Journal of Cardiovascular Magnetic Resonance (2006) **8**, 825–829

ISSN: 1097-6647 print / 1532-429X online
DOI: 10.1080/10976640600778007

Assessment of Left Ventricular Outflow Tract Geometry in Non-Stenotic and Stenotic Aortic Valves by Cardiovascular Magnetic Resonance

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ABSTRACT

Purpose: **To assess the geometry and area of the left ventricular outflow tract (LVOT) in non-stenotic and stenotic aortic valves and to determine the aortic valve area (AVA) in non-stenotic valves by magnetic resonance imaging (MRI) using a modified continuity equation.** ***Methods:*** **Twenty patients (10 male, mean age 54.8 ± 15 years) without known aortic valve disease and 10 patients (7 male, mean age 65.1 ± 14 years) with moderate to severe aortic stenosis were included in this study. MRI was performed using a 1.5 T scanner (Philips Intera CV). AVA was assessed by planimetry on high quality SSFP cine sequences and used as reference standard. LVOT area was defined by calculating a circular area using the LVOT diameter from the 3 chamber view (3CV) and by planimetry. Peak flow velocity was assessed in the LVOT and the proximal aorta. AVA was calculated by a modified Gorlin equation, the continuity equation and a modified continuity equation using the planimetric LVOT area.** ***Results:*** **Planimetric AVA ranged from 2.9 to 6.4 cm^2 in patients with non-stenotic and from 0.3 to 1.3 cm^2 with stenotic valves, LVOT area from 3.4 to 6.1 cm^2 and from 2.6 to 6.5 cm^2, respectively. The LVOT area based on the LVOT diameter derived from the 3CV was significantly underestimated in comparison to planimetry in non-stenotic and stenotic aortic valves (3.3 ± 0.7 vs. 4.7 ± 1.0 cm^2, $p < 0.0001$; mean difference 1.1 ± 0.12 cm^2, CI 0.86–1.36 and 3.7 ± 1.2 vs. 4.7 ± 1.5 cm^2, $p < 0.05$; mean difference 1.0 ± 1.0 cm^2, CI 0.24–1.71). The Gorlin formula showed a poor agreement with planimetry, whereas continuity equation and the modified continuity equation revealed a very good agreement. Planimetry of the LVOT displayed an elliptic shape of the LVOT in all patients with the minimum diameter perpendicular to the 3CV, which was the reason for the above mentioned underestimation.** ***Conclusion:*** **The LVOT area calculated from the 3CV-LVOT diameter underestimates the LVOT area compared to planimetry due to an elliptic shape of the LVOT in patients with non-stenotic as well as with stenotic aortic valves. The modified Gorlin equation proved to be less useful to assess AVA in non-stenotic valves, whereas the continuity equation and a modified continuity equation displayed a very good agreement with planimetric area measurements.**

Received 20 July 2005; accepted 11 April 2006.
Keywords: Magnetic Resonance Imaging, Aortic Valve, Left Ventricular Outflow tract, Continuity Equation, Gorlin Formula.
C.B. was supported by the “Deutsche Gesellschaft für Kardiologie”
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INTRODUCTION

Cardiovascular magnetic resonance has become an important non-invasive tool for the diagnosis and treatment of patients with cardiovascular disease. Due to its high temporal and spatial resolution, cardiovascular magnetic resonance (CMR) provides high quality assessment of both structural and functional alterations of the cardiovascular system. Despite some limitations, velocity-encoded measurements of both blood flow and flow volume yields a measure of valvular incompetence, for which CMR is considered a class I A - indication (1).

The quantification of aortic stenosis by CMR was already described in 1989 (2) and several studies have shown a good agreement between CMR, echocardiography and hemodynamic measurements including intracardiac angiography (3, 4). In clinical routine, several approaches exist to measure the aortic valve area (AVA), most commonly by echocardiography. In addition to visual assessment and planimetry continuous wave Doppler allows the determination of AVA by means of both peak and mean flow velocity (5, 6). Furthermore, using peak or mean flow velocity within the left ventricular outflow tract (LVOT) from pulse wave Doppler and the measurement of LVOT diameter the AVA may be calculated by the continuity equation (5, 6). Besides the use of planimetry (4, 7, 8) or the continuity equation(3) AVA may also be determined by a modified Gorlin formula with data from CMR. However, the continuity equation is based on the assumption of a circular shape of LVOT.

Since multiplanar imaging may easily be performed with CMR the primary goal of this study was to investigate, whether the assumption of a circular LVOT is appropriate. Thereby LVOT area was calculated perpendicular to the outflow tract axis by means of the continuity equation and the results were compared to direct planimetry in patients without and with aortic stenosis. In a second step, the AVA was assessed in patients without known aortic stenosis by direct planimetry, by the modified Gorlin formula, by the continuity equation and by a modified continuity equation using the planimetric LVOT area. Planimetry of the aortic valves was defined as the reference standard.

METHODS

Patients and study protocol

Twenty patients (10 male, mean age 54.8 ± 15 years) scheduled for cardiac MRI without known aortic valve disease and 10 patients (7 male, mean age 65.1 ± 14 years) with moderate to severe aortic stenosis were included in this study. Exclusion criteria were any cardiac rhythm other than sinus rhythm, claustrophobia, hypertrophic cardiomyopathy (with or without obstruction) or a clinically unstable condition.

The study was approved by the local ethics commission, and all participants gave their informed consent to the study.

Cardiovascular magnetic resonance

CMR was performed using a 1.5 Tesla Philips Intera CV (Philips Medical Systems, Best, The Netherlands) scanner with a 5-element phased array coil. To define the position and axis of the left ventricle, three short survey scans were performed. Parallel imaging was employed for all scans (SENSE factor 2.0). A three-chamber-view and a LVOT-view were performed with cine images using a segmented k-space balanced fast-field-echo sequence (steady-state-free-precession, 32 phases per heart cycle, matrix 208 divided into 26 segments, TE 3.2 ms, TR 1.6 ms, flip angle 55°). In-plane resolution was between 1.5–1.8 mm^2 and 2.3–1.8 mm^2 for the functional scans, depending on the field-of-view. Based on these scans, three to four high quality scans of the LVOT parallel to the aortic valve (slice thickness 7 mm) were performed. The aortic valve was visualized comparable to the scans of the LVOT. Cine images were acquired during breath hold (10–15 s).

MRI velocity measurements in phase contrast technique of the aortic valve and the LVOT were performed as described before (3) in free-breathing technique. The maximal encoding velocity was 150 cm/s for the aorta and 100 cm/s for the LVOT in a first step. In case of aliasing measurements were repeated with adjusted values.

Image analysis

For image analysis, a commercial work-station (ViewForum, Philips Medical Systems, The Netherlands) was used. Planimetry of the aortic valve area was performed on all slices acquired in the cardiac phase where the maximal opening area of the leaflets was observed. From these data the minimal value was taken as the reference standard. Peak blood flow velocity recorded at the aortic valve and LVOT levels as well as expulsion time were calculated from time velocity curves. Peak velocity was determined from a maximal single pixel. Pressure gradients were estimated by a modified Bernoulli equation. AVA according to the modified Gorlin equation was calculated by the formula:

(stroke volume)/([expulsion time] x [peak blood flow velocity at the aortic valve level]).

The planimetric area of the LVOT was defined in the corresponding cardiac phase (normally mid-systolic), where LVOT peak blood flow was observed. Maximal and minimal diameter of the LVOT were measured in this geometry, as well. Additionally the diameter of the LVOT was measured in the 3-chamber-view (3CV) – as is normally done in echocardiography, as well – and in a modified and angulated short axis view parallel to the aortic root (Figs. 1 and 2). LVOT area was calculated according to $A = \pi r^2$ with the radial diameter derived from the 3CV.

Statistics

Continuous variables are described as means and standard deviations. Categorical data are presented with absolute frequencies. Linear regression, t-tests and Bland-Altmann analysis was performed to evaluate differences between two methods. P values of < 0.05 were considered statistically significant. *Agreement* between the different methods were tested by regression analysis. All statistic analyses were performed using Prism 3.0 (GraphPad Software Inc, San Diego, California, USA).

RESULTS

Planimetric AVA ranged from 2.9 to 6.4 cm^2 in non-stenotic and from 0.3 to 1.3 cm^2 in stenotic valves, LVOT area from 3.4 to 6.1 cm^2 and from 2.6 to 6.5 cm^2, respectively. Planimetry of the LVOT revealed an elliptic shape of the LVOT in all patients with the minimal diameter perpendicular to the 3CV (Fig. 2). The LVOT area based on the LVOT diameter derived from the 3CV was significantly underestimated in comparison to planimetry in non-stenotic and stenotic aortic valves (3.3 ± 0.7 vs. 4.7 ± 1.0 cm^2, $p < 0.0001$; mean difference 1.1 ± 0.12 cm^2, CI 0.86–1.36 and 3.7 ± 1.2 vs. 4.7 ± 1.5 cm^2, $p < 0.05$; mean

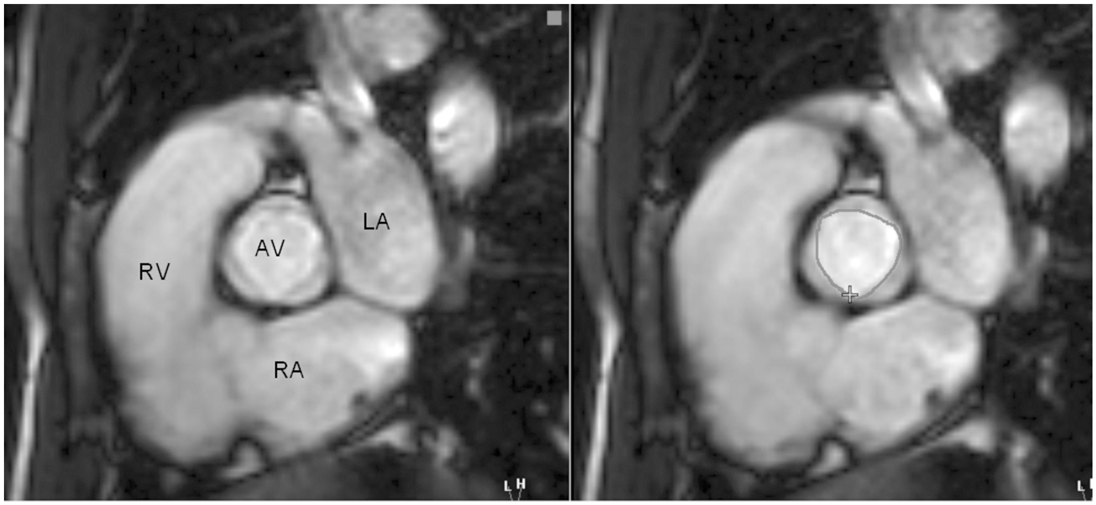

Figure 1. Planimetric assessment of the aortic valve area. AV = aortic valve, LA = left atrium, RA: right atrium, RV = right ventricle.

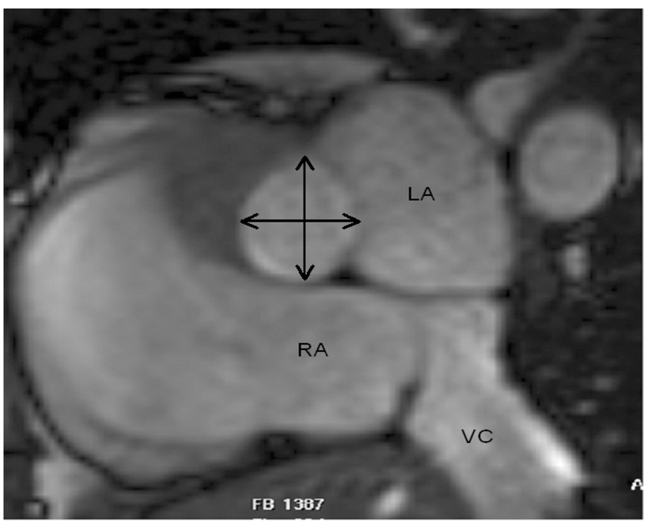

Figure 2. Assessment of the LVOT diameter (cross sectional and longitudinal). RA = right atrium, LA = left atrium, VC = vena cava.

difference 1.0 ± 1.0 cm^2, CI 0.24–1.71). In non-stenotic aortic valves, peak velocity of the aortic valve ranged from 97.3 to 183.2 cm/s, and in stenotic aortic valves from 179.3 cm/s to 334.8 cm/s. Peak velocity in the LVOT ranged from 76.8 to 159.0 cm/s in the non-stenotic valves.

The AVA calculated by the Gorlin formula showed a poor agreement with planimetry (slope 0.46 ± 0.024). The continuity equation using the LVOT diameter taken from the 3-chamber-view showed a much better agreement (slope 0.62 ± 0.033). The best agreement with planimetric AVA was found for the modified continuity equation (slope 0.89 ± 0.044 Fig. 3). Bland-Altmann analysis displayed an underestimation of the AVA for all three approaches (Fig. 4).

The LVOT area based on the LVOT diameter derived from the 3CV was significantly underestimated in comparison to planimetry in non-stenotic and stenotic aortic valves (3.3 ± 0.7 vs. 4.7 ± 1.0 cm^2, $p < 0.0001$; mean difference 1.1 ± 0.12 cm^2, CI 0.86–1.36 and 3.7 ± 1.2 vs. 4.7 ± 1.5 cm^2, $p < 0.05$; mean difference 1.0 ± 1.0 cm^2, CI 0.24–1.71).

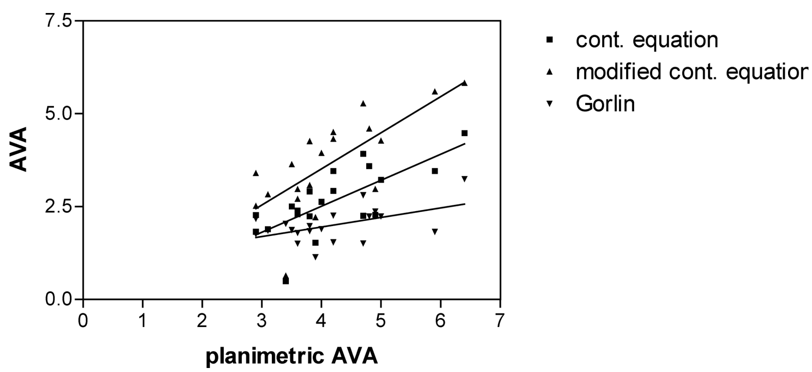

Figure 3. Agreement between planimetric AVA and AVA as assessed by the continuity equation (cont. equation), the modified continuity equation (modified cont. equation) and the Gorlin equation (Gorlin).

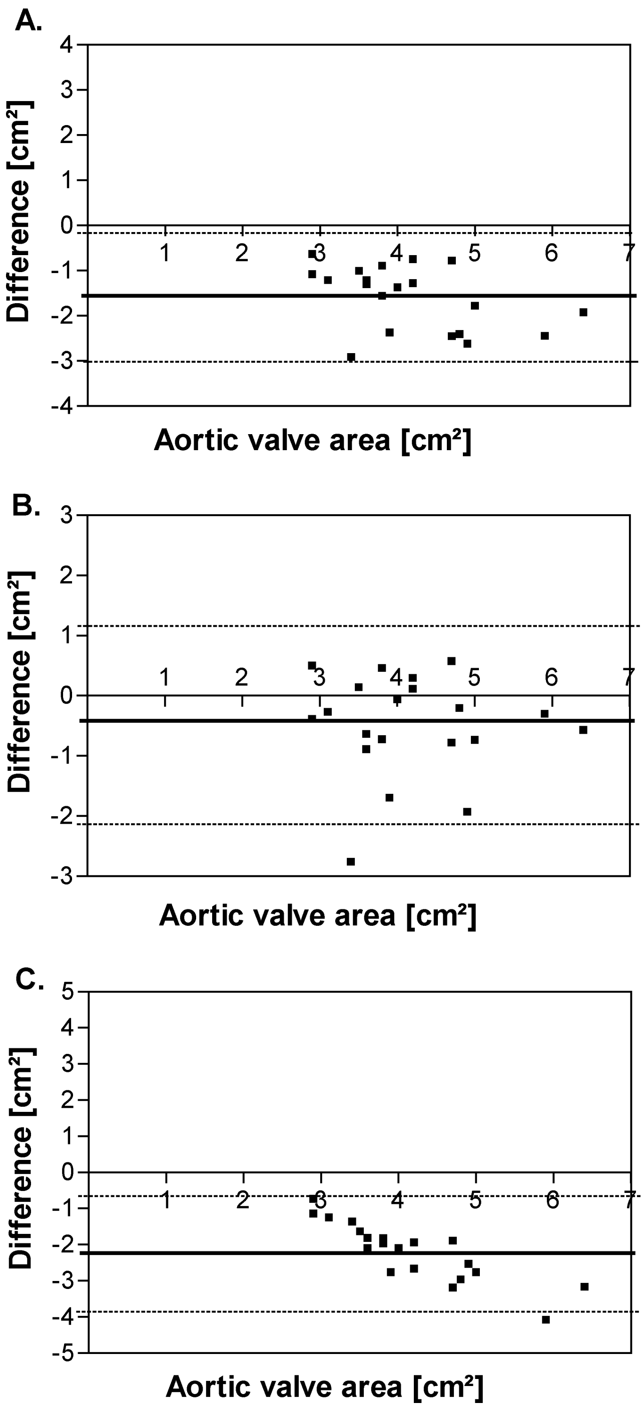

Figure 4. Bland-Altmann analysis for the continuity equation (A), the modified continuity equation (B) and the modified Gorlin formula (C).

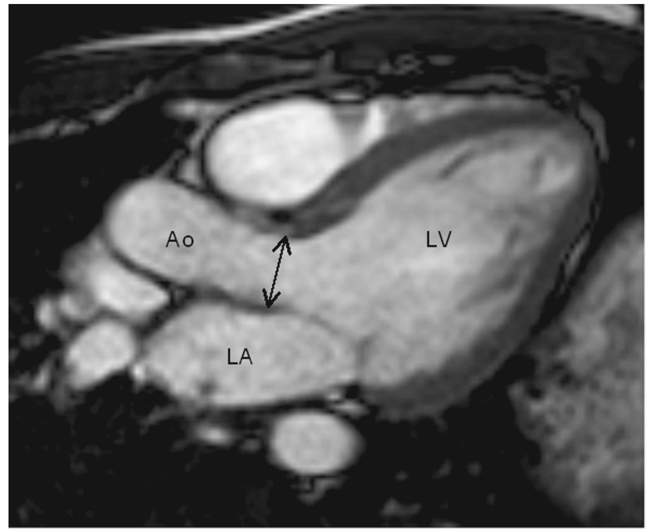

Figure 5. Assessment of the LVOT diameter in the 3-chamber view. Ao = aorta, LV = left ventricle, LA = left atrium.

DISCUSSION

The most important finding of the present study was that the left ventricular outflow tract has an elliptical shape in patients without and with aortic stenosis. Moreover, a modified continuity equation revealed the best agreement with the planimetric aortic valve area in patients without aortic stenosis compared to the continuity equation and the Gorlin formula. The reason may be a significant underestimation of the LVOT area when applying the "standard" continuity equation. The MR images in our study displayed that LVOT geometry resembles more an elliptic rather than a circular shape. In all patients the diameter measured within the 3-chamber-view reflected the oblique diameter of the LVOT, whereas the long axis diameter of the LVOT was comparable to the one obtained from the true LVOT view (Fig. 7). Thus, the LVOT area and the AVA calculated from the diameter within the 3-chamber-view was significantly underestimated.

Interestingly, values of AVA calculated from the Gorlin formula showed a very poor agreement with those from direct

Figure 6. Assessment of the LVOT diameter in a LVOT view. Ao = aorta, LV = left ventricle.

planimetry. Since we tested our different methods to measure AVA only in patients without aortic stenosis, it remains unclear whether our results are transferable to patients with aortic stenosis. However, as the shape of the LVOT was elliptical both in patients with and without aortic valve disease, it remains doubtful whether the "standard" continuity equation as used in echocardiography permits an accurate calculation of the AVA. In stenotic aortic valves peak velocity in the proximal aorta may rise to more than 500 cm/s. On the other hand, accuracy of flow measurements may decrease with slower flows, and this fact might explain the results of our study. Although discrepancies for the calculation of the aortic valve area between Gorlin formula and Doppler - echo continuity equation in patients with aortic stenosis have been described recently (9), it remains unclear at present why the AVA calculated from the Gorlin formula showed such a poor agreement with planimetry in patients without aortic valve disease. Further catheter- and echo-controlled studies are required to answer the question, whether our results with a modified continuity equation are transferable to patients with aortic stenosis.

Study limitations

The cohorts of 20 patients without and 10 patients with known aortic stenosis included in this pilot study are relatively small. The different formula for calculating the AVA were only tested in patients without aortic stenosis. Thus, it remains unclear at present whether our results are transferable to patients with aortic valve stenosis. Moreover, we did not use comparative imaging tools such as echocardiography to reproduce the CMR results from such reference techniques. However, a strong *agreement* between echocardiography and MRI at least for the continuity equation has already been demonstrated recently. And since LVOT planimetry can not be achieved from standard echocardiographic techniques, we did not test both techniques to compare the results of either calculation of AVA.

CONCLUSIONS

Using the LVOT diameter from the 3CV the calculated LVOT area will be underestimated as compared to direct planimetry in patients without and with aortic stenosis because of the elliptic shape of the LVOT. The modified Gorlin formula proved to be less useful to assess AVA in non-stenotic valves whereas the continuity equation and a modified continuity equation displayed a very good agreement with direct planimetry.

ABBREVIATIONS

AVA	aortic valve area
LVOT	left ventricular outflow tract
SSFP	steady state free precession
3CV	3 chamber view

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