The impact of different geometric assumption of mitral annular on the assessment of mitral regurgitation volume by Doppler method

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Research

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Abstract

Background Mitral regurgitation volume (MRvol) by quantitative pulsed Doppler (QPD) method previously recommended suffers from geometric assumption error because of circular geometric assumption of mitral annulus (MA). Therefore, the aim of this study was to evaluate the impact of different geometric assumption of MA on the assessment of MRvol by two-dimensional transthoracic echocardiographic QPD method.

Methods This study included 88 patients with varying degrees of mitral regurgitation (MR). The MRvol was evaluated by QPD method using circular or ellipse geometric assumption of MA. MRvol derived from effective regurgitant orifice area by real time three-dimensional echocardiography (RT3DE) multiplied by MR velocity-time integral was used as reference method.

Results Assumption of a circular geometry of MA, QPD-MAA4C and QPD-MAPLAX overestimated the MRvol by a mean difference of 10.4 ml ($P < 0.0001$) and 22.5 ml ($P < 0.0001$) compared with RT3DE. Assumption of a ellipse geometry of MA, there was no significant difference of MRvol (mean difference = 1.7 ml, $P = 0.0844$) between the QPD-MAA4C+A2C and the RT3DE.

Conclusions Assuming that the MA was circular geometry previously recommended, the MRvol by QPD-MAA4C was overestimated compared with the reference method. However, assuming that the MA was ellipse geometry, the MRvol by the QPD-MAA4C+A2C has no significant difference with the reference method.

Introduction

Mitral regurgitation (MR) is one of the most common heart-valve disorder, and its prevalence increases with age [1]. In the clinical decision-making process regarding mitral valvular lesions, accurate determination of the severity of the MR is of major importance [2, 3]. Echocardiography is the first method of non-invasive assessment of MR, and mitral regurgitation volume (MRvol) is an important parameter to evaluate the severity of MR, which may be calculated by quantitative pulsed Doppler (QPD) method as previously recommended [4]. However, this method suffers from geometric limitations of two-dimensional (2D) echocardiography. In the QPD method, important geometric errors are made in calculating the cross-sectional area (CSA) of the mitral annulus (MA) because of the circular geometric assumption (the CSA of MA was derived as $0.785 d^2$, where d was the diameter of the MA in the apical four-chamber) [5]. Recently, a series of studies have confirmed that MRvol using effective regurgitant orifice area (EROA) (direct planimetry of EROA by real time three-dimensional color Doppler echocardiography) multiplied by the MR velocity-time integral (VTI_{MR}) was highly accurate [6-8]. Therefore, the aim of this study was to evaluate the impact of different geometric assumption of MA on the assessment of MRvol by the traditional 2D transthoracic echocardiographic (TTE) QPD method, by comparison with MRvol derived from EROA by real time three-dimensional color Doppler echocardiography.

Methods

Study population

This study included 88 patients (55 men, 33 women; mean age, 48.2 ± 14.0 years) with varying degrees of MR of different etiologies on color Doppler echocardiography between October 2011 and August 2017. The etiology of MR was ischemia in 32, idiopathic dilated cardiomyopathy in 26, mitral valve prolapse (MVP) in 30. MVP is diagnosed in the parasternal long-axis view as systolic displacement of the mitral leaflet into the left atrial of at least 2 mm from the MA plane [4]. Exclusion criteria included aortic regurgitation or stenosis, mitral stenosis, atrial fibrillation, frequent atrial or ventricular premature beats, congenital heart disease, hypertrophic cardiomyopathy, and poor general image quality. This study was approved by the institutional review board of The Affiliated Hospital of Qingdao University, and all patients underwent echocardiographic examination because of clinical indications and gave written informed consent.

Echocardiographic examination

2D and real time three-dimensional (3D) echocardiography (RT3DE) were performed using the iE33 ultrasound system (Philips Healthcare, Amsterdam, The Netherlands).

2D TTE: MRvol by QPD method using different geometric assumption of MA

2D TTE was performed with a S5-1 transducer and patients were imaged in the left lateral decubitus position. The MA diameter was measured between the inner edges of the base of posterior and anterior leaflets in early to mid diastole at maximal mitral valve (MV) opening in the apical four-chamber (A4C), apical two-chamber (A2C) and parasternal long-axis (PLAX) view [5, 9]. The left ventricular outflow tract (LVOT) diameter was measured just below the aortic valve in early to mid systole in the PLAX view [5, 9]. The pulsed Doppler sample was carefully placed as parallel as possible to the blood flow in the A4C and apical five-chamber (A5C) views to obtain the Doppler spectral profiles of the MA and LVOT. The sample volume was positioned at the level of the MA and LVOT. The modal velocity profile on Doppler recordings was traced to obtain the velocity-time integral (VTI) [5, 9]. Data from three cardiac was averaged.

MRvol by QPD was calculated as the difference between MA forward stroke volume (SV_{MA}) and LVOT forward stroke volume (SV_{LVOT}) (Fig. 1), that was $MRvol = SV_{MA} - SV_{LVOT}$. SV_{LVOT} was calculated as the VTI of LVOT (VTI_{LVOT}) multiplied by the cross-sectional area (CSA) of LVOT (CSA_{LVOT}). The LVOT is circular and the CSA_{LVOT} is derived as: $\pi d^2/4$, that is $0.785 d^2$. Thus, $SV_{LVOT} = 0.785 d^2 \times VTI_{LVOT}$, where d is the diameter of the LVOT in the PLAX view [4].

SV_{MA} was calculated as the VTI of MA (VTI_{MA}) multiplied by the CSA of MA (CSA_{MA}). Assuming that the MA is circular geometry, the CSA_{MA} is derived as $0.785 d^2$. Thus, $SV_{MA} = 0.785 d^2 \times VTI_{MA}$, where d was the diameter of the MA in the PLAX, A4C or A2C view. Assuming that the MA is ellipse geometry, the

CSA_{MA} is derived as $0.785 \times a \times b$. Thus, $SV_{MA} = 0.785 \times a \times b \times VTI_{MA}$, where a is the diameter of the MA in A4C and b in A2C view, a in A4C and b in PLAX view or a in A2C and b in PLAX view [4, 10, 11].

Real-Time 3D Color Doppler Echocardiography: MRvol by RT3DE

3D color Doppler data were acquired immediately after the 2D TTE using the same system equipped with a fully sampled matrix-array X3-1 transducer from the apical view, combining 7 small real-time subvolumes into a larger pyramidal volume. Nyquist limits were set between 40 and 60 cm/sec to avoid any overestimation or underestimation. Patients were asked to hold respiration during imaging acquisition.

Three-dimensional color Doppler data sets were analyzed offline using software (QLAB version 7.1). Using multiplanar reconstruction of the 3D color Doppler data sets, a cross-sectional plane through the vena contracta perpendicular to the jet direction was selected, and the cross-sectional plane was then moved along the jet direction as far as the smallest cross-sectional area [7, 10]. The EROA was determined using manual planimetry of the color Doppler flow signal from an en face view, and the MRvol was calculated as EROA by RT3DE multiplied by the VTI_{MR} (Fig. 2).

Statistical analysis

Continuous data were presented as mean $\pm$ SD. Categorical data were presented as percentages or absolute numbers. One factorial analysis of variance was used to compare the MA diameters measured in different views and the CSA_{MA} calculated using the different geometric assumption. Pearson's correlation analysis was performed to evaluate the relation between QPD and RT3DE measurements of MRvol. Bland-Altman analysis was performed to evaluate the differences in MRvol assessed with QPD and RT3DE. Differences were considered statistically significant at $P < 0.05$. Statistical analysis was performed using MedCalc version 15.2 (MedCalc Software, Mariakerke, Belgium).

Results

Clinical and echocardiographic characteristics of the MR patients are listed in Table 1.

Comparison of MA diameter in different views and CSA_{MA} based on different geometric assumption

As listed in Table 2, ANOVA showed significant differences among the 2D TTE diameters of the MA in three different views. The MA diameters in PLAX view were larger than the MA diameters in A4C or A2C view (MA_{PLAX} vs MA_{A4C} or MA_{A2C} : 3.0 ± 0.4 vs 2.9 ± 0.4 or 2.7 ± 0.3 , $P \leq 0.001$). As for CSA of the MA, the CSA_{PLAX} derived from circular geometric assumption was larger than CSA_{A4C} and CSA_{A2C} or $CSA_{PLAX+A4C}$, $CSA_{PLAX+A2C}$ and $CSA_{A4C+A2C}$ derived from ellipse assumption ($P \leq 0.001$ for all).

Assumption of a circular geometry of MA, MRvol by QPD compared with reference method

Compared with MRvol by RT3DE, MRvol by QPD-MA_{A4C} and QPD-MA_{A2C} showed good correlation ($r = 0.822$, $P < 0.0001$; $r = 0.805$, $P < 0.0001$), while MRvol by QPD-MA_{PLAX} demonstrated poor correlation ($r = 0.574$, $P < 0.0001$). QPD-MA_{PLAX} and QPD-MA_{A4C} overestimated the MRvol by a mean difference of 22.5 ml ($P \leq 0.0001$) and 10.4 ml ($P \leq 0.0001$) compared with RT3DE (Fig. 3). However, QPD-MA_{A2C} underestimated the MRvol by a mean difference of 5.5 ml ($p = 0.0002$) compared with RT3DE (Fig. 4).

Assumption of a ellipse geometry of MA, MRvol by QPD compared with reference method

MRvol by QPD-MA_{PLAX+A4C} and QPD-MA_{PLAX+A2C} demonstrated good correlation compared with RT3DE ($r = 0.789$, $P \leq 0.0001$; $r = 0.776$, $P \leq 0.0001$). QPD-MA_{PLAX+A4C} and QPD-MA_{PLAX+A2C} overestimated the MRvol by a mean difference of 15.2 ml ($P \leq 0.0001$) and 6.8 ml ($P = 0.0002$) when compared with RT3DE. As for QPD-MA_{A4C+A2C}, there was better correlation compared with RT3DE ($r = 0.905$, $P < 0.0001$), and the Bland-Altman analysis revealed no significant difference (mean difference = 1.7 ml, $P = 0.0844$) (Fig. 5). The correlation and difference between MRvol measured by QPD and RT3DE is summarized in Table 3.

Table 1 Patient characteristics (n = 88)

Variable	Value
Age (y)	48.2 ± 14.0
Men/women	55/33
Heart rate (beats/min)	74.8 ± 13.8
Systolic BP (mm Hg)	112.5 ± 18.7
Diastolic BP (mm Hg)	73.1 ± 9.5
LVEDD (cm)	5.9 ± 1.1
LVESD (cm)	4.5 ± 1.5
LVEF (%)	53.1 ± 18.5
LVOT diameter (mm)	2.0 ± 0.1
VTI _{LVOT} (cm)	17.3 ± 5.0
VTI _{MA} (cm)	17.9 ± 5.4
VTI _{MR} (cm)	131.1 ± 29.9
EROA by RT3DE (cm ²)	0.33 ± 0.14

BP, blood pressure; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; LVEF, left ventricular ejection fraction; EROA by RT3DE, the EROA was measured by manual planimetry of the 3D color Doppler signal—Data are expressed as mean ± SD or as number.

Table 2 Results of ANOVA analysis for MA diameter and CSA_{MA}

Variable	Value	ANOVA analysis	
		F	P
MA diameter (cm)			
MA _{PLAX}	3.0 ± 0.4	18.471	0.001
MA _{A4C}	2.9 ± 0.4		
MA _{A2C}	2.7 ± 0.3		
Circular assumption (cm ²)			
CSA _{PLAX}	7.1 ± 1.9	9.992	0.001
CSA _{A4C}	6.6 ± 1.7		
CSA _{A2C}	5.7 ± 1.2		
Ellipse assumption (cm ²)			
CSA _{PLAX+A4C}	6.8 ± 1.6		
CSA _{PLAX+A2C}	6.3 ± 1.4		
CSA _{A4C+A2C}	6.1 ± 1.3		

MA_{PLAX}, MA_{A4C} and MA_{A2C} diameter, the MA diameter was measured in PLAX, A4C and A2C view; CSA_{PLAX}, the CSA of MA was calculated from the MA diameter in PLAX view using circular geometric assumption ($CSA = 0.785 d^2$); CSA_{PLAX+A4C}, the CSA of MA was calculated from the MA diameter in PLAX and A4C view using ellipse assumption ($CSA = 0.785 \times a \times b$).

Discussion

The main finding of this study was that compared with the MRvol using EROA by RT3DE multiplied by the TVI_{MR} , the MRvol was overestimated significantly by the 2D TTE QPD_{A4C} method previously recommended [2, 4]. The overestimates were caused by the circular geometric assumption of the MA, which led to the CSA_{A4C} and corresponding SV_{MA} being overestimated. In our study, assumption of an ellipse geometry of MA, MRvol calculated by QPD_{A4C+A2C} showed better correlation ($r = 0.905$, $P < 0.0001$) and had no significant difference (mean difference = 1.7 ml, $P = 0.0844$) with MRvol by RT3DE.

Table 3 Results of Pearson's correlation and Bland-Altman analysis for MRvol by QPD and reference methods

Method	MRvol[ml]	Pearson's correlation analysis		Bland-Altman analysis		
		<i>r</i>	<i>p</i>	Mean difference (ml)	95% limits of agreement (ml)	<i>p</i>
Circular assumption						
QPD-MA _{PLAX}	66.4 ± 41.1	0.574	0.0001	22.5	-43.6 – 88.6	0.0001
QPD-MA _{A4C}	54.3 ± 27.6	0.822	0.0001	10.4	-20.6 – 41.4	0.0001
QPD-MA _{A2C}	38.4 ± 20.6	0.805	0.0001	-5.5	-31.7 – 20.2	0.0002
RT3DE	43.9 ± 21.3					
Ellipse assumption						
QPD-MA _{PLAX+A4C}	59.1 ± 29.5	0.789	0.0001	15.2	-20.5 – 51.0	0.0001
QPD-MA _{PLAX+A2C}	50.6 ± 25.6	0.776	0.0001	6.8	-24.9 – 38.5	0.0002
QPD-MA _{A4C+A2C}	45.6 ± 21.5	0.905	0.0001	1.7	-16.6 – 20.1	0.0844

QPD-MA_{PLAX}, MRvol was measured by QPD using circular geometric assumption, and the MA diameter was measured in PLAX view; QPD-MA_{PLAX+A4C}, MRvol was measured by QPD using ellipse assumption, and the MA diameter was measured in PLAX and A4C view; RT3DE, MRvol was measured using EROA multiplied by the MR_{VTI}.

MRvol by QPD is simple in theory. Stroke volume (SV) at aortic valve or MV is derived as the product of CSA and VTI of flow at the LVOT or MA. In the absence of MR, SV determinations at LVOT and MA are equal. In the presence of MR, without any intracardiac shunt, the flow through MA is larger than through the LVOT. The difference between the two represents the MRvol [12]. For MRvol by QPD method, it is very important to accurately evaluate the CSA_{MA} and CSA_{LVOT}. The calculation method of CSA_{LVOT} is nearly consistent ($CSA_{LVOT} = \pi d^2 / 4$, where d was the diameter of the LVOT in the PLAX view) [2,4,9]. However, the calculation method of CSA_{MA} is controversial [5]. The MA diameter was measured in the A4C view and the CSA_{MA} was derived as $0.785 d^2$ (where d is the MA diameter in A4C) assuming that the MA is circular

geometry as previously recommended [4,9]. However, previous studies have been demonstrated that the MA has a saddle-shaped contour [13] and the CSA of the MA are oval, with the major and minor diameter [5,14,15]. Ren et al [5] studied geometric errors of the MA by RT3DE. They found that the MA geometry was oval in the 3D en face views with a significant difference between the major and minor diameters. The 2D diameters of the MA_{A4C} was significantly different from both the major and minor diameters. Assuming that the MA was circular geometry, the CSA of the MA_{A4C} by 2D TTE overestimated the CSA compared with RT3DE [5]. In our study, the QPD-MA_{PLAX} and QPD-MA_{A4C} overestimated the MRvol (mean difference = 22.5 ml, $P \leq 0.0001$; mean difference = 10.4 ml, $P \leq 0.0001$) and QPD-MA_{A2C} underestimated the MRvol (mean difference = 5.5 ml, $P = 0.0002$) compared with the MRvol by RT3DE. A possible reason is that the 2D MA_{PLAX} and MA_{A4C} diameters may approach the 3D major diameters, and the MA_{A2C} may be close to the 3D minor diameters as previous findings [5,16]. Based on the assumption of circular geometry, the monoplanar measurements of MA diameter and false geometric assumption are crucial factors of error using the 2D TTE QPD method. This error is important because the MA diameter is squared to derive the CSA_{MA} in the geometric circular assumption formula, which result in an overestimation of the CSA_{PLAX} and CSA_{A4C} and an underestimation of the CSA_{A2C}. Because of these, the corresponding SV_{MA} calculated by CSA_{PLAX} or CSA_{A4C} is overestimated, and the corresponding SV_{MA} calculated by CSA_{A2C} is underestimated. Consequently, the QPD-MA_{PLAX} and QPD-MA_{A4C} overestimated the MRvol and QPD-MA_{A2C} underestimated the MRvol.

Based on that the MA is oval with the major and minor diameters previously demonstrated [5,14,15]. In this study, assuming that the MA was ellipse geometry, there was no significant difference of MRvol (mean difference = 1.7 ml, $P = 0.0844$) between the QPD-MA_{A4C+A2C} and the RT3DE. This is because the MA_{A4C} diameters may approach the 3D major diameters, and the MA_{A2C} may be close to the 3D minor diameters. The CSA_{MA} calculated by 2D MA_{A2C} and MA_{A4C} diameters using ellipse geometric assumption formula ($CSA_{MA} = 0.785 \times a \times b$) may be closer to the real CAS_{MA}, which led to an accurate evaluation of corresponding SV_{MA} and MRvol by QPD-MA_{A4C+A2C}. Since the MA_{PLAX} diameter was larger than the MA_{A4C} (3.0 ± 0.4 vs 2.9 ± 0.4 , $P \leq 0.001$) which resulted in the fact that the CSA_{PLAX+A2C} was larger than the CSA_{A4C+A2C}, the corresponding MRvol by QPD-MA_{PLAX+A2C} was overestimated (mean difference = 6.8 ml, $P = 0.0002$) compared with the RT3DE. As for the overestimation of MRvol (mean difference = 15.2 ml, $P \leq 0.0001$) by QPD-MA_{PLAX+A4C}, this could be related to the fact that the MA_{A4C} diameter was larger than the MA_{A2C} (2.9 ± 0.4 vs 2.7 ± 0.3 , $P \leq 0.001$) which led to an overestimation of the corresponding CSA_{PLAX+A4C} and SV_{MA}, thus overestimating the MRvol. The smaller difference of the result between the MRvol by QPD-MA_{A4C+A2C} and RT3DE was probably because the MA has an elliptic shape with a saddle-shaped 3D structure, and there are dynamic changes in its shape and position in different diseases during the cardiac cycle [18-20].

To the best of our knowledge, no clinical studies have assessed the impact different geometric assumption of MA on the assessment of MRvol by QPD. This study showed that the QPD-MA_{A4C} overestimated the MRvol assuming that the MA was circular geometry as previously recommended, and

assuming that the MA is ellipse geometry, the MRvol with QPD-MA_{A4C+A2C} correlated well and had good agreement compared with MRvol using EROA by RT3DE multiplied by the VTI_{MR}. The QPD-MA_{A4C+A2C} provided more accurate assessment of MRvol using ellipse assumption of MA than the QPD-MA_{A4C} applying circular assumption previously recommended.

Limitations

First, a limitation of a true gold standard for calculating MRvol was absent in the present study. In this study, the MRvol derived from EROA by RT3DE multiplied by the VTI_{MR} was used as the reference method, which has been documented as an accurate method [6,7], and some studies have used it as reference method [10,21]. However, RT3DE has limited spatial resolution of the reconstructed image, which may lead to biased results [22]. Second, this study did not evaluate the dynamic changes of 3D structure and CSA of the MA in different diseases and cardiac cycles. Third, in this study, the relationship between 3D MA diameters and 2D diameters in different views, as well as the geometry of LVOT were not evaluated, which may add to further errors in calculating MRvol by QPD. Finally, further studies are needed to confirm the results of MRvol by QPD-MA_{A4C+A2C} based on ellipse assumption of MA.

Conclusions

Assuming that the MA is circular geometry as previously recommended, the MRvol by 2D TTE QPD-MA_{A4C} was overestimated compared with the MRvol derived from EROA by RT3DE multiplied by the VTI_{MR}. However, assuming that the MA was ellipse geometry, the MRvol by the 2D TTE QPD-MA_{A4C+A2C} was accurate compared with the reference method.

Abbreviations

MRvol: Mitral regurgitation volume; QPD: Quantitative pulsed Doppler; MA: Mitral annulus; MR: Mitral regurgitation; RT3DE: Real time three-dimensional echocardiography; 3D: Three-dimensional; 2D: Two-dimensional; CSA: Cross-sectional area; EROA: Effective regurgitant orifice area; VTI_{MR}: MR velocity-time integral; TTE: Transthoracic echocardiographic; MVP: Mitral valve prolapse; MV: Mitral valve; A4C: Apical four-chamber; A2C: Apical two-chamber; PLAX: Parasternal long-axis; LVOT: Left ventricular outflow tract; A5C: Apical five-chamber; VTI: Velocity-time integral; SV: Stroke volume; SV_{MA}: MA forward stroke volume; SV_{LVOT}: LVOT forward stroke volume; VTI_{LVOT}: VTI of LVOT; CSA_{LVOT}: CSA of LVOT; VTI_{MA}: VTI of MA; CSA_{MA}: CSA of MA; MA_{PLAX}: The diameter of MA was measured in the PLAX view; MA_{A4C}: The diameter of MA was measured in the A4C view; MA_{A2C}: The diameter of MA was measured in the A2C view; CSA_{PLAX}: The CSA of MA was calculated from the MA diameter in PLAX view using circular geometric assumption; CSA_{A4C}: The CSA of MA was calculated from the MA diameter in A4C view using circular geometric assumption; CSA_{A2C}: The CSA of MA was calculated from the MA diameter in A2C view using circular geometric assumption; CSAP_{LAX+A4C}: The CSA of MA was calculated from the MA diameter in PLAX and A4C view using ellipse assumption; CSAP_{PLAX+A2C}: The CSA of MA was calculated from the MA

diameter in PLAX and A2C view using ellipse assumption; QPD-MA_{PLAX}: MRvol was measured by QPD using circular geometric assumption, and the MA diameter was measured in PLAX view; QPD-MA_{A2C}: MRvol was measured by QPD using circular geometric assumption, and the MA diameter was measured in A2C view; QPD-MA_{A4C}: MRvol was measured by QPD using circular geometric assumption, and the MA diameter was measured in A4C view; QPD-MA_{PLAX+A4C}: MRvol was measured by QPD using ellipse assumption, and the MA diameter was measured in PLAX and A4C view; QPD-MA_{PLAX+A2C}: MRvol was measured by QPD using ellipse assumption, and the MA diameter was measured in PLAX and A2C view; QPD-MA_{A4C+A2C}: MRvol was measured by QPD using ellipse assumption, and the MA diameter was measured in A4C and A2C view.

Declarations

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Availability of data and materials

The data and materials used in this study are available from the corresponding author or the first author on reasonable request.

Authors' contributions

WGW and XXF designed this study as the first author and corresponding author. ZBW, JFL, and KG were involved in image acquisition and analysis in this study. LZ and GZT carried out the statistical analysis. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the institutional review board of The Affiliated Hospital of Qingdao University, and all patients underwent echocardiographic examination because of clinical indications and gave written informed consent.

Consent for publication

The authors of this study agreed with this manuscript and its submission to Cardiovascular ultrasound.

Competing interests

The authors declare that there is no conflict of interest.

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Figures

Figure 1

QPD calculations of MRvol. (a) The diameter of LVOT was measured in the PLAX view, and the CSALVOT was derived as $0.785 d^2$. (d) LVOT pulsed Doppler was traced to obtain the VTILVOT. Thus, $SVLVOT = 0.785 d^2 \times VTILVOT = 0.785 \times 2.08^2 \times 13.4 = 45.51$ ml. (b, c) The diameter of MA was measured in the A4C and A2C view. Assuming that the MA is ellipse geometry, the CSAMA was derived as $0.785 \times a \times b$. (e) MA inflow pulsed Doppler was traced to obtain the VTIMA. Thus, $SVMA = 0.785 \times a \times b \times VTIMA = 0.785 \times 3.33 \times 2.65 \times 13.1 = 90.75$ ml. In this example of MR, $MRvol = SVMA - SVLVOT = 90.75 - 45.51 = 45.24$ ml.

Figure 2

MRvol calculated as EROA by RT3DE multiplied by the TVIMR. The 3D color Doppler data was manually cropped by the cross-sectional plane perpendicularly to the regurgitant jet direction up to the smallest cross-sectional area of the regurgitant jet. The EROA was determined using manual planimetry of the color Doppler flow signal from an en face view. Example of a MR patient: EROA = 0.28 cm², TVIMR = 150 cm, MRvol = 0.28×150 = 42 mL.

Figure 3

Assumption of a circular geometry of MA, linear regression plot and Bland-Altman plot showing correlations (A) and agreement (B) between MRvol by QPD-MAA4C and RT3DE.

Figure 4

Assumption of a circular geometry of MA, linear regression plot and Bland-Altman plot showing correlations (A) and agreement (B) between MRvol by QPD-MAA2C and RT3DE.

Figure 5

Assumption of a ellipse geometry of MA, linear regression plot and Bland-Altman plot showing correlations (A) and agreement (B) between MRvol by QPD-MAA4C+A2C and RT3DE.