Clinical research

Non-invasive assessment of mitral valve area during percutaneous balloon mitral valvuloplasty: role of real-time 3D echocardiography

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Background In the last decade, multiple studies depicted discrepancies between mitral valvular orifice area (MVA) measurements obtained with the pressure half-time (PHT) method and invasive methods during the immediate post-percutaneous mitral valvuloplasty (PMV) period. Our aim was to assess the accuracy of Real-Time 3D echo (RT3D) to measure the MVA in the immediate post-PMV period. The invasively determined MVA was used as the gold standard.

Methods and results We studied 29 patients with rheumatic mitral stenosis from two centres (27 women; mean age 48.2 ± 11.3 years), all of which had underwent PMV. MVA was calculated before and after PMV using the PHT method, 2D echo planimetry, RT3D echo planimetry and invasive determination (Gorlin’s method). The RT3D MVA assessment showed a better agreement with the invasively derived MVA before and in the immediate post-PMV period (Bland-Altman analysis: Average difference between both methods and limits of agreement: 0.01 (−0.30 to 0.33) cm² and −0.12 (−0.71 to 0.47) cm² before and immediately after the PMV, respectively. Conclusions RT3D is a feasible and accurate technique for measuring MVA in patients with RMVS. It has the best agreement with the invasively determined MVA, particularly in the immediate post-PMV period.

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KEYWORDS
Mitral valve; Echocardiography; Three-dimensional; Mitral stenosis; Real time

Introduction

Rheumatic mitral valve stenosis (RMVS) still remains an important public health concern in developed countries. When there is favourable mitral valve anatomy, balloon valvuloplasty has become the procedure of choice. In the last decade, many studies have demonstrated large discrepancies in the immediate post-percutaneous mitral valvuloplasty (PMV) period between mitral valvar orifice area (MVA) measurements obtained using the pressure half-time (PHT) method and those derived invasively in the catheterization laboratory. Explanations for
inaccuracies of the PHT method include changes in the left atrium compliance and left ventricular hypertrophy due to age and other simultaneous conditions.

We hypothesised that since three-dimensional (3D) echocardiography allows a different and superior evaluation of mitral valve apparatus, this technique could increase the ability to perform an accurate MVA planimetry immediately after a PMV. The use of the new transthoracic 3D matrix array probe x4 (Philips, Andover, MA) allows online 3D rendering of cardiac structures enabling a fast and accurate analysis of cardiac structures.

Our aim was to determine the accuracy of 3DRT echo in measuring the MVA in the immediate post-PMV period by comparing it with invasively derived MVA using Gorlin’s formula.4

**Methods**

**Patient population**

Twenty-nine consecutive patients with RMVS, from two echocardiographic centres (Hospital Clínic San Carlos, Madrid, Spain and University of Chicago Hospital, IL, USA) comprised our study group. All of the study patients had the established diagnosis of RMVS and the absence of any contraindication for PMV. All underwent a PMV. In patients with multiple valvular lesions, mitral stenosis was the predominant one.

**Non-invasive evaluation**

A complete Echo-Doppler study was performed in all patients using a Sonos 7500 ultrasound machine and a S3 probe (Philips, Andover, MA) 24 h before the PMV and then repeated 24 h after the PMV. 2D views of the mitral valve were obtained from the parasternal window and planimetry was performed. Continuous-wave Doppler recordings through the mitral valve were obtained from the apical four-chamber window and MVA was estimated by using the formula 220/PHT. Three cardiac cycles for patients in sinus rhythm and five for patients in atrial fibrillation were recorded and their results averaged for every patient. The values for comparison were an average of two observers’ measurements.

**RT3D**

RT3D was performed immediately after each 2D study using a Sonos 7500 ultrasound machine and an x4 probe (Philips, Andover, MA). Data were recorded using the aforementioned probe. The system scans a 60° × 30° 3D pyramid of data. From different acoustic windows, multiple cardiac cycles of the mitral valve were recorded using the ‘zoom’ mode. All images were stored in a magneto optical disk or compact disk and transferred for off-line analysis using Tomtec® software (4D Cardio-View RT 1.0 Build 983).

RT3D planimetry was performed en face at the ideal cross-section of the mitral valve during its greatest diastolic opening. The ideal cross-section was defined as the most perpendicular view on the plane with the smallest mitral valve orifice.

**Inter-observer and intra-observer variability**

All the recorded images (PHT, 2D echo, and RT3D) were analysed offline at different times by two independent observers. The same images were also analyzed on a different day by one of these same observers.

**Invasive evaluation**

Invasive haemodynamic evaluation was performed within 24 h of the PMV and immediately after the procedure. The MVA was obtained using the catheter-based data and the Gorlin’s equation. Cardiac output was determined by means of the thermodilution method by using a Swan-Ganz catheter. This was done by protocol, although this method may be influenced or challenged in patients with valvular heart disease. Left ventricle and left atrium pressure tracings were recorded simultaneously by using a 6F pig tail catheter and a conveniently placed percutaneous trans-septal catheter. Planimetry of the area between left atrium and left ventricle pressure tracings was averaged for five beats.

**Statistical analysis**

The statistical package used was SPSS version 11.0. Quantitative data were expressed as mean ± standard deviation. Qualitative data were expressed as absolute number (percentage). Inter-method agreement was evaluated by means of Bland–Altman’s method. Inter- and intra-observer reproducibility was evaluated by means of the Intraclass Correlation Co-efficient (ICC). ICC evaluated the absolute agreement between quantitative variables. Confidence intervals were calculated for the ICCs. Comparisons were considered significant in presence of a p-value < 0.05.

In this study, the comparability of four methods to assess mitral valve area is assessed. In total, this allowed for a total of six comparisons. However, the main interest was the comparison with the gold standard of the Gorlin formula.

**Results**

Twenty-nine consecutive patients with RMVS undergoing PMV comprised our study group. There were 27 (93.1%) women, with a mean age of 48.2 ± 11.3 years. Mitral stenosis was the predominant valvular lesion in all patients. In the pre-PMV period, one patient had moderate mitral regurgitation, whereas two patients had associated mild to moderate aortic regurgitation. None of the patients showed aortic stenosis. Regarding the analysis of the tricuspid valve, none of the patients showed tricuspid stenosis, but 27 showed tricuspid regurgitation. The mean systolic pulmonary pressure was 55 ± 7 mm Hg. Left atrium diameter was 62 ± 8 mm. Systolic and diastolic left ventricular diameters from the parasternal approach were 53 ± 5 and 34 ± 8 mm. Following PMV, three additional patients were noted to have moderate mitral regurgitation. 12 patients were in normal sinus rhythm, 15 in atrial fibrillation and two patients had pacemaker rhythm. Regarding the PVM procedure, the size of the balloon was selected according to the body surface index. The mean body surface was 1.73 ± 0.18, the body mass surface index 27.31 ± 5.06 and accordingly the
mean INOUE balloon used was $28.1 \pm 1.20$. No deep anaesthesia was used for the PVM.

**Comparison of non-invasive with invasive methods**

MVA determined by the different methods in the pre-PMV period were: PHT: $1.1 \pm 0.3 \text{ cm}^2$, 2D echo: $1.1 \pm 0.2 \text{ cm}^2$, RT3D: $1 \pm 0.2 \text{ cm}^2$ and Gorlin’s method: $1 \pm 0.2 \text{ cm}^2$. MVA determined by the different methods in the post-PMV period were: PHT: $1.7 \pm 0.4 \text{ cm}^2$, 2D echo: $1.6 \pm 0.4 \text{ cm}^2$, RT3D: $1.7 \pm 0.3 \text{ cm}^2$ and Gorlin’s method: $1.8 \pm 0.4 \text{ cm}^2$.

In the pre-PMV evaluation, the invasively determined MVA showed a better agreement with RT3D results than with PHT or 2D echo results (Fig. 1). After the PMV, the higher accuracy of the RT3D still remained (Fig. 2). Thus, using the invasively determined MVA as the gold standard, RT3D has a better agreement compared to PHT and 2D echo planimetry in both the pre- and post-PMV periods. Although PHT also compared favourably with invasive data in the pre-PMV period, this agreement is lost in the post-PMV period (see Fig. 3).

The time required to obtain and analyse the RT3D images, evaluated in 10 consecutive patients, was $21 \pm 5 \text{ min}$. The most frequently used view for RT3D planimetry was the apical window (19 patients; 65.5%) followed by the parasternal window (8 patients; 27.6%). Although the presence or absence of atrial fibrillation did not influence the agreement between the measurements with invasive and non-invasive techniques, this fact only affects the time of the echo examination. Among those patients with atrial fibrillation the mean time for the 3D echo evaluation was $33 \pm 7 \text{ min}$.

RT3D echo is, as with other echo modalities, affected by the quality of the acoustic window. In our study, none of the patients showed bad acoustic window. In 23 patients, the quality was optimal and in the rest considered as excellent.

**Inter- and intra-observer variability**

Inter-observer agreement in the pre-PMV period was fairly good: ICC was $0.91$ (0.4–0.97), $0.81$ (0.36–0.94) and $0.90$ (0.7–0.91) for PHT, 2D planimetry and RT3D, respectively. After the PMV, results were similar: ICC was $0.92$ (0.43–0.95), $0.84$ (0.41–0.91) and $0.96$ (0.69–0.92) for PHT, 2D echo planimetry and RT3D, respectively.

**Discussion**

Due to the increasing immigration from developing countries, RMVS remains an important public health concern in developed countries. PMV has become the procedure of choice in symptomatic patients when the stenotic mitral valve is not heavily calcified and mitral regurgitation is not significant because it is cost effective and safe.
severe pulmonary, renal, or malignant diseases. The results of PMV are equivalent to those of surgical, open commissurotomy and both give better results than closed commissurotomy. 

Patients with RMVS who require an intervention can be easily identified using non-invasive techniques and the results can be predicted by a careful pre-PMV Doppler echocardiographic evaluation. Before the PMV, the pressure gradient, the valvular area, and the severity of valvular regurgitation, can be used to evaluate patients reliably. Prior to PMV, Doppler echocardiographic estimation of MVA correlates well with invasive estimation. Immediately following PMV, the PHT method has been shown to have a poor agreement with invasive data. 

There are various reasons for this inaccuracy including: (1) the development of an atrial septal defect in many patients after PMV and (2) the PHT method assumes that the left atrial and left ventricular compliances remain stable; this assumption is not valid in the immediate period following PMV because rapid changes in the left atrial pressure and left ventricular filling occur in this setting, affecting the compliance of both the left atrium and ventricle.

Compared to the PHT method, planimetry (2D or 3D) is not as dependent on haemodynamic variables (heart rate, cardiac index, cardiac rhythm, left ventricular systolic and diastolic dysfunction, left ventricular and atrium compliance, left ventricular hypertrophy and concomitant valvular disease). Accordingly, planimetry of MVA should be more accurate in the setting of PMV.

Planimetry of mitral valve orifice using 2D echo is a valid method but has its own set of limitations, especially following valvuloplasty when the mitral orifice becomes irregular and technically difficult to trace, particularly if calcium is present.

3D echo allows a different and superior evaluation of the mitral valve apparatus, improving the ability to obtain an accurate measurement of the MVA. Restriction of the tips and chordae, during the evolution of the rheumatic mitral valve disease, effectively converts the mitral valve apparatus into a funnel with its restrictive mitral valve orifice being at the tips of the leaflets. Due to the variable geometry of the stenotic mitral valve orifice, correct plane orientation frequently becomes difficult. Minor changes in depth and angle of the ultrasound beam leads to an overestimation of the MVA by anywhere from 63% to 88%. 3D echo has already been shown to be useful to optimise the results and prevent the development of significant mitral regurgitation during balloon mitral valvuloplasty. The use of the new transthoracic 3D matrix array probe that allows on-line 3D rendering, allows fast visualization of the mitral valve apparatus and the acquisition of en face views of the mitral valve from which the accurate measurements of the mitral valve area can be made. This image modality should be routinely used to both monitor the mitral PMV and obtain accurate MVA measurements.

In this study, RT3D was the most accurate echocardiographic technique for measuring MVA. Compared with PHT and 2D echo planimetry, RT3D echo had the best agreement when compared to the invasively derived MVA. Not only did this occur in the pre-PMV period but also in the post-PMV period. Thus, our results show that RT3D is an accurate and practical non-invasive tool for...
measuring MVA in all clinical situations, including the immediate post-PMV period. Importantly, since manipulation of the RT3D echo probe is similar to other clinically used transthoracic 2D probes, sonographers do not need a long training period to be versatile with RT3D image acquisition. We need to know, that although 3D echo provides a more accurate evaluation of the anatomy of the mitral valve, as with 2D echo, it is importantly influenced by the quality of the acoustic window. Needless to say that although the new equipment provides better resolution and image quality, a bad acoustic window will lead to a poor analysis of the patient.

Study limitations

The principal limitation of this study was the use of Gorlin’s method as the Gold Standard. The Gorlin’s equation is a haemodynamic method that has recognized limitations, especially in situations when rapid haemodynamic changes occur, such as the post-PMV period. Significant mitral regurgitation and the presence of an atrial septal defect may confound measurements of trans-mitral volume flow, this could explain the slight loss of agreement between RT3D planimetry and Gorlin estimation of MVA in the post-PMV period, compared to the pre-PMV period. The desired gold standard for comparison should be the true pathologic inspection of the valve. True inspection and measurement would allow us to determine which method is the most accurate.

Echo studies were performed 24 h before and 24 h after the PMV; not immediately before and after the procedure. Therefore, exactly the same haemodynamic situation was not present within the non-invasive and invasive situation. For the calculation of mitral valve area, we have used and compared the PHT. We have not used the continuity equation and therefore the present data could not be extrapolated to those obtained by the Doppler continuity equation. Also, functional data as mitral valve resistance have not been calculated in the present study.

Other limitations are the image quality and the echo-Doppler settings which could also influence MVA measurements.

Clinical implications

RT3D improves the assessment of MVA in the clinical scenarios of early post-PMV period, when other methods have been shown not to be useful. Thus, RT3D is able to replace other non-invasive methods and make invasive evaluation unnecessary in this setting.

Conclusions

Transthoracic RT3D is a feasible and accurate technique for measuring MVA in patients with RMVS. Compared to the PHT method and 2D echo planimetry, RT3D results
have the best agreement with the invasively determined MVA, particularly in the immediate post-PMV period, where PHT is inaccurate.

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