Role of Advanced Cardiac Imaging in Transcatheter Aortic Valve Replacement Planning

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INTRODUCTION
The fast development of transcatheter aortic valve replacement (TAVR) would not have been possible without the invaluable collaboration of multimodal cardiac imaging, particularly transesophageal echocardiography (TEE) and computerized axial tomography (CT scan). Given the elevated morbimortality associated with severe aortic stenosis (AS) presenting high surgical risk, an adequate selection of TAVR candidates is of vital importance for the program’s success. (1) This review describes the role of these techniques for the appropriate selection of candidates, vascular access route evaluation and procedure planning in patients with severe AS considered at high surgical risk.

OBJECTIVES OF IMAGING EVALUATION
The main objectives in the pre-procedural stage include:
1. Ensuring that the patient has a suitable access for the intended route.
2. Ensuring that the selected devise can be implanted safely and successfully based on the aortic valve characteristics and the anatomical relationships between the aortic valve, the aortic root, the left ventricle (LV) and the coronary ostia.
3. Selection of the appropriate device size.

EVALUATION OF THE ILIOFEMORAL ACCESS ROUTE
One of the major challenges encountered using the large introducer sheath required by TAVR, is a detailed assessment of the iliofemoral arterial system in order to prevent feared vascular complications. Effectively, in the PARTNER study, vascular complications occurring in 15.3% of patients were strongly associated with short and long-term mortality. (2)

Angiography
Standard vascular access evaluation is initiated with a conventional angiography, since after undergoing a coronary angiography all patients are referred to routine thoracic aorta, abdominal aorta and iliofemoral system angiography, which provides initial information regarding vessel size and their degree of atheromatosis, calcification and tortuosity.

Computerized axial tomography
Due to its advantages over the known limitations of angiography, CT angiography has become the standard evaluation of iliofemoral access prior to TAVR. As renal function often limits the possible amount of administered contrast agent in these patients, the study can be simplified – immediately after the invasive study –with a mixture of 20 cm³ contrast agent injected through a 4-5 Fr pigtail catheter placed in the infrarenal abdominal artery, at 4 cm³/s during 10 seconds, followed the bolus injection of 60 cm³ saline solution (Figure 1). (3)

Subsequently, minimum arterial diameters obtained from axial sections perpendicular to the major vessel axis must be assessed methodically and in detail. In addition, the degree of calcification and angulations/tortuosities must be examined. In the absence of significant calcification (> 180º calcification in axial section), great atheromatosis or severe tortuosity (> 90º), the lowest diameter of each arterial segment is required to be at least 1 or 2 mm above the projected introducer external diameter to allow safe cannulation. (4) In case this is not possible, alternative approaches, as transapical, transaxilar or transthoracic accesses should be considered. (5)

AORTIC ROOT EVALUATION
The aortic root evaluation should include precise and systematic measurement of:
1. Aortic annulus size.
2. Degree and distribution of aortic valve apparatus calcifications.
3. Localization of coronary ostia.
4. Other factors which may influence the therapeutic plan, as degree of atheromatous disease and aortic arch and ascending aorta diameters.

Transesophageal echocardiography
Current evaluation of patient eligibility for TAVR, including choice of prosthesis size, relies mainly on TEE.
Aortic valve annulus sizing is performed at the level of aortic cusp insertion points or hinge points, establishing the size of the device to be employed. These measurements must be performed with a midesophageal long axis axial view (110° to 140°, “3-chamber view”) during early systole. Once perfect longitudinal alignment of the ventricular chamber with the left ventricular outflow tract and the ascending aorta is obtained—to ensure that the sagittal plane cuts the annulus at its maximum diameter—maximum aortic annulus diameter is measured from the sinus border to the right coronary sinus hinge point (Figure 2).

Oblique or out-of-plane measurements are an important source of error in annulus size estimation. Moreover, it is important to avoid including large commissural or ectopic calcification measurements, which could lead to annulus size overestimation. It should be recalled that important cyclic variations may occur in the position of the sagittal plane due to respiration or within the RR interval.

The new generations of biplane ultrasound machines allow simultaneous acquisitions in the short axis and long axis planes, aiding in the identification of the aortic annulus transverse plane, especially in cases of limited echocardiographic window. On the other hand, initial evidence suggests three-dimensional TEE would be a more accurate alternative reducing possible measurement errors, though more data is still needed to confirm these findings.

Additionally, the echocardiogram allows evaluating other important aspects in the selection of TAVR candidates, as presence of severe mitral regurgitation, severe left ventricular systolic dysfunction or severe pulmonary hypertension. Although presence of these criteria could contraindicate TAVR due to the adverse associated outcomes, balloon aortic valvuloplasty may be employed as a selection methodology, assessing the improvement of these parameters as therapeutic proof.

Computerized axial tomography
Electrocardiogram (ECG)-gated CT angiography or cardiac CT scan have improved our understanding of the three-dimensional anatomical structure of the aortic root, providing images that can be reconstituted in different angles and planes. Actually, the aortic root has a typically oval rather than circular shape, as demonstrated in studies comparing different images. Unlike TEE which measures the aortic diameter from a long axis view, CT scan enables assessment in all its dimensions.

The minimum standards to perform an appropriate cardiac CT scan in patients who are candidates for TAVR require a multislice equipment of at least 64 detectors with possibility of acquiring ECG-gated images (described in detail in Table 1).

Strong current evidence support the routine use of cardiac CT scan to size aortic valve annulus and prosthesis selection, as it is associated to significant reduction of paravalvular aortic regurgitation (PAR) rate. Other PAR determinants, such as aortic annulus eccentricity, extension and asymmetric distribution of annulus and commissural calcium, are proficiently assessed by cardiac CT scan.

Special interest deserves assessment of the distance between coronary artery origin and valve annulus, to establish the risk of coronary occlusion during TAVR. A distance below 10 mm is considered as
high risk, especially in the presence of long leaflets and elevated degree of calcification. (13) Cardiac CT scan allows identifying the best projection for prosthesis implantation/deployment, which has to be performed with X-ray emission perpendicular to the valve plane to ensure tangential visualization of the three Valsalva sinuses. Using methods that determine these angles automatically has been shown to reduce radioscopy times, contrast volume and periprocedural renal failure rate, together with a decrease in inappropriate device position and PAR rate. (14) Usefulness of cardiac CT scan has also been suggested in transapical surgical access planning in patients with previous cardiac surgery. Although bicuspid aortic stenosis has traditionally been a contraindication for patient selection in randomized studies, recent clinical series suggest that presence of bicuspid aortic stenosis with a “pseudo” raphe identified by tomography—as occurs in most cases—would enable safe TAVR if the device fits the annulus dimensions. (15)

It should be pointed out that the emphasis of the study in patients with severe AS should be centered on a multidisciplinary approach, where multimodal images are essential, especially the appropriate integration of images obtained by echocardiography and cardiac CT scan.
HOW IS THE AORTIC VALVE ANNULUS SIZED PROPERLY?

Same as with TEE, aortic annulus sizing is performed at the level of aortic leaflet insertion or hinge points, immediately below which is the left ventricular outflow tract and immediately above the aortic root sinus.

In a working station with adequate software to process tomographic images in multiplanar reconstruction mode, coronal, sagittal and transverse (double oblique axial) sections are obtained, with the three planes blocked at 90º angles. Use of the systolic phase, 30-40% of the RR interval, is recommended for this measurement, though it is preferable to use the best quality sequence, if this were not obtained in the systolic phase.

To identify the aortic annulus we recommend following the method described by Kasel et al (16), referred to as the turn around rule. First, position the cursor in the middle of the aortic root, aligning the long axis of the coronal and sagittal planes (double oblique planes) (Figure 3A). Second, the axial plane must be aligned at the leaflet level, shifting this plane from the aorta towards the ventricle until the most caudal leaflet insertion point (hinge point) appears (Figure 3A). Finally, the transverse plane (axial) must be rotated around its own axis to align the longitudinal planes and thus ensure that each of the three hinge points is individually touched by the transverse plane (Figure 3A).

Once the aortic annulus is defined, maximum, minimum, and mean diameter, perimeter and area are determined (Figure 3B) The aortic annulus can also be measured in oblique coronal and oblique sagittal planes to verify the measurements performed in the axial plane (Figure 3C).

As previously mentioned, prosthesis selection based on annulus perimeter and area measurement seems to reduce PAR rate, (9) so there is already available information regarding the most appropriate prosthesis size, according to concordant annulus diameters and annulus perimeter and area (Table 2).

CONCLUSIONS

The current study of patients with severe AS at high surgical risk must be based on a multidisciplinary...
approach for which multimodal images are essential, especially the appropriate integration of images obtained by echocardiography and cardiac CT scan. Based on existing evidence, we recommend the routine use of CT angiography to evaluate the access route and appropriate device selection, as well as procedure planning.

Conflicts of interest
Dr. Maluenda is proctor for Edwards Lifescience. Doctor Matias Sztejfman is a consultant at Medtronic Inc.

REFERENCES


Table 2. Recommended size for CoreValve® (Medtronic Inc) and SAPIEN XT® (Edwards Lifescience) prosthesis according to tomographic aortic annulus measurements

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Diameter range (mm)</th>
<th>Perimeter range (mm)</th>
<th>Area range (mm²)</th>
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<tbody>
<tr>
<td>CoreValve®</td>
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<tr>
<td>23 mm</td>
<td>18-20</td>
<td>56.5-62.8</td>
<td>254.5-314.2</td>
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<td>26 mm</td>
<td>20-23</td>
<td>62.8-72.3</td>
<td>314.2-415.5</td>
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<td>29 mm</td>
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<td>72.3-84.8</td>
<td>415.5-572.6</td>
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<td>31 mm</td>
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<td>81.7-91.1</td>
<td>530.9-660.5</td>
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<td>23 mm</td>
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<td>60.0-71.0</td>
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<td>29 mm</td>
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