. This is also true for other methods, such as the PISA or 3D-TTE and the intra- and interobserver variability of the reference method (2D planimetry) is also around 0.15/0.20 cm². Planimetry should be performed at the tip the leaflets and despite theoretical advantages of 3D echocardiography for plane selection, distinction between tip of the leaflets and chordae are not always easy and may also explain part of the difference between 2D-TTE and 3D-TEE. These considerations underline the need of combining multiple methods for the assessment of MS severity. Finally, there is no absolute gold standard for MVA measurement in MS. Nowadays, catheterization and MVA calculation using the Gorlin formula is seldom used and only indicated when there is a discrepancy between echocardiographic measurements and clinical status. Other echocardiographic methods such as the pressure half-time, the continuity equation, or the proximal isovelocity surface area method can be used but all have their own limitations. Thus, 2D-planimetry, which is considered as the reference method, was logically used for comparison.

**Conclusion**

In this study, we show that 3D-TEE provides fast, accurate, and reproducible MVA measurements, by both experienced and non-experienced operators. Thus, 3D-TEE could be considered as an alternative tool for the evaluation of MS severity, especially in
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patients with poor echocardiographic windows or for team less accustomed to evaluate MS patients.

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References