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Identification of Coronary Artery Orifice to Prevent Coronary Complications in Bioprosthetic and Transcatheter Aortic Valve Replacement

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Background: The aim of this study was to identify anatomical variations in coronary artery orifices among high-risk patients with a small aortic root undergoing bioprosthetic aortic valve replacement (BAVR) and transcatheter aortic valve replacement (TAVR) in order to prevent coronary orifice obstruction perioperatively.

Methods and Results: Coronary orifice and root structure were identified in 400 patients using aortic multidetector-row computed tomography (MDCT). We measured the aortic root diameter; intercommissural distances; and distance from coronary orifice to valve annulus, commissure, and sinotubular junction. We examined positional relationships between the coronary orifice and stent post, or sewing cuff of the bioprosthetic valve and leaflet of the transcatheter aortic valve. Most left coronary artery orifices were distributed near the center of the non-left and left-right commissures; right ones were relatively distributed on the non-right commissural side. Thirty-four patients (8.5%) with BAVR (coronary orifice near the commissure: 31, 7.8%; low takeoff: 5, 1.3%; and both: 2) and 39 (9.8%) with TAVR were at risk for coronary orifice obstruction. During BAVR, one-stitch rotation of the stent and one-stitch rotation with intra-annular implantation were used in near-commissure and low takeoff cases, respectively. During TAVR, percutaneous coronary intervention may be required in the height of the coronary orifice was ≤10 mm from the base of the ventricle aortic junction.

Conclusions: Potential coronary complications during BAVR and TAVR in high-risk patients for coronary obstruction were identified using preoperative aortic MDCT. Choice of appropriate surgical technique or valve is essential. (*Circ J* 2015; **79:** 2157–2161)

Key Words: Aortic valve replacement; Coronary circulation; Imaging; Multidetector computed tomography; Transcatheter aortic valve replacement/implantation

Bioprosthetic aortic valve replacement (BAVR) and transcatheter aortic valve replacement (TAVR) in patients with a small aortic root are associated with certain risks, including blood flow obstruction or occlusion of the coronary artery orifices by the stent post or sewing cuff of the bioprosthetic aortic valve, and leaflet of the transcatheter bioprosthetic valve.[1,2] In Japan, many aortic valve replacement (AVR) patients have a small aortic root[3] and a small overall diameter between coronary orifices and commissures; thus, coronary orifices may compete with the stent post or height of the transcatheter bioprosthetic valve leaflet. To prevent coronary issues in BAVR and TAVR, it is important to recognize anatomical variations in the coronary artery orifices and aortic root structure. Therefore, the aim of this study was to identify anatomical variations of the coronary artery orifices and the positional relationship between coronary orifices and the stent post, sewing cuff, and height of the transcatheter bioprosthetic valve leaflet. We hypothesized that this information would help determine the appropriate surgical technique for preventing coronary complications in high-risk patients with small aortic root who undergo BAVR and TAVR.

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Methods

Subjects

A total of 504 consecutive patients who underwent preoperative screening on computed tomography at Tokyo Women's Medical University, Medical Center East between January 2011 and August 2014, were enrolled in the present study. Exclusion criteria consisted of bicuspid aortic valve, annulo-aortic

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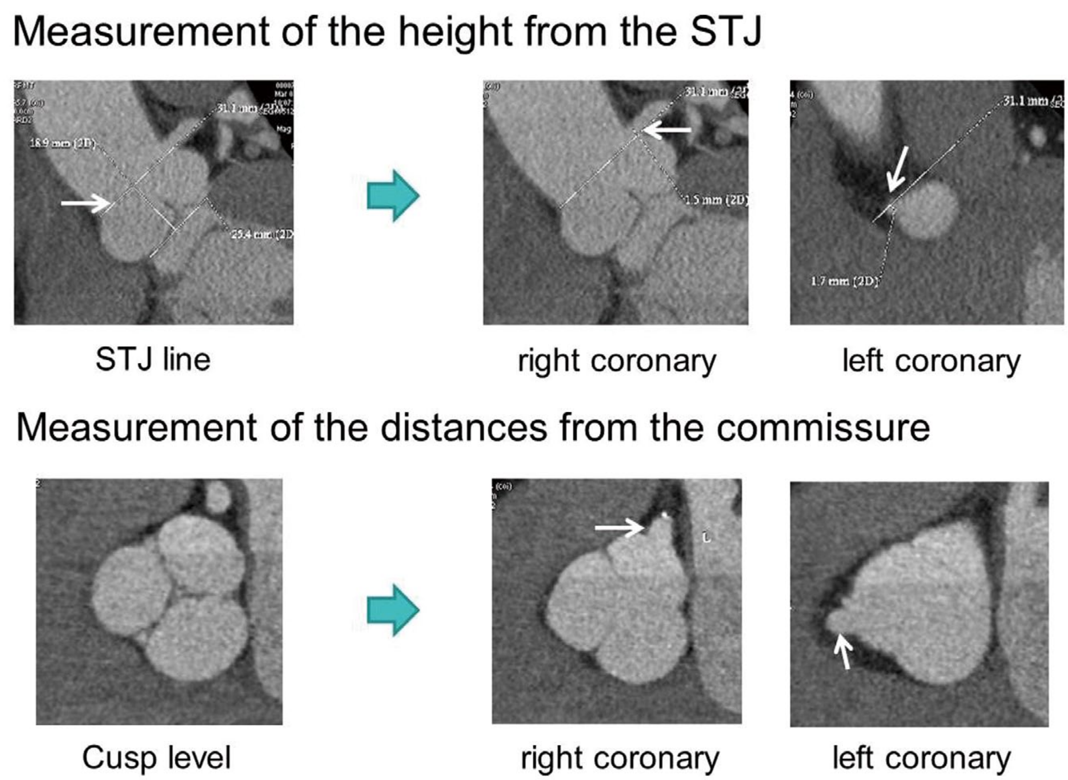

Figure 1. Measurement of distances from the sinotubular junction (STJ) to the coronary artery orifices, and from the commissure to the coronary artery orifices.

ectasia, coronary artery arising from inappropriate aortic sinus, or Bland-White-Garland syndrome, because the objective was to investigate normal anatomical relationships and variations in the coronary orifices, annulus, and commissures. Finally, 400 patients were included in this study. Of these, 221 were men; mean patient age was 68±8 years (range, 32–87 years), and mean body surface area was 1.58 m^2. This study was approved by the institutional review board, and informed consent was obtained from patients to perform multidetector-row computed tomography (MDCT) and surgery.

Image Reconstruction

The coronary orifice and root structure were identified using electrocardiographically gated 64-column MDCT. All MDCT was carried out using LightSpeed VCT XT (GE Healthcare). We chose aortic MDCT, because it is routinely used in preoperative examinations prior to cardiac surgery. Venous access was achieved via a right upper extremity vein using a 20-G cannula. Contrast media (80–100 ml) was injected through the cannula. The timing of the scan was determined using an automated bolus tracking technique by placing the region of interest over the descending aorta and setting the trigger threshold to 180 HU.

All images were reconstructed using INFINITT (INFINITT Healthcare), and they were reviewed with axial projection. Subsequently, we used imaging tools to examine the images (eg, volume rendering and multiplanar reconstructions).

Measurements

Figure 1 shows the actual MDCT method used, which involved two steps. First, the sinotubular junction (STJ) line was identified, and the diameters of the STJ, sinus of Valsalva, and basal ring (ie, base of the ventriculo-aortic junction) were measured. Second, the MDCT image was rotated to detect the coronary artery orifice, and the distance from the STJ was measured. Similarly, the cusp level was identified, and distance of the coronary artery orifice from the cusp level was measured. Thereafter, the distance between the commissure and coronary artery orifice, and that between the basal ring and coronary artery orifice were measured.

Based on the measurements obtained, location of the coronary orifice was plotted on a scatter plot to show the distance between the valve annulus and STJ, and the distance between the commissure. In BAVR, we examined the positional relationship between the coronary orifice and stent post or annulus (ie, position of the sewing cuff), and we chose valve implantation techniques that would prevent blood flow obstruction to coronary artery orifices in high-risk patients. Moreover, we examined coronary orifices with a risk of flow obstruction using the transcatheter bioprosthetic valve.

Statistical Analysis

StatView 5.0 (SAS Institute) was used to perform statistical analysis. Student's t-test was used to compare average values. For 95% CI, $P<0.05$ was considered statistically significant. Data are presented as mean±SD. Diameters of the STJ, sinus

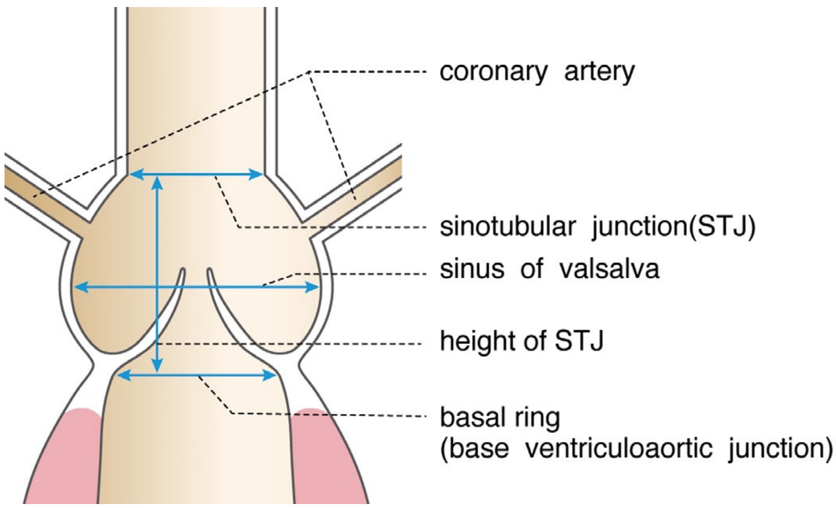

Figure 2. Cross-sectional view of the aortic root. Mean intercommissural distances; diameters of the sinotubular junction (STJ), sinus of Valsalva, and basal ring; and distance from the STJ from the basal ring are measured.

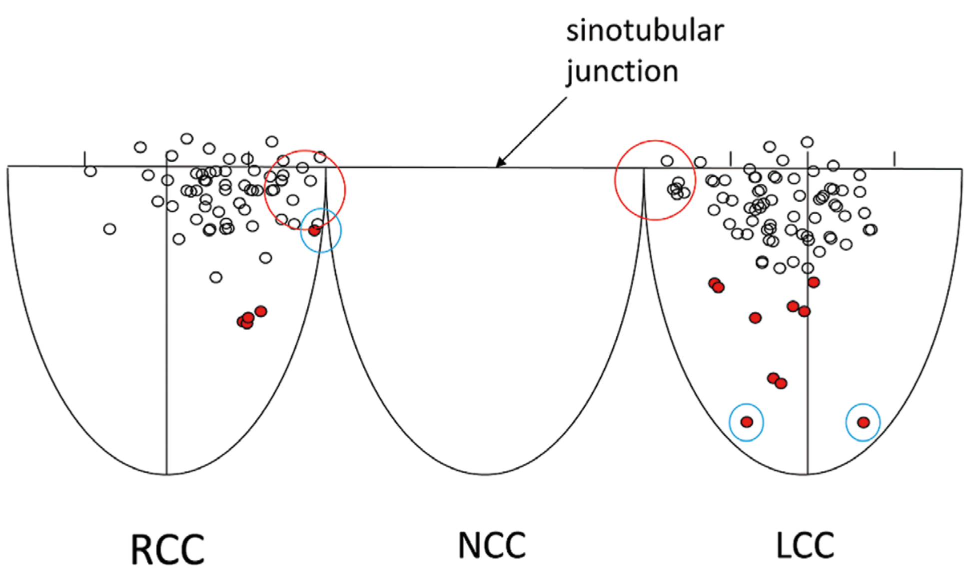

Figure 3. Distribution of coronary artery orifices among the 400 patients. Large red circles, 31 cases of coronary artery orifice (7.8%) associated with risk of coronary issues due to stent interference. Blue circles, 5 cases of coronary artery orifice (1.3%) associated with low takeoff due to sewing cuff interference. Red dots, 39 cases of coronary artery orifice (9.8%) associated with risk of coronary issues due to transcatheter aortic valve. In these cases, the height of the coronary orifice from the base of the ventriculo-aortic junction was ≤10 mm. LCC, left coronary cusp; NCC, non-coronary cusp; RCC, right coronary cusp.

of Valsalva, and basal ring were defined as the average of the maximum and minimum diameter, because these structures are oval, and not circular.

Results

Mean intercommissural distance for the right, left, and non-coronary sinuses was 24.7±2.0 mm, 22.0±1.8 mm, and 23.2±1.9 mm, respectively. Mean diameter of the STJ, sinus of Valsalva, and basal ring was 22.1±1.8 mm, 25.5±2.3 mm, and 22.6±2.7 mm, respectively. The distance from the STJ to the basal ring was 18.7±2.0 mm (Figure 2).

Figure 3 shows the distribution of the coronary artery orifices among the 400 patients. The left coronary artery orifice arose from below the STJ in 374 patients (93.5%) and at the level of the STJ in 17 (4.3%). The highest left coronary orifice position was 1.8 mm above the STJ. The right coronary artery orifice arose from below the STJ in 362 patients (90.5%) and at the level of the STJ in 23 (5.8%). Very low takeoff orifices (near the annulus) such as those located at a distance <5 mm between the coronary orifice and annulus were present in 5 patients (1.3%; left coronary, n=3; right coronary, n=2). In these patients, the lowest takeoff of the left coronary orifice was 3.1 mm above the annulus, and the lowest takeoff of the right coronary orifice was 3.5 mm above the annulus. Moreover, height of the coronary orifice from the base of the ventriculo-aortic junction ≤10 mm was present in 39 patients (9.8%; left coronary, n=24; right coronary, n=15). Distance from the right coronary orifice to the STJ was not significantly different from that of the left coronary orifice (right, 4.1±3.4 mm; left, 5.4±3.7 mm; P=0.19). Double orifices of the left coronary artery were observed in 3 patients, and small accessory coronary orifices were noted in 82 (20.5%).

With regard to the position of coronary artery orifices between the commissures, most of the left coronary artery orifices were distributed centrally between the non-left (N-L) commissure and the left-right (L-R) commissure (distance from the left coronary artery orifice to the center of the cusp ≤5 mm: 319 patients, 79.8%). The right coronary artery orifices, however, were relatively near the non-right (N-R) commissure, with a greater number of near-commissure cases than that for the left coronary artery orifices (distance from the right coronary artery orifice to the center of the cusp ≤5 mm: 237 patients, 59.3%; average distance from the coronary artery orifice to the center of the cusp: left, 2.3±2.5 mm vs. right, 4.1±3.1 mm; P=0.03). Furthermore, some coronary artery orifices were found near the commissure, and the distance between the coronary orifice and commissure was <3 mm in 31 patients (7.8%; left coronary, n=9; right coronary, n=22). The small accessory coronary orifices also tended to be located near the commissure.

Thirty-four patients (8.5%) had a risk of coronary complications because of potential interference from the stent post or sewing cuff in BAVR. Of these, 2 patients had low takeoff, and the orifices were located near the commissure.

Regarding TAVR, 39 patients had a risk of coronary flow obstruction because the height of the coronary orifice was ≤10 mm from the base of the ventriculo-aortic junction.

For BAVR, one-stitch rotation of the stent post and one-stitch rotation with intra-annular implantation were used in the near-commissure and low takeoff cases, respectively. No coronary-related or other postoperative complications were observed in any of the patients.

Discussion

In this study, we investigated the position of coronary artery orifices using aortic MDCT to identify the risk of coronary complications during BAVR and TAVR. Currently available imaging techniques are capable of precisely visualizing the position of coronary artery orifices. Besides CT, catheter examination, magnetic resonance imaging (MRI), and transesophageal echocardiography (TEE) have also been used to identify coronary artery orifices in previous studies.[4–7] It is not possible, however, to identify exact positions of the coronary artery orifices during examination with a catheter. Moreover, TEE and MRI are not routine preoperative examinations for AVR surgery, and TEE is invasive. Therefore, we did not select these imaging methods. Previous reports assessing the utility of CT for identifying coronary arteries have suggested the use of coronary CT.[8–11] In the present study, we used aortic CT, which takes images of the patient from the neck to the groin. Given that the chest range was gated, aortic CT can evaluate the positions of coronary artery orifices accurately. In addition, aortic MDCT is a routine preoperative examination for cardiac surgery at Tokyo Women's Medical University, Medical Center East. It is important to identify any anomalies, vascular atheroma, the safety of assistive devices (eg, intra-aortic balloon pump insertion), or the presence of carcinoma of other organs before cardiac operations, because these factors influence the indications for operation, approach, and operative procedures. In comparison with other methods, preoperative aortic MDCT is not more expensive and is not invasive. Nevertheless, considering the effect of contrast agents on kidney function, obtaining enhanced CT is difficult in patients with renal failure. Various methods and software for CT imaging, however, have been developed recently, and enhanced CT can be used in many patients without severe renal dysfunction.

Measurement results for the aortic root were identical to those reported previously.[12,13] Regarding the location of the coronary artery in the present study, with a few exceptions, most of the left coronary artery orifices were distributed near the center of the N-L and L-R commissures. In contrast, the right coronary artery orifices were distributed on the N-R commissural side instead of the R-L commissural side. Muriago et al, and Turner and Navaratnam also reported similar findings in autopsy studies.[14,15] The right coronary artery is anatomically designed to pass around the tricuspid valve; therefore, it is appropriate for its orifice to be located on the N-R commissural side. Hence, this bias may be an appropriate finding. Similarly, to pass behind the pulmonary artery, the left coronary artery may need to originate from the middle of the left coronary sinus.

Coronary artery orifices located near a commissure are at risk of coronary flow obstruction by the stent post of the bioprosthetic valve. In this study, distance between the coronary artery and commissure ≤3 mm indicated a risk of coronary flow obstruction, because the stent width used in Japan is 4–8 mm. In this study, orifices were located near the commissure in 31 patients (7.8%; left coronary, n=9; right coronary, n=22). According to Vlodaver et al, coronary artery orifices are located within a distance of 5 mm from the commissure in 6% of adult hearts.[16] Based on this finding, physicians must be aware that certain patients are at risk for occlusion of the coronary artery orifices by the stent post in BAVR, particularly those who have a small aortic root. In such patients, because the distance between the commissures is short and the aortic root space is small, the stent post tends to be located close to coronary artery orifices. Therefore, coronary complications can occur more frequently during or following BAVR in patients with a small aortic root than in patients with a normally sized aortic root.

Similarly, in TAVR, the height of the coronary artery orifice from the base of the ventriculo-aortic junction is very important to avoid the risk of occlusion. In this study, height ≤10 mm indicated a risk of coronary flow obstruction by the transcatheter aortic valve, and was therefore used as an indication for transcatheter aortic valve (ie, height of the transcatheter aortic valve, which hangs over the ventriculo-aortic junction, is 7 mm), as per a past report.[2] In this study, orifice height was ≤10 mm in 39 patients (9.8%; left coronary, n=24; right coronary, n=15).

Considerable variation was seen in the location of coronary artery orifices. Similar findings have been reported previously, and the coronary orifice was reported to be located as high as >1 cm from the STJ in some cases.[17–19] Such a location is called a high takeoff and can be a cause of sudden death.[17] In contrast, cases of low takeoff, that is, distance 6.3 mm from the annulus, have also been reported.[20] In low takeoff cases, the distance between the sewing cuff and coronary artery orifice is very short, which can lead to obstruction of the orifice by the cuff. In a previously reported case of low takeoff, wherein the coronary artery orifice was occluded, the orifice was located very close to the sewing cuff.[1]

In patients with high takeoff and a small aortic root, care should be taken to prevent injury to the coronary artery, given that the aortic incision may be made relatively close to the STJ in order to ensure a good surgical field.

Based on the present findings, we considered the possibilities for preventing coronary complications in patients undergoing BAVR who were at risk for coronary artery orifice occlusion. The available techniques included one-stitch rotation, intra-annular implantation, and the use of low-profile bioprosthetic valve. One-stitch rotation is a very useful and simple procedure, because it is not significantly different from normal valve replacement. The use of one stitch rotation alone, however, would not be adequate for compensating for problems encountered with low takeoff. In such cases, we also performed intra-annular implantation, but it should be noted that intra-annular implantation in patients with a narrow annulus is difficult. In such cases, the use of mechanical valves and enlargement of the aortic annulus with Nicks or Manouguian procedure should be considered. The choice of procedure should also be based on patient age, the complexity of the procedure, operative time, and hemostasis.

Recently, the number of cases of TAVR has increased in Japan.[21,22] Hence, determination of the position of the coronary artery orifice and the structure of the aortic root is very important; thus, the present findings should be useful in preoperative evaluation for TAVR. According to the present results, approximately 10% of patients were at risk of coronary obstruction during TAVR. For TAVR, percutaneous coronary intervention (PCI) to the orifice at risk of obstruction may be required. Moreover, in those with a small aortic root, BAVR may also need to be considered.

Given that the aim of this study was to investigate normal anatomical relationships and variations in the location of the coronary orifice, annulus, and commissures, we excluded patients with bicuspid aortic valve. We believe, however, that identifying coronary orifices in the bicuspid aortic valve is also important, because bicuspid valve anatomy can vary. Therefore, the relationship between the bioprosthetic valves and coronary orifices in the bicuspid aortic valve should be investigated in future studies.

Study Limitations

The averages noted herein, such as those for the sinus of Valsalva, may not be applicable to the general population. Given that we included patients undergoing preoperative CT screening, cardiac abnormalities were likely to be present in these patients, but this may not pose a major problem given that we excluded cases of abnormally sized sinus of Valsalva.

Conclusions

Following evaluation of the position of coronary artery orifices and root structures on aortic MDCT, we were able to identify anatomical variations of coronary orifices in patients with normal anatomy. Potential coronary complications caused by obstruction of orifices by the stent post or sewing cuff during BAVR, and transcatheter aortic valve during TAVR in patients at high risk for coronary obstruction were identified. In such cases, appropriate techniques such as one-stitch rotation, intra-annular implantation, or the use of low-profile bioprosthetic valves or mechanical valves in BAVR, and PCI or BAVR conversion may be helpful.

Disclosures

The authors declare no conflicts of interest.

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