Updates on Transcatheter Aortic Valve Replacement and the Role of Multi-Detector Computed Tomography: What a Radiologist Should Know

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The indications of the transcatheter aortic valve replacement (TAVR) procedure have been widely expanded and the number of cases has significantly increased in the past 15 years due to continued evolution of prosthetic devices, increased experience of cardiologists, and advancements in the cardiovascular imaging field. In this review article, we summarize updates on TAVR guidelines, state-of-the-art prosthetic devices, recommended pre- and post-procedural multi-detector computed tomography (MDCT) protocols, required imaging parameters and measurements, and post-procedural complications. We also address issues concerning the Asian population and patients with bicuspid aortic valve and emphasize some of the challenges ahead. MDCT is the recommended modality of choice for pre-procedural planning for TAVR and current guidelines state that MDCT should be performed by well-trained personnel and interpreted and analyzed by experienced radiologists who not only have a sound understanding of TAVR with respect to its indications, prosthetic devices, procedure, and complications, but also work in close collaboration with the Heart Team.

Key words Transcatheter aortic valve replacement · Multidetector computed tomography · Aortic valve stenosis · Aortic dissection.

INTRODUCTION

Aortic valve stenosis (AS) is the most common progressive valvular disease in adults and shows an increased incidence in the elderly, making it a disease burden that cannot be overlooked in aging/aged societies. Aortic valve replacement is usually required for patients with severe AS. The mortality rate is dismal and increases to 50% within 2 years as patients with symptomatic AS progress to heart failure [1,2]. Before the ad-

vent of transcatheter aortic valve replacement (TAVR), surgical aortic valve replacement (SAVR) remained the standard treatment for patients with severe AS, reporting both low mortality and good clinical outcomes [3,4]. However, the treatment choice has tilted towards the much less invasive TAVR procedure since it was first introduced 15 years ago. To date, several clinical trials have demonstrated either superiority or non-inferiority of TAVR to SAVR, especially in inoperable or high surgical risk patients [5-7]. More recent studies have suggested the feasibility of expanding the indication of TAVR to intermediate or even low surgical risk populations [8-11]. As a result of this growing evidence the case number of TAVR procedures has been

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rapidly growing worldwide and has surpassed that of SAVR in recent years [12].

NEW GUIDELINES FOR TAVR

General rules should be applied when considering the choice of treatment for AS according to the latest 2017 the American Heart Association/the American College of Cardiology (AHA/ACA) and the European Society of Cardiology/the European Association for Cardio-Thoracic Surgery (ESC/EACTS) guidelines, as summarized in Table 1 [13-16]. The guidelines recommend surgical risk stratification in terms of morbidity and mortality using the Society of Thoracic Surgeons (STS) score and the European System for Cardiac Operative Risk Evaluation (EuroSCORE) II for adults undergoing cardiac surgery [17-19]. These scores are derived from the demographic and clinical vari-

ables of the patient and the website-based calculators can be accessed as follows: STS score, <http://riskcalc.sts.org/stswebriskcalc/#/calculate>; EuroSCORE II, <http://www.euroscore.org/calc.html>. A low surgical risk is defined as an STS/EuroSCORE II <4% in the absence of other established risk factors including frailty, porcelain aorta, and sequelae of chest radiation. For AS patients who are not stratified as low risk, TAVR is favored over SAVR in the absence of severe comorbidities that suggest SAVR is unlikely to improve the quality of life or survival. In such cases the patients should be carefully and individually evaluated by the Heart Team based on clinical, anatomical, technical, cardiac, and extracardiac characteristics. It should be noted that current evidence on TAVR is limited to patients older than 75 years, and that the long-term durability of TAVR prosthetic devices has not been established to date [12].

Table 1. Factors to be considered by the Heart Team for decision making between SAVR and TAVR, based on the recommendations in the American Heart Association/the American College of Cardiology (AHA/ACA) and the European Society of Cardiology/the European Association for Cardio-Thoracic Surgery (ESC/EACTS) 2017 guidelines on the management of valvular heart disease

	Favors TAVR	Favors SAVR
Clinical characteristics		
STS/EuroSCORE II <4%		+
STS/EuroSCORE II ≥4%	+	
Presence of severe comorbidity	+	
Age <75 years		+
Age ≥75 years	+	
Previous cardiac surgery	+	
Frailty	+	
Restricted mobility and conditions that may affect the rehabilitation process after the procedure	+	
Suspicion of endocarditis		+
Anatomical and technical aspects		
Favorable access for transfemoral TAVR	+	
Unfavorable access (any) for TAVR		+
Sequela of chest radiation	+	
Porcelain aorta	+	
Presence of intact coronary bypass grafts at risk when sternotomy is performed	+	
Expected patient-prosthesis mismatch	+	
Severe chest deformation or scoliosis	+	
Short distance between coronary ostia and aortic valve annulus		+
Size of aortic valve annulus out of range for TAVR		+
Aortic root morphology unfavorable for TAVR		+
Valve morphology unfavorable for TAVR (bicuspid, degree of calcification, calcification pattern)		+
Presence of thrombi in aorta or LV		+
Cardiac conditions in addition to aortic stenosis that require consideration for concomitant intervention		
Severe CAD requiring revascularization by CABG		+
Severe primary mitral valve disease, which could be treated surgically		+
Severe tricuspid valve disease		+
Aneurysm of the ascending aorta		+
Septal hypertrophy requiring myectomy		+

CABG: coronary artery bypass grafting, CAD: coronary artery disease, EuroSCORE: European System for Cardiac Operative Risk Evaluation, LV: left ventricle, SAVR: surgical aortic valve replacement, STS: Society of Thoracic Surgeons, TAVR: transcatheter aortic valve replacement

Table 2. The latest generation of commercially available transcatheter aortic valves

Manufacturer	Valve name	Valve type	Available sizes (mm)	Design	Special features	Delivery system	Access routes	Illustration*
Edwards life science	Sapien 3	Balloon expandable	20, 23, 26, 29	Bovine pericardium; cobalt chromium frame	Outer sealing skirt to minimize PVR	14F eSheath for 20, 23, and 26 mm valves; 16F eSheath for 29 mm valve; transaortic or transapical through an 18F or 21F sheath	Transfemoral, transaortic, transapical
	CoreValve Evolut PRO	Self-expanding	23, 26, 29	Porcine pericardium; nitinol frame	Recapturable; repositionable; sealing skirt available to minimize PVL	14F Sheath for 23, 26 mm valves; 16F Sheath for 29 mm valve	Transfemoral, transaortic, trans-subclavian, transcarotid
Boston scientific	ACURATE neo	Self-expanding	23, 25, 27	Porcine pericardium; nitinol frame	Fully recaptured and repositioned after partial deployment; caps native leaflets and provides coronary clearance; skirt sealing against PVL; minimal protrusion into LVOT; low risk of PPI	18F sheath for 23 mm valve, 20F for 25, 27 mm valve	Transfemoral
	LOTUS Edge	Controlled mechanical expansion	23, 25, 27	Bovine pericardium; nitinol frame	Fully repositioned, even after full deployment; adaptive seal technology is designed to minimize PVL; depth guard technology is used to reduce the LVOT interaction and PPM rate	18F sheath for 23 mm valve, 20F for 25, 27 mm valve	Transfemoral, transaortic
Abbott	Portico	Self-expanding	23, 25, 27, 29	Porcine pericardium; nitinol frame	Fully recaptured and repositioned after partial deployment; sealing cuff and large cell geometry to minimize PVL; valve height for minimal protrusion into the LVOT	18F sheath for 23, 25 mm valve, 19F for 27, 29 mm valve	Transfemoral, transaortic, trans-subclavian

*The data and illustrations of all devices are adapted from the official web site of individual manufacturer (Edwards Life Science, <https://www.edwards.com/gb/devices/heart-valves/transcatheter>; Medtronic, <http://www.medtronic.com/us-en/healthcare-professionals/products/cardiovascular/heart-valves-transcatheter/transcatheter-aortic-valve-replacement-platform.html>; Boston Scientific, <http://www.bostonscientific.com/en-EU/products/transcatheter-heart-valve.html>; Abbott, <https://www.sjmglobal.com/en-int/professionals/featured-products/structural-heart-tissue-heart-valves/aortic-and-mitral-valves/portico-aortic-valve>). PVR: paravalvular regurgitation, LVOT: left ventricular outflow tract, PPI: permanent pacemaker implantation

TYPES OF PROSTHESIS

Two major types of transcatheter aortic valve prostheses have been widely studied in randomized clinical trials—the balloon-expandable and self-expanding prostheses [20] distributed by Edwards life science and Medtronic respectively. The latest commercially available prosthetic devices are summarized in Table 2 [20,21]. Compared with the balloon-expandable prosthesis, advantages of the self-expanding prosthesis include its repositionability, no need for rapid ventricular pacing in order to alleviate hemodynamic disturbance, and a lower risk of annular rupture. However, complications such as paravalvular regurgitation (PVR) and permanent pacemaker implantation (PPI) are more commonly seen with the self-expanding prosthesis. Newer devices have been reported to have a lower complication rate but more solid evidence from large-scale randomized direct comparison studies is still lacking [22,23].

PRE-TAVR EVALUATION

The 2017 AHA/ACC and ESC/EACTS guidelines state that multi-detector computed tomography (MDCT) is the preferred imaging modality for pre-procedural evaluation of patients undergoing TAVR. The imaging assessment should encompass the following: the size and shape of the aortic root and the aortic valve annulus, the distance from aortic annulus to coronary ostia, the distribution of calcifications and the number of aortic valve cusps, and evaluation of the possible peripheral access routes including the minimal/maximal luminal diameters, the atherosclerotic plaque burden, and the degree of tortuosity of the vessels, as well as presence of aneurysms and/or thrombi [13]. Cardiovascular abnormalities such as valvular disease (e.g., bicuspid aortic valve), cardiac mass, septal hypertrophy, intracardiac thrombus (Fig. 1), or aortic aneurysm should also be documented.

MDCT PROTOCOLS

The Society of Cardiac Computed Tomography (SCCT) expert consensus document on MDCT imaging for pre-procedural planning for TAVR suggests the use of an at least 64-slice CT scanner equipped with a wide detector (“the wider the better”) for faster acquisition time and contrast volume reduction [24]. The recommended MDCT protocols summarized in Table 3 have been modified from technical documents from Medtronic and the SCCT expert consensus. In general, for evaluation of aortic root, most centers use an electrocardiography (ECG)-gated contrast enhanced systolic phase MDCT scanning technique; for evaluation of the peripheral access routes, non ECG-gated MDCT angiography with high pitch is usually adopted to reduce the radiation dose.

As with any other cardiovascular imaging, TAVR MDCT is not without limitations. First, administration of heart rate lowering agents (e.g., β -blockers) is not always possible because the typical cohort consists of mostly elderly individuals with a high incidence of comorbidities such as atrial fibrillation, and this can result in image degradation. Contrast-induced nephropathy could also be a concern in an elderly patient group [25]. The radiation dose of TAVR MDCT is relatively high but can be reasonably reduced with automated tube current modulation and iterative image reconstruction. Image acquisition using a dual-source MDCT with prospective ECG gating, a high pitch of 3.4, and a low tube voltage of 100 kVp could reduce the radiation dose to less than 5 mSv and decrease the required amount of contrast agent at a lower injection rate, while still allowing for adequate vascular enhancement without sacrificing the image quality [26]. Such an approach could be beneficial for patients with severe renal insufficiency [27,28].

In terms of image evaluation and CT measurements, a sequential double-oblique reconstruction that best reveals the anatomy

Fig. 1. A 71-year-old female with severe aortic valve stenosis and atrial fibrillation. Pre-TAVR multi-detector computed tomography (A) and transesophageal echocardiography (B) revealed a large thrombus (white arrow) in the left atrial appendage. Surgical aortic valve replacement was performed instead of TAVR for thrombus removal. TAVR: transcatheter aortic valve replacement.

Table 3. Pre-procedural transcatheter aortic valve replacement multi-detector computed tomography protocol recommendations

Aortic root recommended parameters	
IV injection with iodine contrast	80–100 mL (320 mg/mL or higher), modify per patient as appropriate; reduce contrast volume and adhere to protocols for the prevention of contrast-induced nephropathy is recommended
Injection rate	4–6 mL/sec
Bolus tracking, delay	Delay time is calculated using protocol for the current scanners (bolus tracking or similar) with the peak of contrast concentration in the ascending aorta during acquisition
ECG leads	Required
ECG-gating	Prospective or retrospective; systolic phase preferred (usually 30–50% phase)
Scan direction	Cranial-caudal
Scan coverage	From above the aortic arch to below the cardiac apex
Detector collimation	0.4–0.625 mm
Pitch	0.2–0.43 adapted to the heart rate
Dose modulation	80 or 100 kV, auto mAs, prospective scan can reduce radiation dose; if a retrospective scan is used, modulation and full current between 30 and 80% of the cardiac cycle; 120 kV for patients with BMI >30; multi-phase (“cine”) imaging is not necessary
Slice thickness	≤1 mm
Slice overlap	0.4 mm
Reconstruction kernel	Medium smooth
Post-processing	Reconstruct the cleanest systolic phase from a signal-noise ratio and motion artifact perspective An automated “best-systolic” reconstruction can also be used
Peripheral access recommended parameters	
Protocol	Standard CT angiography protocol
Bolus tracking, delay	Delay time is calculated using protocol for current scanners (bolus tracking or similar) with the peak of contrast concentration in the area of interest
ECG-gating	Non-ECG-gated; if ECG-gated high-pitch spiral acquisition is available, its use may be advantageous
Scan coverage: femoral access	Abdominal aorta above the celiac artery and down to the femoral head
Scan coverage: subclavian access	Above the subclavian arteries and down to mid-thorax
Scan coverage: combined access	Above the subclavian arteries and down to the femoral head
Slice thickness	<1 mm
Slice overlap	Small
Post-processing	Manual multi-planar reformation or semi-automated centerline reconstruction should be used to achieve cross-sectional visualization and measurement of vessel dimensions; the minimal luminal diameter along the course of the vascular access should be determined

ECG: electrocardiography, BMI: body mass index

of the aortic valve and annulus is most commonly used. Post-processing methods for assessing the aortic root and the ascending aorta have been described in detail by Achenbach et al. [24] and Leipsic et al. [29]. It is pivotal to accurately establish the size of the aortic annulus in order to optimize prosthetic device selection (Fig. 2). The required parameters and measurements for pre-procedural TAVR MDCT are summarized in Table 4 [24,25,30]. The routine MDCT measurements are illustrated in Fig. 3.

ACCESS ROUTES

The transfemoral approach is the preferred route of access for TAVR whenever feasible. Alternative routes include trans-aortic, trans-subclavian, and transapical access. Although less

commonly used, transcarotid, transcaval, and antegrade aortic routes are also possible [31]. The choice of access route depends on the prosthetic device selected, the physical properties of the corresponding delivery system, and the adequacy of the vascular routes being investigated. Prominent atherosclerotic wall calcification (specifically circumferential), too small a diameter of the native vessel (smaller than the outer diameter of the delivery sheath to be used), and marked tortuosity of the iliac arteries in the case of transfemoral approach have been identified as risk factors for procedural complications. When two or more of these features are present in the iliofemoral arteries, an alternative transapical, trans-subclavian, or transaortic approach could be considered [25,32].

Fig. 2. Steps in aortic annulus measurement. 1) Use of the double-oblique reconstruction plane method to correctly reformat the image along the valve plane (A, B, C). 2) Identification of the lowest points of all three aortic valve leaflets (red *)-the ventriculoarterial junction on one transverse image (D). 3) The bottom of the aortic root is formed by the virtual ring, the aortic annulus-the annular plane (E). The annular plane image can be used to measure the true long-axis (red line in F) and short-axis (blue line in F) annular diameters, the annular area (black area in G), and the annular perimeter (yellow circle in G).

TAVR PROCEDURE

TAVR is usually performed under general anesthesia and transesophageal echocardiography (TEE) guidance in a hybrid operating room [23]. After the access route has been secured, balloon aortic valvuloplasty is first performed to dilate the stenotic native aortic valve, allowing for a better passage of the transcatheter prosthetic device to its final position. Next, the unexpanded prosthetic device is introduced and its position checked; if the position is optimal, deployment of the prosthetic device is initiated while monitoring in a plane perpendicular to the aortic annulus. For the balloon-expandable device, balloon expansion is conducted during rapid ventricular pacing in order to minimize cardiac output and prevent device migration during deployment. In contrast, the self-expanding device does not require ventricular pacing during deployment because of its self-expanding frame, which conforms to the native aortic annulus [25]. Both improper positioning of the prosthetic device during deployment and undersizing of the annulus, which results in insufficient grip on the aortic wall, may lead to device migration (Fig. 4) [33].

POST-TAVR COMPLICATIONS

Paravalvular regurgitation

Preventing or minimizing the amount of PVR post-TAVR is essential in order to improve long-term clinical outcomes [34].

The following factors have been shown to correlate with the occurrence and severity of PVR: 1) valve undersizing, 2) incorrect positioning of the prosthetic valve, and 3) incomplete contact of the prosthetic device to the native aortic annulus due to annular/valve calcifications [25]. Some of the newer prosthetic devices with design modifications such as sealing skirts have yielded a lower PVR rate [21].

Conduction defects requiring permanent pacemaker implantation

Device expansion within the annulus may cause extrinsic compression to the atrioventricular node and bundle branch fibers due to their close anatomical proximity. Compared with their balloon-expandable counterparts, self-expanding prostheses have a higher rate of conduction disorder. This is partly attributable to their increased length, which plunges deeper into the left ventricular outflow tract (LVOT) and possibly induces a conduction deficit [23]. The number of cases requiring post-TAVR PPI has been reduced with newer prosthetic devices [21].

Cerebrovascular events

The risk of 30-day stroke after TAVR is similar across different prosthetic devices despite varied treatment approaches (e.g., 2.4% for CoreValve vs. 3.0% for Edwards Valve in one multicenter registry) [35]. With technological improvements in prosthetic devices, refined patient selection, and increased operator experience, a decline in post-TAVR stroke incidence

Table 4. Required multi-detector computed tomography parameters and measurements in pre-procedural transcatheter aortic valve replacement evaluation

Aortic annulus
Annulus short and long diameters; annulus perimeter and perimeter-based effective diameter; annulus area and area-based effective diameter (to determine prosthesis size)
Ideal fluoroscopic projection angle (for valve implantation)
Aortic valve
Length of aortic leaflets; pattern and extent of calcifications (for prevention of coronary ostium obstruction by prosthesis)
Presence of calcified cusps
Cuspidity (bicuspid, tricuspid, other variants)
Aortic root
Height and width of the sinus of Valsalva (for self-expandable prosthesis)
Distance from the aortic annulus plane to the coronary artery ostia (for balloon-expandable prosthesis)
Sinotubular junction diameter (for self-expandable prosthesis)
Aorta
Branch anatomy of aortic arch (subclavian approach; used also for embolic protection device)
Kinking or Tortuosity or elongation
Intraluminal calcification, thrombi, and dissections (transaortic approach)
Ascending aorta, aortic arch, and descending aorta diameters (for self-expandable prosthesis)
Width at 40 mm from the annulus
Position relative to the sternum
Angulation between ascending aorta and left ventricular outflow tract
Left atrium and ventricle
Thrombus in left atrial appendage? (prefer delayed phase image)
Basal septal hypertrophy and wall thrombus?
Geometry and position of the apex (transapical approach)
Subclavian and brachiocephalic arteries (trans-subclavian approach, preferred left side)
Minimal luminal diameters
Calcifications
Ilio-femoral arteries (transfemoral approach)
Minimal luminal diameters bilaterally
Tortuosity and angulation
Calcifications
Aneurysm

has been observed [35]. Although diffusion-weighted (DW) MRI has detected post-procedural ischemic brain lesions in more than two-thirds of patients, the clinical relevance of these brain lesions remains uncertain. One study that longitudinally followed patients with DW MRI-detected brain lesions reported complete resolution of the lesions after 6 months post-TAVR [36].

Occlusion of the coronary ostia

Coronary ostia may be occluded by either a malpositioned prosthetic device or displaced native valve leaflets, with a reported incidence rate of about 0.66% in one multicenter registry [37]. A close proximity of the coronary ostia to the valve annulus, bulky calcification of either the right or left valve leaflets, and a narrow sinus of Valsalva identified on MDCT imaging are the most significant predictors for this complication [23,38]. A low-lying coronary ostium (<12 mm) and a shallow sinus of Valsalva (<30 mm) are the two anatomic predictors most strongly

ly associated with coronary obstruction [37,38].

Valve thrombosis

All types of prostheses have thin leaflets (<0.35 mm), typically thinner than those of surgical valves, and normally appear as fine hypodense lines on MDCT. Studies have shown that thickening of one or more prosthetic valve leaflet on MDCT is indicative of valve thrombosis and is associated with a moderate increase in trans-prosthetic gradients. It is also speculated that this finding may be associated with an increased risk of thromboembolic events and reduced valve durability. With the use of MDCT for post-TAVR evaluation, subclinical prosthetic valve thrombosis has been increasingly recognized [12,39,40].

Injuries to the aorta and left ventricle

Aortic dissection (Fig. 4), rupture of the aortic root, and injury to the left ventricle are rare but life-threatening complications

Fig. 3. Demonstration of multi-detector computed tomography measurements for pre-procedural transcatheter aortic valve replacement evaluation. (A) After sequential double-oblique reconstructions, all parameters including (B) maximal diameter, minimal diameter, average diameter and perimeter of the aortic annulus, (C) the distance from the annulus plane to the left coronary artery ostia, (D) the distance from the annulus plane to the right coronary artery ostia, (E) the aortic root angle, (F, G, H, I) the luminal diameter of bilateral subclavian arteries, (J, K, L, M) the luminal diameter of bilateral common iliac arteries, and (N, O, P, Q) the luminal diameter of bilateral femoral arteries were measured.

of TAVR [41–43]. Aortic root rupture is more frequently encountered if balloon-expandable prosthetic devices are used in patients with calcified LVOT, particularly when the prostheses are aggressively oversized [44].

Complications at the access routes

Pseudoaneurysms, arteriovenous fistulas, and hematoma may occur at any of the peripheral vascular access sites for TAVR [33].

POST-PROCEDURE EVALUATION

Current guidelines recommend that patients who have under-

gone TAVR should undergo transthoracic echocardiography before hospital discharge. The role of MDCT in the immediate post-procedure follow-up is limited. Echocardiography should be routinely performed within 30–90 days to establish baseline valve function, at 1 year after TAVR, and annually thereafter. Transvalvular gradient, the presence and the degree of PVR/central regurgitation, and the overall left ventricular function should be monitored during echocardiography (Fig. 5) [12].

Although its utility has not been fully established, MDCT angiography may be helpful in triaging patients who develop new onset of symptoms after a TAVR procedure. In addition, MDCT with multi-phase reconstruction and cine imaging offers evalu-

Fig. 3. Demonstration of multi-detector computed tomography measurements for pre-procedural transcatheter aortic valve replacement evaluation. (A) After sequential double-oblique reconstructions, all parameters including (B) maximal diameter, minimal diameter, average diameter and perimeter of the aortic annulus, (C) the distance from the annulus plane to the left coronary artery ostia, (D) the distance from the annulus plane to the right coronary artery ostia, (E) the aortic root angle, (F, G, H, I) the luminal diameter of bilateral subclavian arteries, (J, K, L, M) the luminal diameter of bilateral common iliac arteries, and (N, O, P, Q) the luminal diameter of bilateral femoral arteries were measured.

ation of the morphology, position, expansion as well as the dynamic movement of the prosthesis valve leaflets [39]. Hypokinesia of a thickened prosthetic leaflet usually suggests dysfunction of the prosthetic device. The post-TAVR MDCT protocol we recommended is summarized in Table 5 [33].

SPECIAL ISSUES IN THE ASIAN POPULATION

The number of candidates for TAVR is expected to rise in Asia, especially in the North Eastern region of Asia where elderly populations are growing. Some anatomical features specific to

Fig. 4. A 91-year-old female with severe aortic valve stenosis underwent TAVR (Medtronic Evolut R 29 mm valve). Post-TAVR multi-detector computed tomography in (A) axial (B) sagittal and (C) coronal views showed concomitant migration of the prosthetic device into the ascending aorta and type A aortic dissection, which progressed to cardiac tamponade and led to her death within one day after the TAVR. TAVR: transcatheter aortic valve replacement.

Fig. 5. An 81-year-old female with severe aortic valve stenosis being treated with TAVR (Medtronic CoreValve). Both immediate post-TAVR transthoracic echocardiography in long axial view (A) and transthoracic echocardiography 30 days after TAVR (B) revealed color jets (red arrow) running in between the prosthetic device (yellow arrows) and the aortic wall, indicating moderate paravalvular regurgitation. Ao: aorta, LA: left atrium, LV: left ventricle, TAVR: transcatheter aortic valve replacement.

Asian patients may cause more complications and lead to increased mortality. The more prevalent small annulus and lower left coronary height in an Asian cohort is associated with a higher incidence of coronary obstruction (approximately 1.3%). In addition, the prevalence of bicuspid aortic valve (BAV) has been reported to be greater than 5.8% in Asians, which is higher than rates reported in Europe and North America (1.3% to 4.7%) [45-47].

MINIMALIZED INVASIVENESS OF TAVR

The core strength of TAVR lies in its minimal invasiveness. The advantages of TAVR over SAVR include decreased procedural time, lower complication rates, shortened hospital length of stay, and reduced cost. However, studies on how to safely and efficaciously perform the procedure without the need for general anesthesia or TEE guidance are still ongoing [20,48-50].

BICUSPID AORTIC VALVES

BAV-a common congenital anomaly-is susceptible to mechanical shear stress, which over time causes fibrosis, calcification, and stenosis of the valve (Fig. 6). The phenotypes of BAV are classified based on the presence or absence of raphe (commissural fusion) and the number of raphe if present. In Sievers' classification, BAV is described as follows: type 0, without raphe; type 1, with one raphe; and type 2, with two raphes. BAV Imaging classification categorizes BAV into three types: tricommissural, bicommissural raphe, and bicommissural non-raphe [51,52]. In two Asian multicenter studies more than 95% of BAV was documented as the bicommissural type, 62-93% of which were the non-raphe subtype [51,53]. Evidence has shown that due to the abnormal geometry and eccentricity of the native bicuspid valve and the often co-existing dilatation of the ascending aorta, patients with BAV receiving TAVR may be predisposed to

Table 5. Post-procedural transcatheter aortic valve replacement multi-detector computed tomography protocol recommendations

Aortic root recommended parameters

IV injection with iodine contrast	80–100 mL (320 mg/mL or higher), modify for each patient as appropriate; reduced contrast and adherence to protocols is recommended for prevention of contrast-induced nephropathy
Injection rate	4–6 mL/sec
Bolus tracking, delay	Delay time calculated using protocol for current scanners (bolus tracking or similar) with the peak of contrast concentration in the ascending aorta during acquisition
ECG leads	Required
ECG-gating	Retrospective; whole cardiac cycle
Scan direction	Cranial-caudal
Scan coverage	From above the aortic arch to past the cardiac apex
Detector collimation	0.4–0.625 mm
Pitch	0.2–0.43 adapted to the heart rate
Dose modulation	100–120 kV, auto mAs
Slice thickness	≤1 mm
Slice overlap	0.4 mm
Reconstruction kernel	Medium smooth
Post-processing	Ten equally spaced phases along the cardiac cycle for evaluation of the aortic root and prosthetic valve “Cine” imaging for dynamic evaluation of the prosthetic valve

ECG: electrocardiography

Fig. 6. (A) A 63-year-old male with severe AS. Transverse MDCT image showed a Sievers classification type 0 (without raphe) BAV with prominent leaflet calcification. Surgical aortic valve replacement was performed due to his heavily calcified BAV. (B) A 59-year-old male with mild AS. Transverse MDCT image showed a Sievers classification type 1 (raphe and two commissures) BAV. He was medically treated and advised to follow up. AS: aortic valve stenosis, MDCT: multi-detector computed tomography, BAV: bicuspid aortic valve.

mal-apposition, inadequate anchoring, and improper positioning of the prosthesis, resulting in significant PVR and prosthetic malfunction [20,54,55]. Although current guidelines advise against TAVR as the first-line treatment for severe AS in the setting of congenital BAV, more recent evidence from observational studies has shown that TAVR for bicuspid AS patients yielded a low 30-day mortality rate and, perhaps more importantly, a high success rate comparable to that of TAVR for tricuspid AS patients, especially if newer generations of prosthetic devices are used. Nevertheless, a higher complication rate of significant PVR and PPI in the BAV group was still observed [56–58]. More stud-

ies on BAV with respect to the methodology of annular sizing, valvular shape and function, the durability of prosthesis devices, and concomitant aortopathy in BAV patients, in addition to outcome studies and randomized controlled trials particularly targeting younger BAV patients, are required before drawing final conclusion [59,60].

CONCLUSION

TAVR still faces some challenges. The suboptimal results of TAVR in patients with BAV require further study. Issues regard-

ing the feasibility of TAVR in younger patient groups, the long-term durability of the prosthetic devices, the introduction of a more personalized prosthesis device catering to individual needs, and many more issues should be addressed in the future.

MDCT is the recommended image modality for pre-procedural planning of the TAVR procedure. TAVR MDCT should be performed by well-trained personnel and interpreted and analyzed by experienced radiologists who not only have a sound understanding of TAVR with respect to its indications, prosthetic devices, procedure, and complications but also work in close collaboration with the Heart Team.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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