CLINICAL STUDY

Planimetry of the Orifice Area in Aortic Valve Stenosis Using Phase-Contrast Cardiac Magnetic Resonance Imaging

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Summary

Manual planimetry is a well-established method using transesophageal echocardiography (TEE) to assess the severity of aortic stenosis (AS). TEE, however, is a less than optimal approach in patients with calcified valves. Even when using cine-cardiac magnetic resonance (CMR), it is often difficult to evaluate the true border of the aortic orifice because of jet turbulence. With phase-contrast sequences of CMR, high flow signals at the aortic orifice can be clearly visualized, even in cases with severe calcification and jet turbulence. Therefore, the aims of the present study were to compare the utility of CMR using phase-contrast imaging with TEE and cine-CMR for the performance of planimetry of the aortic valve. The study cohort consisted of 30 consecutive patients with moderate or severe aortic valve stenosis documented by TEE who had undergone phase-contrast and cine-CMR for the evaluation of AS. Manual planimetry of the area of high flow signal was traced over the phase-contrast images at systolic peak, when the aortic valve is maximally opened. The results showed that the aortic valvular area (AVA) value derived from TEE correlated better with phase-contrast planimetry ($r^2 = 0.84$, $P < 0.05$) than cine-mode planimetry ($r^2 = 0.57$, $P < 0.05$). Bland-Altman plots indicated that the variation of measuring AVA was greater using the cine-mode method than the phase-contrast method. In conclusion, phase-contrast CMR offers a tool for evaluating the severity of aortic valve stenosis noninvasively. Phase-contrast CMR has the potential to become a routine clinical option as an alternative to TEE, at least in selected cases.

Key words: Aortic stenosis

Accessing the aortic valvular area (AVA) is crucial for evaluating the severity of aortic stenosis (AS). Manual planimetry is a well-established method using transesophageal echocardiography (TEE) to assess the severity of AS. Several studies have evaluated the method of measuring anatomic (geometric) AVA by direct visualization of the valvular orifice by TEE.1-3 Planimetry by TEE, however, is a less than optimal approach in patients with calcified valves. This is because leaflet calcification and jet turbulence can make accurate visualization of the true orifice difficult and because of the complex three-dimensional shape of the stenotic orifice. Additionally, because TEE is a semi-invasive method, there is a need for an alternative reliable noninvasive modality to assess the severity of AS. Recently, some studies have indicated that the aortic orifice can be clearly visualized in a noninvasive manner using cine-cardiac magnetic resonance (CMR), even in cases with severe calcification.4,5 However, even when using cine-CMR, it is often difficult to evaluate the true border of the aortic orifice because of jet turbulence.

With phase-contrast sequences of CMR, high flow signals at the aortic orifice can be clearly visualized, even in cases with severe calcification and jet turbulence4,5 (Figure 1A and B). Therefore, the aims of the present study were to compare the utility of CMR using phase-contrast imaging with TEE for the performance of planimetry of the aortic valve.

Methods

The study cohort consisted of 30 consecutive patients with moderate or severe aortic valve stenosis documented by TEE who had undergone phase-contrast CMR for the evaluation of AS between April 1, 200, and June 6, 2008. Patients with a rhythm other than the sinus rhythm (i.e., atrial fibrillation) or with incessant ectopic beats, and who were determined to have more than moderate aortic regurgitation, were all excluded in order to acquire a homogeneous sample population without introducing any confounding factors. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and

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was approved by our institutional review board. Written informed consent was obtained from each patient. Patients were imaged using a 1.5 T magnetic resonance imaging scanner (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany). All images were acquired by electrocardiogram-gated breath-hold technique. Images parallel to the aortic annulus were acquired employing the fast imaging with steady-state free precession (TrueFISP) CMR protocol. Repetition time (TR) was 42.6-71 milliseconds; echo time (TE), 1.22 milliseconds; flip angle, 80°; views per segment, 15-25; field of view, 340 × 298 mm; matrix size, 168 × 192; breath-hold time, 10-15 seconds; slice thickness, 8 mm; and nominal spatial resolution (voxel size), 1.77 × 1.77 × 8.0 mm. Encoded velocity (VENC) was initially set at 4 m/s in the aortic root and increased in cases where aliasing was observed. Through several times of trial and error, we finally set VENC to be ±50 cm/second of acquired velocity. The imaging plane was carefully positioned perpendicular to the aorta root and nearest to but never touching the tips of the leaflet. Typical images are shown in Figure 1C and D. From this localization, cine-mode images and phase-contrast images were obtained. Manual planimetry of the area of high flow signal was traced over the phase-contrast images at systolic peak, when the aortic valve is maximally opened. TEE two-dimensional images were acquired using the iE 33 ultrasound system (Philips Medical Systems, Bothell, WA, USA), in standard imaging windows. After placing the probe to visualize the standard long-axis view of the aortic valve and the ascending aorta, we rotated the image plane from 0° to 180° yielding the best short-axis image of the aortic valve opening. Carefully placing the probe at the position showing the smallest orifice during maximum opening in systole, we measured the orifice in magnified image zoom mode.

Statistical analyses were performed using Prism 6 for Windows (version 6.07).

**Results**

Patient characteristics are shown in the Table. Mean age was 70 ± 8.3 years (range 56-86 years). All patients were in sinus rhythm at the time of the study; 14 patients had a bicuspid valve (47%), 2 presented with rheumatic changes (6.7%), and 14 had calcified valves (47%). The mean ejection fraction was 53 ± 15% (range 17-71%), with < 40% being observed in six patients.

The mean AVA measured by cine-mode planimetry and phase-contrast was 0.77 ± 0.18 cm² (range 0.50-1.3 cm²) and 0.71 ± 0.20 cm² (range 0.44-1.3 cm²), respectively. The mean AVA measured by TEE was 0.73 ± 0.20 cm² (range 0.50-1.3 cm²). The AVA value derived from TEE correlated better with phase-contrast planimetry ($r^2 = 0.84$, $P < 0.05$, Figure 2A) than cine-mode planimetry ($r^2 = 0.57$, $P < 0.05$, Figure 2C). Bland-Altman plots are shown in Figure 2B and D, indicating that the variation of measuring AVA was greater using the cine-mode method than the phase-contrast method. Phase-contrast planimetry
### Table. Patient Characteristics

| Patient no. | Age (years) | Sex | LVEF (%) | LVEDd (mm) | LVEds (mm) | AVA (cm²) | PV (m/second) | AR |
|-------------|-------------|-----|----------|------------|------------|-----------|--------------|----|
| 1           | 68          | F   | 63       | 42         | 28         | 0.66      | 4.8          | mild |
| 2           | 72          | F   | 65       | 40         | 24         | 0.45      | 4.7          | mild |
| 3           | 71          | F   | 65       | 44         | 25         | 0.97      | 4.9          | mild |
| 4           | 60          | F   | 62       | 41         | 27         | 0.61      | 5.8          | mild |
| 5           | 80          | F   | 32       | 50         | 43         | 0.36      | 4.7          | trivial |
| 6           | 75          | F   | 66       | 39         | 23         | 0.71      | 4.8          | trivial |
| 7           | 71          | M   | 55       | 40         | 25         | 0.52      | 5.4          | trivial |
| 8           | 81          | M   | 49       | 42         | 34         | 0.69      | 3.9          | trivial |
| 9           | 80          | F   | 37       | 48         | 41         | 0.55      | 4.8          | trivial |
| 10          | 75          | F   | 66       | 34         | 22         | 0.76      | 3.9          | trivial |
| 11          | 68          | M   | 48       | 50         | 28         | 0.98      | 3.5          | trivial |
| 12          | 70          | F   | 65       | 40         | 26         | 0.78      | 5.1          | trivial |
| 13          | 83          | M   | 42       | 59         | 46         | 0.76      | 4.9          | mild |
| 14          | 72          | M   | 67       | 40         | 23         | 0.67      | 3.9          | trivial |
| 15          | 66          | M   | 52       | 48         | 31         | 0.48      | 5.4          | trivial |
| 16          | 58          | M   | 57       | 44         | 32         | 0.75      | 5.2          | mild |
| 17          | 71          | M   | 66       | 41         | 25         | 0.74      | 5.8          | mild |
| 18          | 74          | M   | 64       | 45         | 31         | 0.66      | 4.7          | mild |
| 19          | 66          | F   | 57       | 53         | 35         | 1.1       | 3.3          | mild |
| 20          | 62          | M   | 71       | 50         | 32         | 0.9       | 5.2          | trivial |
| 21          | 77          | M   | 57       | 46         | 2.7        | 0.7       | 6            | mild |
| 22          | 56          | F   | 65       | 45         | 28         | 0.83      | 4.7          | mild |
| 23          | 64          | M   | 22       | 65         | 56         | 1         | 2.8          | mild |
| 24          | 67          | M   | 17       | 63         | 55         | 0.57      | 3.9          | mild |
| 25          | 48          | M   | 48       | 52         | 32         | 0.75      | 5.2          | mild |
| 26          | 86          | M   | 66       | 45         | 27         | 1         | 2.8          | trivial |
| 27          | 69          | M   | 53       | 58         | 42         | 0.74      | 4.1          | mild |
| 28          | 70          | F   | 24       | 65         | 59         | 0.64      | 4.2          | trivial |
| 29          | 70          | M   | 26       | 60         | 54         | 1.2       | 1.8          | mild |
| 30          | 64          | M   | 58       | 45         | 28         | 1         | 4.3          | trivial |

F indicates female; M, male; LVEF, left ventricular ejection fraction; LVEDd, left ventricular end-diastolic diameter; LVEds, left ventricular end-systolic diameter; AVA, aortic valve area; PV, peak aortic jet velocity; and AR, aortic regurgitation.

Intraobserver reproducibility was good with $r^2 = 0.88$ ($P < 0.05$). Phase-contrast planimetry interobserver reproducibility was also good with $r^2 = 0.68$ ($P < 0.05$).

### Discussion

To the best of our knowledge, this is the first study documenting an association between measurements of AVA by planimetry using phase-contrast CMR and TEE. We have shown that phase-contrast CMR can be used to investigate the severity of aortic valve stenosis by determining the AVA planimetrically. Better correlation and less variation were observed when using phase-contrast planimetry than cine-mode.

TEE is a reliable technique for estimating the etiology of AS, but it is not always reliable, particularly in patients with heavy calcifications. Additionally, its semi-invasiveness is uncomfortable for the patient. With phase-contrast sequences of CMR in this study, high flow signals at the aortic orifice can be clearly visualized, even in cases with severe calcification. Fine correlation between AVA derived from TEE and phase-contrast CMR planimetry indicates that phase-contrast CMR is potentially a major option for evaluating the severity of AS noninvasively and could be offered to patients who refuse or are not suitable for TEE. CMR also provides information about the annulus of the aortic valve, its geometry, and its motion. CMR results are highly reproducible and can give additional information, such as wall motion, wall thickness, and cardiac output. It also has the major advantage of being rapid; it can be performed within 30 minutes. Moreover, when using contrast agents, information concerning the viability of the myocardium can also be obtained.

In conclusion, phase-contrast CMR offers a tool for evaluating the severity of aortic valve stenosis noninvasively. Phase-contrast CMR has the potential to become a routine clinical option as an alternative to TEE, at least in selected cases.

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Disclosures

Conflicts of interests: None.

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