

# The Measurement of Opening Angle and Orifice Area of a Bileaflet Mechanical Valve Using Multidetector Computed Tomography

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## ABSTRACT

**Background and Objectives:** The aim of this study was to assess mechanical valve function using 64-slice multidetector computed tomography (MDCT). **Subjects and Methods:** In 20 patients (mean age,  $50 \pm 12$  years; male-to-female ratio, 10 : 10), 30 St. Jude bileaflet mechanical valves (15 aortic and 15 mitral valves) were evaluated using MDCT. We selected images vertical and parallel to the mechanical valve. The valve orifice area (OA) and valve length were determined by manual tracing and the opening and closing angles were measured using a protractor. The OA and length of the mechanical valves were compared with the manufacturer's values. **Results:** The geometric orifice areas (GOAs) based on the manufacturer's values and the OAs determined by MDCT were  $3.4 \pm 0.2 \text{ cm}^2$  and  $3.4 \pm 0.3 \text{ cm}^2$  for the mitral valves and  $2.1 \pm 0.3 \text{ cm}^2$  and  $2.1 \pm 0.4 \text{ cm}^2$  for the aortic valves, respectively. The correlation coefficients between the OA measures were 0.433 for the mitral valves and 0.874 for the aortic valves (both  $p < 0.001$ ). The lengths based on the manufacturer's values and determined by MDCT were  $29.3 \pm 1.99 \text{ mm}$  and  $29.6 \pm 1.65 \text{ mm}$  for the mitral valves and  $21.5 \pm 2.1 \text{ mm}$  and  $20.7 \pm 2.3 \text{ mm}$  for the aortic valves, respectively. The correlation coefficients between the measures were 0.651 for the mitral valve and 0.846 for the aortic valve (both  $p < 0.001$ ). The opening and closing angles determined by MDCT were  $10.9 \pm 0.6^\circ$  and  $131.1 \pm 3.2^\circ$  for the mitral valves and  $11.1 \pm 0.9^\circ$  and  $120.6 \pm 1.7^\circ$  for the aortic valves, respectively. **Conclusion:** MDCT is an accurate modality with which to assess the function and morphology of bileaflet mechanical valves. (Korean Circ J 2009;39:157-162)

**KEY WORDS:** Valve; Heart; Computed tomography.

## Introduction

Traditionally, after mechanical valve replacement, transthoracic Doppler echocardiography (TTE) has been considered the diagnostic standard method for assessing and establishing mechanical valve (MV) function.<sup>1)</sup> However, an assessment of MV function by TTE has limitations, such as excessive metallic artifacts and a poor echo window in obese patients. Further, TTE is of limited value for patients with chronic obstructive pulmonary disease and for the evaluation of a MV in the aortic position.<sup>2)</sup> Even though transesophageal Doppler echo-

cardiography (TEE) can provide better image quality,<sup>3)</sup> TEE is a semi-invasive method and can show metallic artifacts. It is difficult to obtain a perpendicular image of the MV with a fluoroscopic examination<sup>4)</sup> and an accurate measurement of the opening angle is difficult to obtain.<sup>4-8)</sup> Recently, the use of 64-slice multidetector computed tomography (MDCT) has been shown to be valuable for the measurement of coronary artery stenoses,<sup>9-12)</sup> determination of coronary calcium scores,<sup>13)</sup> measurement of left ventricular ejection fractions,<sup>14)</sup> follow-up of percutaneous coronary intervention,<sup>15)16)</sup> and follow-up of coronary artery bypass grafts.<sup>17-20)</sup> The aim of this study was to assess MV function using 64-slice MDCT.

## Subjects and Methods

### Subjects

This prospective study was performed on 20 patients

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between 1 March and 31 August 2006 at St. Mary's Hospital of The Catholic University of Korea in Seoul, Korea. The patients received 30 St. Jude medical (SJM) valves (bileaflet mechanical valves: 15 aortic and 15 mitral valves; St. Jude Medical, Inc., Minneapolis, MN, USA). Patients were enrolled in the study if they met all of the following inclusion criteria: 1) a previous mitral valve replacement performed at St. Mary's Hospital; 2) normal sinus rhythm {mean heart rate, 69 beats per minute (bpm); range, 50-97 bpm} as measured by an electrocardiogram; 3) a poor echo window, as seen on TTE; 4) refusal to undergo TEE, and 5) if in a clinically stable condition, the patient was able to hold his/her breath for 15 seconds. The Institutional Review Committee of our hospital approved this study. The subjects were informed of the investigative nature of the study and written consent was obtained before entry.

### Multidetector computed tomography protocol and image reconstruction

Computed tomographic studies were performed on a 64-slice MDCT (Lightspeed VCT; GE Healthcare, Milwaukee, WI, USA). The heart rate during CT acquisition ranged from 50-97 bpm (mean, 69 bpm). The patients did not receive additional premedications, such as  $\beta$ -blockers, for control of their heart rate.

The MDCT protocol was as follows: slice collimation ( $64 \times 0.625$  mm), gantry rotation time (350 ms), table feed (6 mm/s), tube voltage (120 kVp), and tube current (600 mAs). Eighty mL of contrast agent (Iopromide, Ultravist 300; Schering, Berlin, Germany) was injected intravenously at 5 mL/s for 16 seconds. Fifty mL of saline solution chaser at 5 mL/s for 10 seconds was also injected. All examinations were performed using retro-

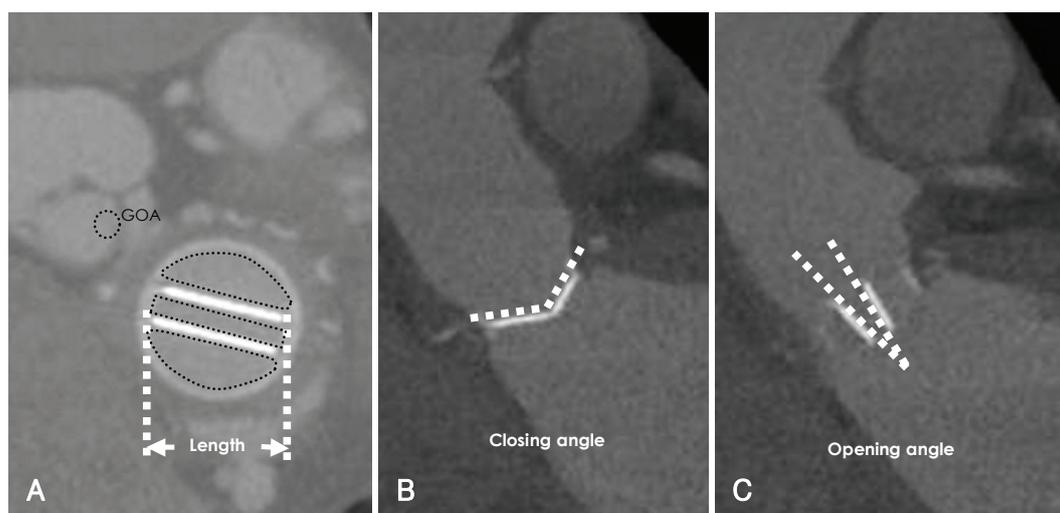
spective electrocardiography (ECG)-gating. Image data was reconstructed using the cardiac image reconstruction algorithm provided with the scanner. Images were reconstructed at consecutive 10% increments of the relative R-R interval, yielding 10 phases of information. All post-processing was performed on a GE AW Workstation (Advantage Windows Workstation 4.3), using the Card IQ function software (GE Healthcare). Image data was reconstructed in the vertical and parallel images of the MV. The opening and closing phases of the MV were selected visually for image analysis. Window settings were adjusted to properly visualize the valve with less beam-hardening artifact.

### Image analysis

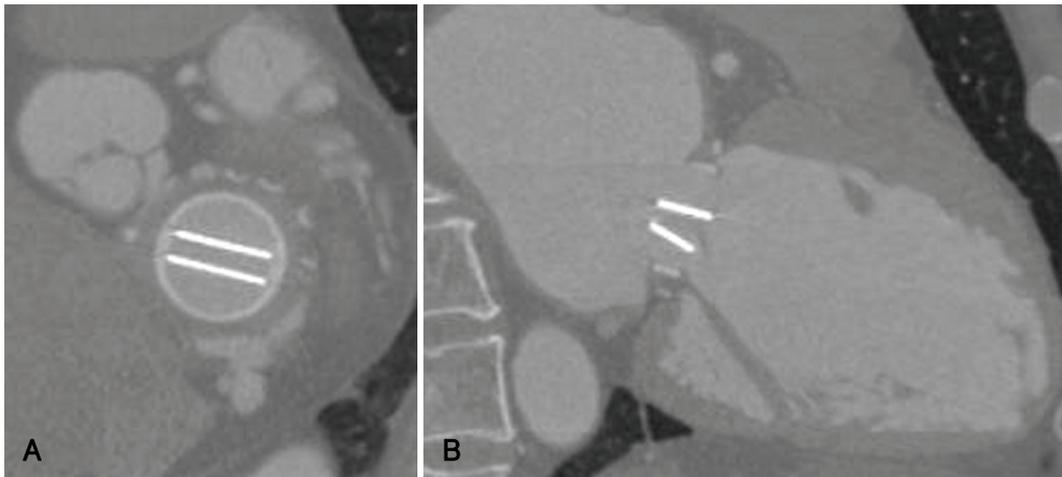
The images were analyzed using an Image-Pro Plus Image analyzer (Media Cybernetics, Bethesda, MD, USA) and the values determined for the geometric orifice area (GOA) and valve length by 64-slice MDCT were compared with the manufacturer's values. The open and closing angles were measured with a protractor. The manufacturer's values were approximately  $10^\circ$  for the open angle and  $120$ - $130^\circ$  for the closing angle (Fig. 1). Figs. 2 and 3 give examples of the morphologic and functional assessment by MDCT after undergoing valve replacement.

### Statistical analysis

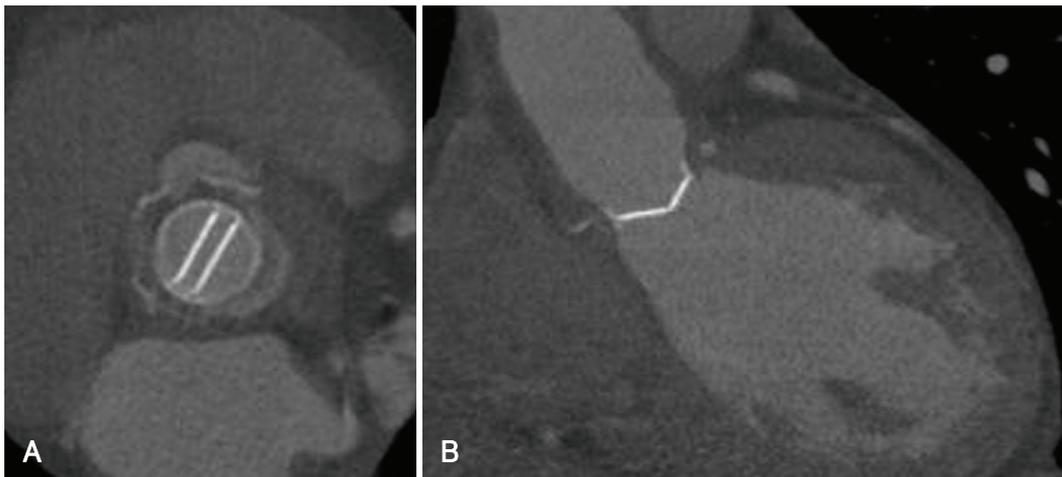
Data are expressed as the mean and standard deviation (SD), and statistical analysis was done using Statistical Package for Social Science (SPSS) 13.0 (SPSS Inc., Chicago, IL, USA). Linear regression analysis and the limits of agreement according to Bland and Altman were determined to compare geometric parameters of the bileaflet mitral MV between the manufacturer's va-



**Fig. 1.** The GOAs, lengths, and opening/closing angles of SJM valves determined by 64-slice MDCT. The images are analyzed using an Image-Pro Plus Image module (Media Cybernetics) and were compared with the manufacturer's values for the GOAs, lengths (A), opening angles (B), and closing angles (C) of the SJM valves as determined by 64-slice MDCT. GOAs and lengths were measured on the vertical image of the mechanical valve. The opening and closing angles were measured on parallel images of the mechanical valve. GOA: geometric orifice area, SJM: St. Jude Medical, MDCT: multidetector computed tomography.



**Fig. 2.** A 39-year-old woman who presented for assessment of function after undergoing SJM mitral valve replacement (valve size, 29 mm) for infective endocarditis. In the mitral valve, the GOA determined by MDCT was  $3.35 \text{ cm}^2$  and the manufacturer's value was  $3.5 \text{ cm}^2$ . The valve length determined by MDCT was 28.6 mm and the manufacturer's value was 29 mm. The opening angle determined by MDCT was  $11.2^\circ$  and the manufacturer's value was  $10^\circ$ , and the closing angle determined by MDCT was  $132.1^\circ$  and the manufacturer's value was  $130^\circ$ . A: a vertical reformatted image of the valve shows the SJM mitral valve (#29) with symmetric opening of mechanical components. The valve is intact, based on measurement of the GOA and the length. B: a parallel reformatted image of valve shows the SJM mitral valve (#29). The valve is intact based on measurement of the opening and closing (not shown) angles. SJM: St. Jude Medical, GOA: geometric orifice area, MDCT: multidetector computed tomography.



**Fig. 3.** A 54-year-old woman who presented for assessment of function after undergoing SJM aortic valve replacement (valve size, 19 mm) for severe aortic stenosis. In the aortic valve, the GOA determined by MDCT was  $1.68 \text{ cm}^2$  and the manufacturer's value was  $1.7 \text{ cm}^2$ . The valve length determined by MDCT was 18.6 mm and the manufacturer's value was 19 mm. The opening angle determined by 64-slice MDCT was  $11.7^\circ$  and the manufacturer's value was  $10^\circ$ , and the closing angle determined by MDCT was  $119.6^\circ$  and the manufacturer's value was  $120^\circ$ . A: a vertical reformatted image of valve shows the SJM aortic valve (#29) with symmetric opening of the mechanical components. The valve is intact based on measurement of the GOA and the length. B: a parallel reformatted image of valve shows the SJM aortic valve (#29) with symmetric opening of the mechanical components. The valve is intact based on measurement of the opening (not shown) and closing angles. SJM: St. Jude Medical, GOA: geometric orifice area, MDCT: multidetector computed tomography.

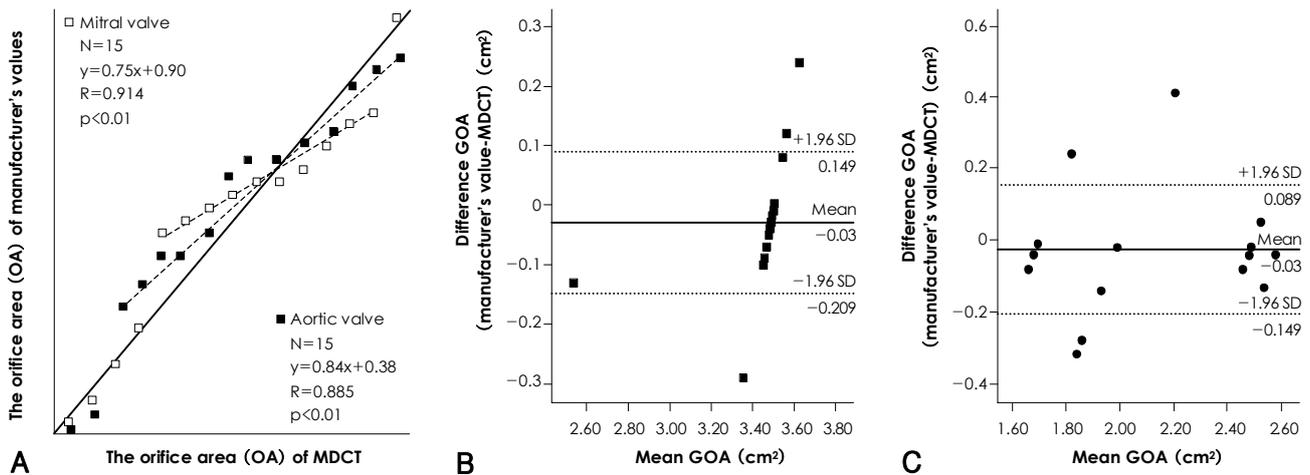
lues and the MDCT measurements. Student's t-test was used to compare the manufacturer's values with those determined by MDCT.  $P < 0.05$  was considered statistically significant.

## Results

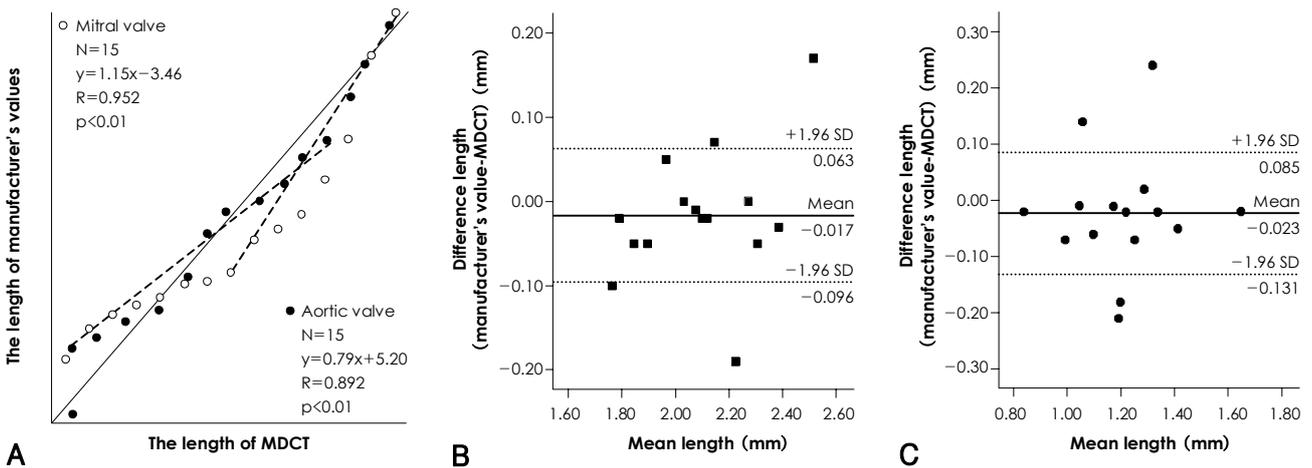
The mean age of the patients (10 females and 10 males) in the study was  $50 \pm 12$  years. Ten patients received replacement of mitral or aortic bileaflet MVs. Five patients received double MV replacements. The mean follow-

up duration after undergoing bileaflet MV replacement was  $99 \pm 74$  months.

The mean size of the bileaflet aortic MVs was  $21.5 \pm 2.1$  mm (range, 19-25 mm) and the bileaflet mitral MVs was  $29.3 \pm 2.0$  mm (range, 25-33 mm). The manufacturer's values and the MDCT-determined GOAs were  $3.4 \pm 0.3 \text{ cm}^2$  and  $3.4 \pm 0.2 \text{ cm}^2$  for the mitral valves and  $2.1 \pm 0.4 \text{ cm}^2$  and  $2.1 \pm 0.3 \text{ cm}^2$  for the aortic valves, respectively. The correlation coefficients for the GOAs based on the manufacturer's values compared with those determined by MDCT were 0.433 for the



**Fig. 4.** The correlation coefficients and Bland-Altman analysis for the GOA based on the manufacturer's value and determined by 64-slice MDCT. A: the correlation coefficients for the GOA based on the manufacturer's value compared with those determined by MDCT were 0.433 for the mitral valve and 0.874 for the aortic valve ( $p < 0.001$ ). B: the Bland-Altman analysis of bias revealed that there were no significant bias between the GOA based on the manufacturer's value and MDCT for the mitral valve (observed bias, 1.121; 95% confidence interval, 0.823-1.1418). C: the Bland-Altman analysis of bias revealed that there were no significant bias between the GOA based on the manufacturer's value and MDCT for the aortic valve (observed bias, 0.938; 95% confidence interval, 0.642-1.223;  $p < 0.001$ ). The solid line is the mean difference; the dotted lines mark the standard deviations of the differences. Mean GOA=(manufacturer's value+MDCT)/2. GOA: geometric orifice area, MDCT: multidetector computed tomography.



**Fig. 5.** The correlation coefficients and Bland-Altman analysis for the valve length based on the manufacturer's value and determined by 64-slice MDCT. A: the correlation coefficients for the valve lengths based on the manufacturer's values compared with those determined by MDCT were 1.145 for the mitral valve and 0.790 for the aortic valve ( $p < 0.001$ ). B: the Bland-Altman analysis of bias revealed that there was no significant bias between the GOA based on the manufacturer's value and MDCT for the mitral valve (observed bias, 1.121; 95% confidence interval, 0.823-1.1418). C: the Bland-Altman analysis of bias revealed that there was no significant bias between the GOA based on the manufacturer's value and MDCT for the aortic valve (observed bias, 0.938; 95% confidence interval, 0.642-1.223;  $p < 0.001$ ). The solid line is the mean difference; the dotted lines mark the standard deviations of the differences. Mean length GOA=(manufacturer's value+MDCT)/2. GOA: geometric orifice area, MDCT: multidetector computed tomography.

mitral valves and 0.874 for the aortic valves ( $p < 0.001$ ) (Fig. 4A).

The Bland-Altman analysis of bias revealed that there was no significant bias between the GOAs based on the manufacturer's values and the MDCT measurements for the mitral valves (observed bias, 1.121; 95% confidence interval, 0.823-1.1418) (Fig. 4B) and for the aortic position valves (observed bias, 0.938; 95% confidence interval, 0.642-1.223;  $p < 0.001$ ) (Fig. 4C).

The manufacturer's values and the MDCT-determined valve lengths were  $29.3 \pm 1.99$  mm and  $28.6 \pm 1.65$  mm for the mitral valves and  $21.5 \pm 2.1$  mm and  $20.7 \pm 2.3$

mm for the aortic valves, respectively. The correlation coefficients between the valve lengths based on the manufacturer's values compared with the MDCT measurements were 0.651 for the mitral valves and 0.846 for the aortic valves ( $p < 0.001$ ) (Fig. 5A).

The Bland-Altman analysis of bias revealed that there was no significant bias between the lengths based on the manufacturer's values and the MDCT measurements for the mitral valves (observed bias, 0.791; 95% confidence interval, 0.639-0.934) (Fig. 5B) and for the aortic valves (observed bias, 1.008; 95% confidence interval, 0.702-1.313;  $p < 0.001$ ) (Fig. 5C). The opening and closing angles

determined by MDCT were  $10.9 \pm 0.6^\circ$  and  $131.1 \pm 3.2^\circ$  for the mitral valves and  $11.1 \pm 0.9^\circ$  and  $120.6 \pm 1.7^\circ$  for the aortic valves, respectively.

## Discussion

The use of MDCT has facilitated the non-invasive detection of coronary artery calcifications,<sup>13)</sup> visualization of the lumens and walls of the coronary arteries, and the ability to obtain information on the presence and severity of coronary artery disease (CAD).<sup>9-12)</sup> Over the last several years, a dramatic improvement in MDCT technology has allowed for an assessment of valve morphology and calcification in patients with mitral and aortic stenoses.<sup>21)22)</sup>

MDCT has led to advances in the assessment of cardiovascular anatomy and function and has created new clinical applications in cardiovascular imaging.<sup>23)</sup> These applications include follow-up of percutaneous coronary intervention,<sup>15)16)</sup> follow-up of coronary artery bypass grafts,<sup>17-20)</sup> assessment of the anatomy of the pulmonary vein of patients with atrial fibrillation,<sup>24-28)</sup> and determination of the coronary sinus of patients planning cardiac resynchronization therapy. Some studies have reported that the MDCT is a sensitive and objective method for accessing the morphology and calcification of native aortic and mitral valves.<sup>21)22)</sup>

TTE is recommended in a step-by-step approach in the evaluation of patients with suspected prosthetic valve dysfunction. If a high gradient is detected, additional tests may be needed, including TEE and a fluoroscopic examination. However, TTE has some limitations (i.e., excessive metallic artifacts), and TEE and fluoroscopic examination do not always provide for a definitive diagnosis.

For both the GOAs and valve lengths, the values determined by 64-slice MDCT were as accurate as the manufacturer's values based on correlation coefficients, not only for the mitral valves (GOA, 0.433; length, 0.651;  $p < 0.001$ ), but also for the aortic valves (GOA, 0.874; length, 0.846;  $p < 0.001$ ). Therefore, we consider 64-slice MDCT to be an accurate modality for the morphologic and functional assessment of bileaflet MVs.

It is well-known that 64-slice MDCT requires exposure to a higher radiation dose (approximately 10 milli-Sieverts (mSv)) than the mean effective dose of diagnostic coronary artery angiography (usually between 3.0 and 6.0 mSv). To evaluate and generalize the function and morphology of bileaflet MVs using MDCT, patient selection should be made with care.

## Limitations

The first limitation of this study was it was only performed on patients who received SJM valves, a kind of bileaflet MV and the majority of patients had normal

left ventricular function. Our study did not include patients with Ball-in-cage type valves (e.g., the Starr-Edwards prostheses) or other bileaflet mechanical prostheses (e.g., the Carbomedics prostheses and bioprostheses).

Secondly, it may be questioned whether an assessment of the GOA or length by 64-slice MDCT is superior for hemodynamic conditions, such as significant regurgitation. Although panni, thrombi, and vegetations were not detected in this study, the opening and closing angles determined by 64-slice MDCT may also provide better information for a severe mismatching valve. This will require future study.

## Conclusions

MDCT is a powerful and promising modality by which to assess the function and morphology of bileaflet MVs. If appropriate patient selection has been undertaken, such as for patients with a normal sinus rhythm, a poor echo window on TTE, refusal to undergo TEE, and patients in a clinically stable condition, the optimal use of this technology could prove essential for comprehensive evaluation of valve function.

## Acknowledgments

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