Original Article

# Feasibility study of using low-kilovoltage, prospective gating, high-pitch, dual-source computed tomography prior to transcatheter aortic valve replacement: analysis of image quality and radiation dose

**Yanhe Ma[1], Bo Fu[2], Anhong Yu[1], Yapeng Yang[1], Prabhakar Shantha Rajiah[3], Hong Zhang[1]**

[1]Department of Radiology, Tianjin Chest Hospital, Tianjin University, Tianjin, China; [2]Department of Cardiovascular Surgery, Tianjin Chest Hospital, Tianjin, China; [3]Department of Radiology, Mayo Clinic, Rochester, MN, USA

*Contributions:* (I) Conception and design: Y Ma, H Zhang; (II) Administrative support: H Zhang; (III) Provision of study materials or patients: B Fu; (IV) Collection and assembly of data: Y Ma; (V) Data analysis and interpretation: B Fu, A Yu, Y Yang, Y Ma; (VI) Manuscript writing: All authors; (VII) Final approval of the manuscript: All authors.

*Correspondence to:* Hong Zhang, MM. Department of Radiology, Tianjin Chest Hospital, Tianjin University, No. 261 Taierzhuang South Road, Jinnan District, Tianjin 300222, China. Email: yuxinli72@163.com.

**Background:** Computed tomography (CT) scans before transcatheter aortic valve replacement (TAVR) are used to evaluate the aortic valve and guide the selection of appropriate valve stents. Accurate imaging evaluation can ensure the success rate of surgery while reducing the incidence of complications. Multiple studies have adopted a protocol of coronary artery, aortic valve, and total aortic scan, with the patients receiving higher radiation doses. The aim of this study was to evaluate the image quality, radiation dose, and diagnostic performance of dual-source computed tomography (DSCT) with high-pitch spiral scanning for TAVR.

**Methods:** A total of 240 patients being evaluated for TAVR were continuously enrolled. Based on the differences in electrocardiography (ECG) gating and tube voltage, the patients were divided into 4 groups: group A, 70-kV prospective ECG gating, high-pitch helical; group B, 70-kV retrospective ECG gating; group C, 100-kV prospective ECG gating, high-pitch helical; and group D, 120-kV prospective ECG gating, high-pitch helical. Image quality was evaluated on a 4-point scale. The image signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated for objective evaluation. The radiation doses of all patients were recorded. The image quality and radiation dose of each group were compared.

**Results:** There were no differences in age, body mass index (BMI), subjective image quality scores, CT values between the aorta and the coronary artery, or image CNR between the 4 groups. The mean radiation doses of groups A–D were 4.13±0.69, 4.79±0.58, 12.00±1.62, and 15.01±1.90 mSv, respectively. The mean radiation dose in group A (70-kV prospective ECG gating) decreased significantly ($P<0.05$).

**Conclusions:** Using low-kilovoltage, high-pitch DSCT can provide comparable image quality for TAVR evaluation and significantly reduce the radiation dose.

**Keywords:** Computed tomography (CT); transcatheter aortic valve replacement (TAVR); radiation dose; low dose

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## Introduction

Transcatheter aortic valve replacement (TAVR) is an efficacious procedure for patients with severe aortic stenosis who are at a high risk of surgical aortic valve replacement, even in moderate or low-risk populations of aortic stenosis (1-3). To ensure the success of TAVR surgery and reduce the complications of surgery, it is important that accurate imaging evaluation be completed before TAVR procedure (4). Multidetector computed tomography (MDCT) scans are now commonly used to size the prosthetic valve based on aortic annulus measurements, assess high-risk factors and evaluate the access vessels for size, tortuosity and any other complications (4,5).

MDCT scanning of the heart can be performed using non-gated and electrocardiography (ECG)-gated scanning protocols, which can be subdivided into retrospective and prospective cardiac-gated scanning protocols. Retrospective ECG gating allows for the reconstruction of multiple cardiac cycles in time, ensuring a successful examination but with a higher radiation dose than in prospective ECG gating (5). The size and shape of the aortic annulus vary significantly during the cardiac cycle, with the aortic annulus area and circumference increasing during systole (6). Most preoperative MDCT examinations of TAVR are performed using a combined scanning protocol, with the coronary artery, aortic valve, and entire aorta (including iliac and femoral arteries) evaluated in one examination, inevitably increasing the radiation dose and amount of contrast. The purpose of our study was to evaluate the feasibility of preoperative low-radiation dose imaging with third-generation dual-source computed tomography (DSCT) for TAVR, as well as to evaluate image quality and radiation dose.

### Highlight box

**Key findings**

- The low-kilovoltage, prospective gating, high-pitch scanning modes of dual-source computed tomography (DSCT) can effectively reduce the radiation dose of patients. The image quality is comparable for the preoperative evaluation of transcatheter aortic valve replacement (TAVR).

**What is known and what is new?**

- It is necessary to perform computed tomography (CT) scanning before TAVR surgery. Prospective electrocardiography (ECG) gating model has been used for CT scans of coronary arteries.
- Prospective ECG gating scan and low-kilovoltage, combined with DSCT's unique high-pitch technology, can be applied to TAVR preoperative evaluation to directly reduce radiation dose while obtaining sufficiently good images.

**What is the implication, and what should change now?**

- For patients who require TAVR, low-dose scans can be performed before surgery to evaluate the condition of the aortic valve and aorta.

## Methods

### *Study population*

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the ethics committee of Tianjin Chest Hospital [No. IRB-SOP-016(F)-001-02]. Informed consent was taken from all individual participants.

Patients who underwent TAVR and preoperative CT between November 2019 and January 2023 were included in the study. Indications for the TAVR procedure were provided by clinical cardiologists. Exclusion criteria for CT examination were severe contrast allergy and renal insufficiency (glomerular filtration rate less than 30 mL/min/1.73 $m^2$), and a total of 240 cases were included. In addition, to avoid repeat examinations and increase the radiation dose, patients who had undergone coronary angiography before CT examination were not included in this group of studies. Patients with high heart rate, arrhythmias, or breath-holding difficulties were not excluded from this study.

### *CT scanning*

All patients underwent third-generation DSCT (SOMATOM Force CT; Siemens Healthineers, Erlangen, Germany). None of the participants were administered beta blockers or nitroglycerine premedication. Two sequential scans were performed, first in the foot-head direction with ECG gating to assess the aortic root and coronary arteries from the carina to the cardiac apex and then in the head-foot direction with prospective large-pitch scanning (FLASH mode) to assess the aortal and femoral arteries.

Depending on the tube voltage and cardiac gating during the evaluation of aortic and coronary scans, the patients were divided into 4 groups: group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating. Other scan

 

**Table 1** Coronary artery scanning protocols

| Variables | Group A | Group B | Group C | Group D |
|---|---|---|---|---|
| Tube voltage (kV) | 70 | 70 | 100 | 120 |
| Tube current (mAs) | Automatic modulation | Automatic modulation | Automatic modulation | Automatic modulation |
| Rotation time (seconds) | 0.25 | 0.25 | 0.25 | 0.25 |
| Acquisition (mm) | 192×2 | 192×2 | 192×2 | 192×2 |
| ECG-gate | Prospective | Retrospective | Prospective | Prospective |
| Phase range (R-R interval) (%) | 20–90 | 0–100 | 20–90 | 20–90 |
| Slice thickness (mm) | 0.75 | 0.75 | 0.75 | 0.75 |
| Kernel | Br44 | Br44 | Br44 | Br44 |

Group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating. kV, kilovoltage; ECG, electrocardiography.

conditions and scan ranges were the same across the groups: rotation time of 0.25 s/week and collimation width of 2 mm ×192 mm ×0.6 mm. Automatic tube current modulation (CAREDose 4D, Siemens Healthineers) was used. A small field of view (FOV; 200 mm) was used to evaluate the aortic valve and coronary arteries, and the reconstruction was performed at 5% intervals during the cardiac cycle, with a reconstructed convolution kernel of Bv40, a reconstructed layer thickness of 0.75 mm, and a layer interval of 0.3 mm; a large FOV (300 mm) was used to evaluate the whole aorta, with a reconstructed layer thickness of 1.0 mm, an interval of 0.7 mm, and a reconstructed convolution kernel of Br44 (*Table 1*).

The contrast injection was performed in 2 phases, with 90 mL of contrast agent (370 mgI/mL; iopromide; Bayer Healthcare, Berlin, Germany) followed by 40 mL of saline at a rate of 4.5–5.5 mL/s. The scan was triggered using the threshold trigger method, with the region of interest set 1 cm below the left diaphragm in the descending aorta, and the CT value reached 100 Hounsfield unit (HU).

### *Image quality*

The images were postprocessed and evaluated at the workstation a dedicated software (CT TAVI Planning-Vascular Scene, IntelliSpace Portal 9.0, Philips Healthcare, Amsterdam, The Netherlands). Volume rendering, multiplanar reconstruction, curved planar reconstruction, maximum intensity projection, and vascular straightening were selected. Subjective evaluations were performed in combination with axial images. Two experienced radiologists (10 and 8 years of experience) scored the image quality of aorta and coronary arteries using the double-blind method according to the following scale: 4, excellent (no motion artifacts, no significant noise, and good vessel brightness); 3, good (no motion artifacts, slight blurring around vessels, and good vessel brightness); 2, fair (a few motion artifacts but not affecting vessel evaluation; significant blurring around vessels; fair vessel brightness); 1, poor (heavy motion artifacts and obvious vessel mislamination, heavy perivascular blurring, inability to distinguish vessels from surrounding components, and poor vessel brightness).

When the difference in scores between two observers is 1, the lower score will be the final score. When the difference is greater than 1, the final score is based on the unified opinion of the two observers after consultation. Two points and more than two images met diagnostic requirements.

Objective evaluation included the measurement of left and right coronary artery, the aortic root, ascending aorta (approximately 3.5 cm from the aortic valve annulus), aortic arch, thoracic aorta (on same plane as the aortic valve annulus), renal artery-level abdominal aorta, and femoral arteries on both sides being set as the area of interest. The size of the area of interest of the ascending aortic root, aortic arch, thoracic aorta, and abdominal aorta was 100±5 $mm^2$; The target in left coronary artery, right coronary artery and the bilateral femoral arteries were approximately two-thirds of the lumen of the measurement level for the area of interest. Measurements were averaged over 3 consecutive levels to avoid plaque formation. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured and calculated as follows: at the level of the aortic annulus, the CT values within the area of interest of the paraspinal muscle and the anterior thoracic

 

**Table 2** Comparison of general data

| Index | Group A (n=60) | Group B (n=60) | Group C (n=60) | Group D (n=60) | P |
|---|---|---|---|---|---|
| Sex (male/female) | 28/32 | 29/31 | 26/34 | 29/31 | 0.941* |
| Age (years) | 79.40±5.08 | 80.60±6.43 | 80.10±5.39 | 80.40±4.84 | 0.814 |
| Height (cm) | 162.55±6.16 | 162.00±7.22 | 162.37±5.59 | 161.73±6.16 | 0.962 |
| Weight (kg) | 55.87±5.73 | 55.12±6.01 | 56.20±5.99 | 54.63±5.52 | 0.561 |
| BMI (kg/m$^2$) | 21.23±2.69 | 21.10±2.77 | 21.39±2.79 | 20.95±2.05 | 0.914 |

Group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating. *, the use of the kappa test; $\chi^2$=0.715; the remaining variables were analyzed using one-way analysis of variance. BMI, body mass index. Data are presented as mean ± standard deviation, or number.

air were measured as 100±5 mm$^2$, the CT value within the measured vessel was used as the signal intensity, and the standard deviation of the noise of the anterior thoracic air was used as the background noise. CNR was calculated as follows: CNR = (the mean CT value of the target vessel − paraspinal muscle CT value)/ the standard deviation of the noise of the anterior thoracic air. Meanwhile, SNR was calculated as follows: SNR = the mean CT value of the target vessel/ the standard deviation of the noise of the anterior thoracic air.

### *Radiation dose*

The scan length (L; in cm), volume CT dose index ($CTDI_{vol}$; in mGy), dose-length product (DLP; DLP = L × $CTDI_{vol}$), and effective dose (ED; in mSv; ED = k × DLP; k=0.014) were recorded for each participant (7).

### *Statistics*

SPSS 21.0 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Continuous variables are expressed as the mean ± standard deviation, and discrete variables are expressed as numbers and percentages. The differences in age, DLP, ED, signal intensity, noise, SNR, and CNR of the 4 groups were analyzed with analysis of variance (ANOVA) and compared between the groups. Subjective scores for sex and image quality were tested using the kappa test. Differences were considered statistically significant at P<0.05.

## Results

### *General information*

All 240 participants successfully underwent CT examinations, and their general information is shown in *Table 2*. There were no statistically significant differences in sex, age, weight, height, or BMI among the 4 groups of participants.

### *Comparison of image quality*

The images of Group A can meet the evaluation of the aortic valve (*Figure 1A-1D*), the entire aorta (*Figure 1E,1F*), and the coronary artery (*Figure 1G-1J*). The image quality of the 4 groups of participants did not differ in subjective scores (P=0.955) (*Figure 2*). The images obtained met the diagnostic requirements (*Table 3*), with 96.67%, 98.33%, 96.67%, and 96.67% of images with a subjective score of 2 or more in groups A–D, respectively, and 3 cases with a score of 1, all of which have severe coronary artery tomography artifacts due to arrhythmia or coronary artery movement during patient scanning.

The results of the objective evaluation of the image quality are shown in *Table 4*. The differences in CT values and CNR at different levels among the 4 scanning protocols were not statistically significant.

### *Comparison of radiation dose*

A comparison of radiation dose parameters is presented in *Table 4*. The DLP and ED of groups A and B with the 70-kV coronary artery scanning protocol were significantly lower than those of groups C and D, respectively. The mean radiation dose in group A was lower than that in group B (P<0.05). Relative to group C at 100 kV, the ED of groups A and B was reduced by approximately 65.58% and 60.08%, respectively. Relative to group D at 120 kV, the ED of groups A and B was reduced by approximately 72.49% and 68.09%, respectively. The ED of group A was reduced by approximately 13.78% compared with that of group B.

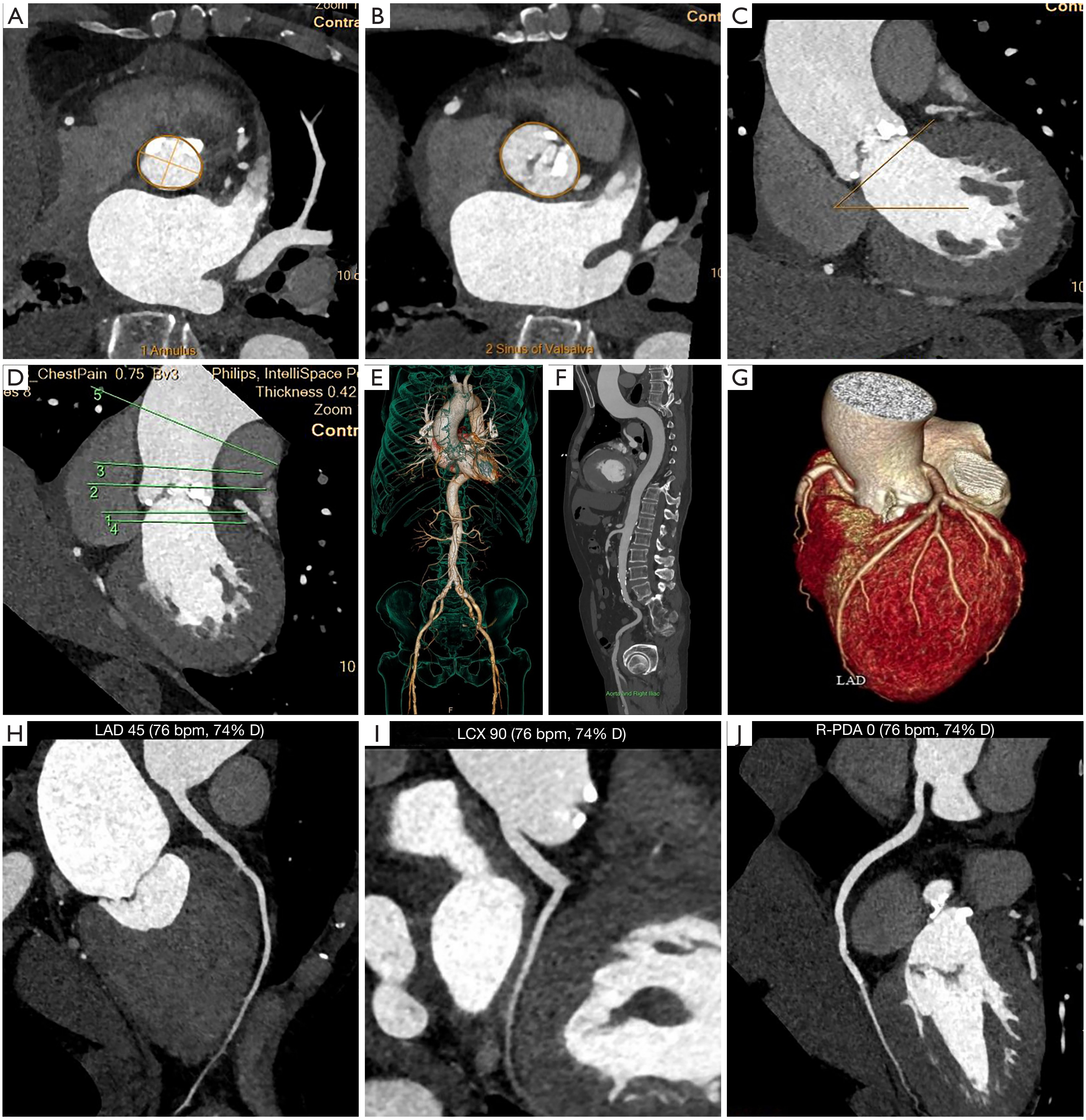


**Figure 1** A 70-year-old male. A 70-kV prospective cardiac-gated scan of the coronary arteries and a 100-kV large-pitch scan of the whole aorta were performed. (A) The aortic annulus, (B) sinus of the aorta (sinus of Valsalva), and (C) aortic valve projection angles. (D) The locations of the main levels of the central axis of the left ventricular outflow tract and aortic root selected in 3 orthogonal planes. The evaluation of the (E) total aorta and (F) peripheral access. 3D display of the entire artery and measurement of the skeletal and femoral arteries performed with high image quality. (G-J) Coronary artery evaluation of the patient, with the coronary artery alignment, lumen, and wall conditions clearly displayed. The image quality met diagnostic needs. F, front; LAD, left anterior descending artery; bpm, beat per minute; D, diastole; LCX, left circumflex artery; R-PDA, right-posterior descending artery.

 

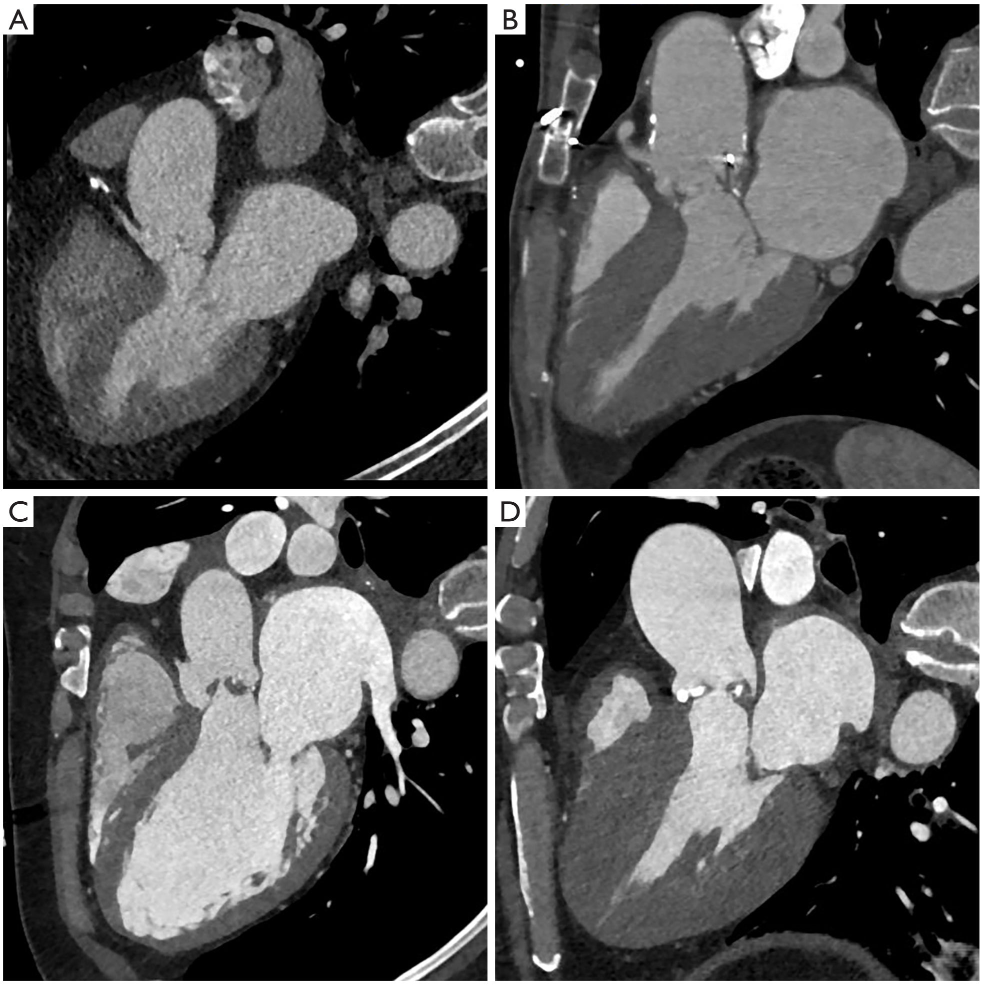


**Figure 2** Reconstructed images of the left ventricular outflow tract and aortic valve in the A-D group. Among the four images, the image noise in (A) is relatively high, but it does not affect the evaluation of the valve. Group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating.

## Discussion

The preoperative evaluation of TAVR relies on imaging, especially CT. Owing to the varying CT equipment used, there were different CT scanning protocols (7,8). Our findings suggest that a prospective electrocardiographic gated scanning of the aortic root and large-pitch CTA scanning of the entire aorta using third-generation dual-source CT can be used for the preoperative evaluation of TAVR with simultaneous evaluation of the coronary artery, aortic root, and surgical access and a significantly lower radiation dose.

The size and morphology of the aortic annulus vary with the cardiac cycle, with the size of the aortic annulus being larger in systole than in diastole (6). Most studies recommend measuring the aortic annulus during systole to select the appropriate valve type and to reduce complications. However, in some patients with septal hypertrophy, the maximum size of the aortic annulus can occur during diastole in the context of reverse kinetics (9). In contrast, patients undergoing TAVR are older, and the presence of coronary artery disease is also considered clinically, making it necessary to evaluate the presence of severe coronary artery stenosis in the TAVR evaluation (10). Evaluation of the aortic valve and coronary arteries requires the acquisition of both systolic and diastolic images. Retrospective cardiac gating can cover the entire cardiac cycle, and peak tube currents are applied during systole and diastole to ensure image quality. A prospective cardiac

 

**Table 3** Subjective evaluation of image quality

| Score | Group A, n (%) | Group B, n (%) | Group C, n (%) | Group D, n (%) |
|---|---|---|---|---|
| 4 | 36 (60.00) | 33 (55.00) | 38 (63.33) | 39 (65.00) |
| 3 | 16 (26.67) | 18 (30.00) | 16 (26.67) | 13 (21.67) |
| 2 | 6 (10.00) | 8 (13.33) | 4 (6.67) | 6 (10.00) |
| 1 | 2 (3.33) | 1 (1.67) | 2 (3.33) | 2 (3.33) |

Group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating. The use of the kappa test: $\chi^2$=3.147, P=0.963.

**Table 4** Image quality and radiation dose of the 4 groups

| Indicator | Group A | Group B | Group C | Group D |
|---|---|---|---|---|
| CT value (HU) | | | | |
| Aortic root | 420.51±64.62 | 418.92±50.36 | 437.44±51.19 | 420.94±40.86 |
| Left coronary artery | 423.17±65.06 | 421.09±58.62 | 444.49±55.09 | 423.76±45.56 |
| Right coronary artery | 417.71±63.41 | 419.72±57.96 | 443.08±50.48 | 423.43±44.62 |
| Ascending aorta | 431.84±64.86 | 440.34±46.50 | 433.58±51.53 | 437.84±42.34 |
| Aortic arch | 411.83±61.32 | 415.09±49.31 | 418.90±57.18 | 408.51±57.07 |
| Thoracic aorta | 449.43±45.72 | 437.55±58.54 | 445.65±56.83 | 449.59±64.28 |
| Abdominal artery | 459.70±56.01 | 468.39±51.06 | 450.27±60.27 | 455.79±56.45 |
| Right femoral artery | 478.04±71.13 | 494.57±86.49 | 480.87±63.51 | 476.39±62.64 |
| Left femoral artery | 475.18±50.50 | 485.79±82.32 | 477.75±78.34 | 467.68±73.91 |
| CNR | | | | |
| Aortic root | 46.22±6.38 | 46.39±9.16 | 45.79±7.70 | 47.14±9.27 |
| Left coronary artery | 46.40±6.72 | 45.74±7.96 | 45.90±7.62 | 46.24±7.87 |
| Right coronary artery | 46.22±6.38 | 46.39±9.16 | 45.79±7.70 | 47.14±9.27 |
| Ascending aorta | 47.56±5.61 | 49.19±10.29 | 45.33±7.57 | 49.37±10.65 |
| Aortic arch | 45.58±7.13 | 46.14±11.27 | 43.85±9.25 | 45.36±9.38 |
| Thoracic aorta | 50.39±8.44 | 48.37±8.40 | 46.63±7.42 | 50.58±11.35 |
| Abdominal artery | 51.62±8.97 | 52.54±10.59 | 47.48±9.82 | 51.27±10.13 |
| Right femoral artery | 53.82±10.14 | 55.42±12.10 | 51.15±10.73 | 53.81±11.18 |
| Left femoral artery | 50.31±7.57 | 54.92±14.07 | 50.52±10.74 | 52.26±9.01 |
| DLP (mGy·cm) | 294.83±49.09$^{†,‡,§}$ | 342.27±41.37$^{‡,§}$ | 856.89±115.69$^{§}$ | 1072.49±135.94 |
| ED (mSv) | 4.13±0.69$^{†,‡,§}$ | 4.79±0.58$^{‡,§}$ | 12.00±1.62$^{§}$ | 15.01±1.90 |

Data are presented as mean ± standard deviation. Group A, 70-kV prospective cardiac gating; group B, 70-kV retrospective cardiac gating; group C, 100-kV prospective cardiac gating; and group D, 120-kV prospective cardiac gating. $^{†}$, compared with group B, P<0.05; $^{‡}$, compared with group C, P<0.05; $^{§}$, compared with group C, P<0.05. CT, computed tomography; HU, Hounsfield unit; CNR, contrast-to-noise ratio; DLP, dose-length product; ED, effective dose.

 

gating technique can selectively acquire cardiac cycle phases, but a wider acquisition window width should be used for TAVR scanning to include both systole and diastole and thus ensure the accuracy of aortic valve evaluation (11). In addition, due to the general age of the patients undergoing TAVR, the radiation dose is not an important consideration, and a narrower temporal phase scan is not required. Therefore, we chose a time window of 20–90% of the cardiac cycle for prospective ECG-gated scans in group A to further reduce the radiation dose while ensuring image quality and evaluation requirements. The results of this study also showed that the use of prospective ECG gating combined with low-voltage scanning can guarantee coronary image quality, consistent with the results of other low-kilovoltage coronary studies (12). In addition, coronary CTA combined with CT-FFR can reduce unnecessary coronary angiography before TAVR surgery (13,14). The use of beta blockers and nitroglycerin before examination to calculate the CT-FFR can improve the diagnostic accuracy (15).

The application of dual-source CT and large-pitch aortic scanning techniques has significantly reduced the radiation dose during aortic scanning (16). Normally, an increase in pitch reduces the resolution of the z-axis and image quality, but DSCT has a higher detector width, rotation speed, and patient table speed, which reduces the overlap during conventional spiral scanning and ensures the feasibility of large-pitch aortic scanning (11). It is well known that the CT radiation dose is inversely proportional to the square of the tube voltage, so the low tube voltage during scanning is the most direct and effective method and the most commonly used method in clinical practice (17). However, the reduction in the tube voltage increases the noise and reduces the image quality, which is compensated for by iterative reconstruction. Compared with reconstruction with filtered inverse projection, iterative reconstruction can significantly improve the image contrast (18). Several studies have shown that third generation DSCT with a large spiral and low-tube voltage combined with an iterative reconstruction technique can ensure image quality while reducing radiation dose (18,19). This study found there to be no significant differences in CT values and CNR in any parts of the aorta (ascending aorta, aortic arch, thoracic aorta, abdominal aorta, and bilateral femoral arteries, *Figure 2*), which is consistent with the results of other studies (8,19,20). The dual-energy acquisition method can also reduce radiation dose in vascular scanning (21). This method can be used for virtual plain scanning to diagnose cardiovascular diseases, reducing radiation dose and contrast agents (22).

Our study had the following limitations. First, the number of patients in each group was limited by their age and clinical needs. Second, in this study, we only evaluated the quality of CTA images of the coronary arteries without comparing the results with those of coronary angiography and without comparing the accuracy of diagnosing coronary artery stenosis in each group. Finally, to ensure the acquisition of systolic and diastolic images during the cardiac cycle, we set a larger acquisition time window for the R-R interval when prospective cardiac gating was used in this study. The radiation dose could be further reduced if the appropriate temporal phase of the aortic annulus could be clarified.

## Conclusions

In conclusion, low-tube voltage prospective cardiac gating combined with a large-pitch total aortic scan protocol with third-generation DSCT can be used for the preoperative evaluation of TAVR. The use of prospective cardiac-gated scanning allows for the simultaneous evaluation of the coronary artery and aortic valve and combined with large-pitch total aortic scanning, the aorta and surgical pathway can be evaluated. Through this approach, the radiation dose to the patient can be significantly reduced while ensuring image quality.

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## Footnote

*Data Sharing Statement:* Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1734/dss

*Peer Review File:* Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1734/prf

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1734/coif). The authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the ethics committee of Tianjin Chest Hospital (No. IRB-SOP-016(F)-001-02). Informed consent was taken from all individual participants.



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