Multislice Computed Tomography for Detection of Patients With Aortic Valve Stenosis and Quantification of Severity

Gudrun M. Feuchtner, MD,* Wolfgang Dichtl, MD,† Guy J. Friedrich, MD,† Mathias Frick, MD,† Hannes Alber, MD,† Thomas Schachner, MD,‡ Johannes Bonatti, MD,‡ Ammar Mallouhi, MD,* Thomas Frede, MD,* Otmar Pachinger, MD,* Dieter zur Nedden, MD,* Silvana Müller, MD†

Innsbruck, Austria

OBJECTIVES
The purpose of this study was to evaluate whether multislice computed tomography (MSCT) provides a reliable, noninvasive imaging modality for identification of patients with degenerative aortic valve stenosis (AS) by quantifying the aortic valve area (AVA) in comparison to the accepted diagnostic standard transthoracic echocardiography (TTE).

BACKGROUND
Management of patients with degenerative AS is based on the severity of disease. The severity of AS in clinical practice is assessed by TTE and classified as mild, moderate, or severe according to the AVA.

METHODS
Forty-six patients were examined with contrast-enhanced, electrocardiogram-gated, 16-row MSCT for the evaluation of the diagnostic accuracy. In 30 patients, quantification of the AVA with MSCT was compared to TTE using the continuity equation with Doppler velocity-time integral for calculation of the AVA.

RESULTS
Sensitivity of MSCT for the identification of patients with degenerative AS was 100%, and the specificity was 93.7%. Thirty of 46 patients had AS determined by TTE. Quantification of AVA by MSCT (mean AVA = 0.94 cm²) in patients with AS showed a good correlation to TTE (r = 0.89; p < 0.001). Bland-Altman plot illustrated good intermodality agreement between the two methods (limits of agreement, 0.20; 0.29).

CONCLUSIONS
Multislice computed tomography may provide an accurate, noninvasive imaging technique for detection of patients with AS and quantification of AVA. (J Am Coll Cardiol 2006;47: 1410–7) © 2006 by the American College of Cardiology Foundation

Degenerative aortic valve stenosis (AS) is the second most common cardiovascular disease and has an incidence of 2% to 7% in the Western European and North American populations over 65 years of age (1). Management of patients with AS is based on disease severity, which is usually classified by determination of the aortic valve area (AVA). An AVA >1.5 cm² indicates mild, an AVA between 1.5 cm² to 1 cm indicates moderate, and an AVA below 1 cm² is considered as severe AS according to American College of Cardiology/ American Heart Association guidelines (2) in addition to an increased peak transvalvular velocity >2 m/s. Patients with severe AS may require aortic valve surgery even when they are asymptomatic. Currently, AVA is routinely assessed by transthoracic echocardiography (TTE) using the Doppler continuity equation approach. However, TTE may be technically inadequate for some patients, and semi-invasive transesophageal echocardiography (TEE) or cardiac catheterization is required to establish a firm diagnosis.

Sixteen-row multislice computed tomography (MSCT) is a new, noninvasive imaging modality that has already provided new perspectives in the field of cardiac imaging over the past few years. Multislice computed tomography has been shown to be highly accurate for detection of significant coronary artery stenosis >50% (3–6) and coronary bypass graft occlusion (7). Furthermore, MSCT allows a characterization of atherosclerotic plaque morphology (8). However, to date there is little data (9) regarding the value of MSCT in the assessment of valvular pathologies.

The purpose of this study was to assess the clinical accuracy of MSCT in the identification of patients with asymptomatic AS and to evaluate whether quantification of AVA by MSCT correlates with the currently accepted diagnostic standard TTE.

METHODS
Study population. A total of 46 patients (10 women and 36 men with a mean age of 69 years [range 45 to 78 years]) were examined between October 2003 and December 2004 with MSCT and TTE. The institutional review board approved the studies on cardiac MSCT in: 1) 30 patients with AS; and 2) 16 patients with known coronary artery disease (CAD) before minimal invasive coronary bypass surgery. Written informed consent was obtained from all patients. Patient exclusion criteria were renal dysfunction, other contraindications for the use of iodine contrast agent (e.g., known allergy), and cardiac arrhythmia.
Computed tomography (CT) examination technique. Computed tomography data were acquired using a 16-row multislice CT scanner (Sensation 16, Siemens Medical Systems, Forchheim, Germany) with a collimation of 12 × 0.75 mm, a table translation speed of 6.7 mm/s, and a gantry rotation time of 0.42 s. Tube voltage was 120 kV, tube current 300 to 450 mAs, and radiation exposure 6.7 to 13 mSv (10). Electrocardiogram (ECG) dose modulation was not used. Scan direction was craniocaudal during a single inspiratory breath-hold, and the ECG–signal was recorded simultaneously. A bolus of 120 ml non-ionic iodine contrast agent at a concentration of 320 mg/dl (Visipaque, Amersham, Buckinghamshire, United Kingdom) was injected intravenously into an antecubital vein with a 20-gauge cannula at a flow rate of 3 to 4 ml/s using an automated injector (Ulrich Medizintechnik, Ulm, Germany). A fixed scan delay of 25 s was used. A beta-blocker was injected intravenously (1 to 5 mg of metoprolotartrat, Beloc, Schering, Kenilworth, New Jersey) before the examination if the heart rate was >80 beats/min.

CT image reconstruction. Transaxial slices were generated at increments of 0.6 (effective slice thickness of 1 mm). Further reconstruction parameters were as follows: smooth convolution kernel (B 10 f), image matrix 512 × 512 pixel, field of view 170 to 200 mm. The acquired data set was referenced retrospectively to the simultaneously recorded ECG signal. The reconstruction window was positioned within mid-to-late systole corresponding to ejection phase in concordance with T-wave (Fig. 1). The time point of reconstruction window (R) was positioned within mid-late systole approximately corresponding to T-wave. The time point of reconstruction window was estimated by subtracting the time of isovolumetric contraction (1) (0.05 s) from overall duration of cardiac cycle dependent on heart rate. bpm = beats/min.

CT image analysis. Images were transferred to a dedicated off-line computed workstation (Leonardo, Siemens Medical Systems, Forchheim, Germany) and reconstructed using multplanar reformation and volume rendering technique. Three different views, a left coronal oblique view (Fig. 2A), left sagittal oblique (Fig. 2B) view, and several cross-sectional transversal levels (Fig. 2C) ranging from the top of the leaflets to the infundibulum (Fig. 3), were generated for aortic valve analysis. Aortic valve area was measured in all transverse planes. The smallest measurable AVA value in cm² was regarded as an effective AVA. One experienced reviewer (G.F.) circled the effective AVA with a digital caliper (Fig. 2C) blinded to TTE measurement of the AVA. A second reader (D.W.) (not blinded) circled the AVA independently in order to calculate the interobserver variability. For calculation of the diagnostic accuracy, CT images of the patients from the second study pool (CAD before surgery) were blindly analyzed by both readers. The aortic valve image quality was graded on a 5-point scale in consensus reading by two observers (G.F. and W.D.): grade 1 = excellent (sharp delineation of AVA, no artifact); 2 = good (good delineation of AVA, minimal artifact not affecting AVA); 3 = mediocre (minimal artifact at AVA level, acceptable delineation of AVA); 4 = poor (disrupted delineation of AVA, moderate artifact); 5 = insufficient, non-diagnostic image quality (no delineation of AVA, severe artifact).

TTE. All measurements were performed using a standard ultrasound system (Acuson Sequoia 256, Acuson-Siemens Medical Systems, Malvern, Pennsylvania) equipped with a 3.5/1.75-MHz transducer by an experienced class III observer (S.M.). Doppler flow data were acquired from the left ventricular outflow tract (LVOT) and included LVOT velocity measurement using pulsed-wave Doppler and
LVOT diameter. The peak transvalvular velocity was measured in all patients. A peak transvalvular velocity >2 m/s was considered as the diagnostic cutoff for the detection of patients with AS. Additionally, the AVA was calculated using continuity equation approach with Doppler velocity-time integral according to Dumesnil (11) exclusively in patients who had an increased peak transvalvular velocity.

Statistical analysis. The sensitivity, the specificity, the positive predictive value, and the negative predictive value of MSCT for identification of patients with AS was calculated. Statistical analysis was performed using SPSS software (version 8.0, SPSS Inc., Chicago, Illinois). The correlation between AVA measured by MSCT and TTE was determined by linear regression analysis. A two-tailed probability value <0.05 was considered statistically significant. Bland Altman analysis (12) was performed in order to evaluate intermodality agreement by plotting the AVA difference between MSCT and TTE against AVA averages. The mean of the difference with a bias of ±1.96 SD denotes the limits of agreement. Interobserver variability of AVA between two independent readers was computed as a percentage of the mean differences between the corresponding observations divided by the average of all observations.

RESULTS
Thirty of the 46 patients had AS as determined by TTE. The sensitivity of MSCT for detection of patients with AS.
degenerative AS was 100% (30 of 30) (95% confidence interval [CI]: 88.3 to 100), and the specificity was 93.7% (15 of 16) (95% CI: 69.7 to 99.0). One patient was false-positive on MSCT. The positive predictive value was 97% (95% CI: 83.8 to 99.4), and the negative predictive value was 100% (95% CI: 79.6 to 100). Table 1 shows the AVA values for each patient with degenerative AS. Figure 4 demonstrates the AVA during mid-late systole by MSCT. Linear regression analysis shows a good correlation between AVA quantified by MSCT and TTE ($r = 0.89; p < 0.001; 95\% \text{ CI} 0.78$ to $0.95$) in patients with AS (Fig. 5). The Bland-Altman plot (Fig. 6) implies a good intermodality concordance placing 27 of 30 patients between the limits of agreement ($0.29; -0.20$) and suggests a slight overestimation of AVA ($0.04 \text{ cm}^2$) by MSCT compared to TTE. Interobserver variability of AVA by MSCT was mean 4.6% (absolute $0.48 \text{ cm}^2 \pm 0.03 \text{ SD}$). Image quality graded on a 5-point scale was excellent ($n = 29$), good ($n = 14$), and mediocre ($n = 3$). The mean heart rate in our study population was 60 beats/min $\pm 10.6 \text{ SD}$ (range 40 to 81 beats/min). A beta-blocker was administered to 4 of the 46 patients. A right ventricular pacemaker was present in 4 of the 46 patients, but metal artifacts from the wires did not extend to the aortic valve level and did not hamper image quality of the valve. Examination time for the patient ranged between 10 and 15 min, and the mean time required for post-processing, including three-dimensional image reconstruction of aortic valve, was 8 to 15 min. A bicuspid valve was found in 2 of the 46 patients by MSCT (Figs. 4E to 4H); these were not seen by TTE (Table 1). Patients with tricuspid valves are shown in Figures 4A to 4D and Figure 7.

### DISCUSSION

This study shows that MSCT accurately identifies patients with AS and allows quantification of AVA with a good correlation to the current diagnostic standard TTE. Identification of patients with degenerative AS using MSCT has not been previously reported.

**Cardiac MSCT.** The application of CT to cardiac imaging has long been limited by insufficient temporal resolution. However, the introduction of 16-row MSCT...
scanners with high gantry rotation time (>0.42 s) in 2002 has improved temporal resolution to 105 to 250 ms and the spatial resolution to $0.5 \times 0.5 \times 0.6 \text{ mm}^3$ (13).

In addition, advanced technical features such as retrospective ECG-gating offer image reconstruction at any time during the cardiac cycle, which permits a dynamic
display of heart motion (“cine CT” with image reconstruction at every 10% of the RR-interval). Thus, the maximal opening of the aortic valve during mid-late systole can be identified, and quantification of AVA is possible. Mid-late systole represents a phase with relatively less cardiac motion and has been shown to be adequate for image acquisition (14).

**Value of echocardiography.** Currently, TTE is widely used for primary diagnostic evaluation of AS; TTE is real-time imaging basically relying on dynamic flow parameters by using velocity-time integral for the calculation of the AVA. Potential limitations associated with the use of the continuity equation include difficulty in accurately measuring the LVOT diameter and estimating the maximal velocity of the LVOT and the aorta before flow acceleration. Furthermore, low cardiac output (2,15), concomitant aortic valve regurgitation (15,16), severe valve calcifications, and other unusual anatomic configurations impairing the echocardiographic window may also limit TTE results. Alternatively, TEE or cardiac catheterization may be used for further diagnostic assessment of the severity of AS; TEE determination of AVA is planimetric in its approach. Transesophageal echocardiography is semi-invasive, and caution is needed because of shadowing and reverberation artifacts from the calcified leaflets. The non-planar aortic valve anatomy may also lead to errors. Indeed, its noninvasive character...
makes MSCT an attractive alternative imaging technique. Compared to TTE, overall physician time with MSCT would be roughly similar, approximately 20 to 30 min.

**Value of TEE and cardiac magnetic resonance imaging CMR.** Transesophageal echocardiography planimetry (17) and CMR (18) have been shown to provide a reproducible measurement of the AVA. In contrast to MSCT, slice tracking is not possible with two-dimensional cine CMR because the correct mid-to-end systolic position has to be identified in a longitudinal view in order to avoid being out of plane. By using MSCT, any plane at any level (‘slice tracking’) during the cardiac cycle can be reconstructed retrospectively.

**Clinical applications of MSCT.** Currently, a routine clinical implementation of MSCT for diagnostic evaluation of AS cannot be recommended. However, MSCT may play a role in patients in whom a direct measurement of AVA is important but cannot be obtained by TTE. Multislice computed tomography can also be applied in clinical practice to detect asymptomatic AS in patients who undergo coronary MSCT angiography, for example in patients with suspected CAD. Detection of asymptomatic patients is desirable because patients with asymptomatic, severe AS may require short-term follow-up examinations or surgery.

**Study limitations.** The incidence of true disease was very high (30 of 46; 65%) in our study population because the patients were assigned to cardiac MSCT (i.e., before cardiac surgery [e.g., minimal invasive coronary bypass graft surgery or valve surgery]). Therefore, our study population is not representative of the type of population evaluated for AS by TTE in an outpatient setting. Thus, the high sensitivity portrays a level of accuracy that is unlikely to be achievable in a broad spectrum of patients. Further, a very smooth convolution kernel (B 10 f) was used for image reconstruction that might be occasionally inappropriate for the simultaneous evaluation of calcifying coronary arteries. Alternatively, a medium resolution kernel (B 25 f, B 30 f) can be applied for both coronary artery and aortic valve analysis.

**Limitations of MSCT.** Patients not in sinus rhythm, for example persistent atrial fibrillation, cannot be assessed because ECG-gating requires heart rate regularity. Heart rate should be below 80 beats/min to avoid motion artifacts from the residual cardiac motion. Therefore, a beta-blocker may be given to selected patients, but should be administered with great care to patients with severe AS. Radiation exposure ranges between 6.7 to 10.9 mSv for male patients and 8.1 to 13 mSv for female patients (10), which is approximately in the range of cardiac catherization (2.7 to 15.3 mSv) depending on patient and procedure (19) and is significantly lower than compared with a myocardial single photon emission computed tomography (20 mSv) (20). Electrocardiogram dose modulation, which clearly reduces the radiation exposure about 45% to 48% (21), is not recommended in this setting because the tube output is lowered exclusively within systole, thus hampering image quality. Iodine contrast agents cannot be administered to patients with renal dysfunction, known allergy, and untreated hyperthyreosis.

**Conclusions.** Sixteen-MSCT provides an accurate, noninvasive imaging modality for identification of patients with AS. We do not advocate MSCT as a primary diagnostic imaging technique in clinical practice because currently used TTE is accurate, safe, quick, and cost-effective. Multislice computed tomography could be used alternatively in pa-
tients in whom TTE is inadequate and in patients with suspected CAD who undergo coronary MSCT angiography for the detection of concomitant, asymptomatic AS.

Reprint requests and correspondence: Dr. Gudrun Maria Feuchtner, Clinical Department of Radiology II, Innsbruck Medical University, Anichstr. 35, A-6020 Innsbruck, Austria. E-mail: Gudrun.Feuchtner@uibk.ac.at.

REFERENCES


APPENDIX

For accompanying videos for Figures 4A and 4B, and 4G, please see the online version of this article.