OPINION ARTICLE

Role of Advanced Cardiac Imaging in Transcatheter Aortic Valve Replacement Planning

GABRIEL MALUENDA[1, 2], MIGUEL OYONARTE[1], MATÍAS SZTEJFMAN[3]

INTRODUCTION

The fast development of transcatheter aortic valve replacement (TAVR) would not have 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 coronariography 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 therapeu tic 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.

Received: 11/18/2013 *Accepted:* 01/09/2014
Address for reprints: Dr. Gabriel Maluenda, Centro Cardiovascular, Hospital San Borja Arriarán, Universidad de Chile, Av. Santa Rosa 1234 Santiago, Chile. Tel. +56-2-574-9342. e-mail: gabrielmaluenda@gmail.com

Rev Argent Cardiol 2014;82:129-133 - http://dx.doi.org/10.7775/rac.82.i1.3513

[MTSAC] Cardiovascular Center, Hospital Clínico San Borja Arriarán, Universidad de Chile. Santiago, Chile
[2] Departament of Cardiology, Clínica Alemana. Santiago, Chile
[3] Departament of Cardiology, Sanatorio Güemes. Buenos Aires, Argentina

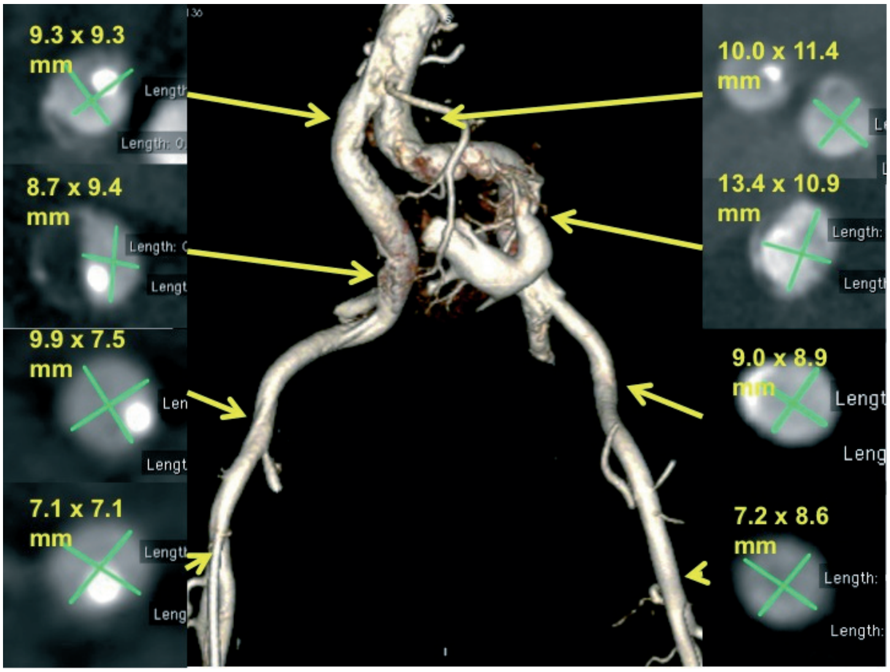

Fig. 1. Iliac artery CT angiography obtained with 20 cm3 contrast injection through a pigtail catheter positioned in the infrarenal abdominal artery

(6) 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 (110º to 140º, "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). (7)

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, (8) 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. (9)

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. (10) 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. (11) 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

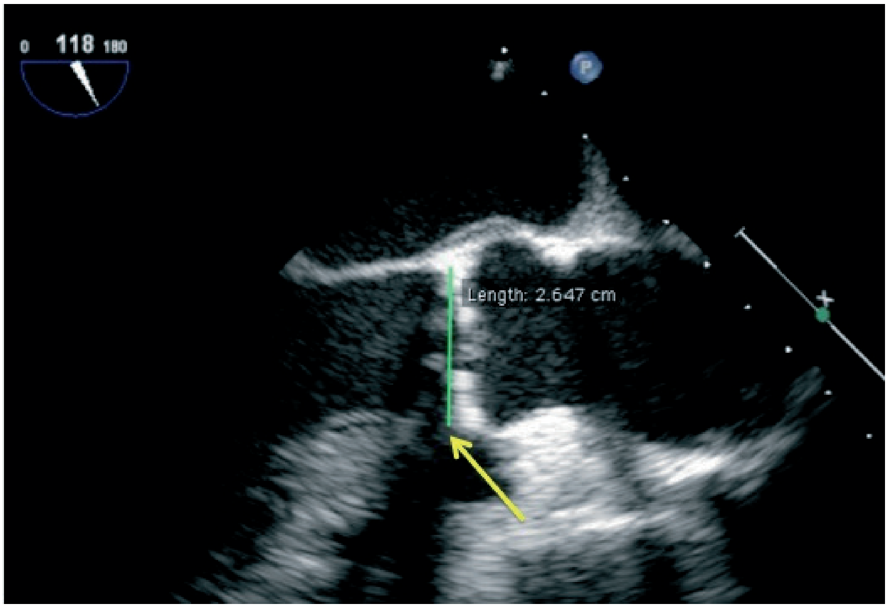

Fig. 2. Aortic annulus sizing performed by transesophageal echocardiography in a "3 chamber view", after aligning the left ventricle, the left ventricular outflow tract and the aortic root. Maximum annulus diameter is measured from the sinus border to the hinge point of the right coronary sinus (*arrow*).

Table 1. Cardiac CT angiography requirements to evaluate candidates for transcatheter aortic valve replacement

Multislice equipment having at least 64 detectors and possibility for acquiring electrocardiogram-gated images
- Obtain standard gated images without contrast in all patients to assess calcium
- Obtain retrospective gated images with acquisition of the whole cardiac cycle
- Make a standard sweep from the diaphragm to the aortic arch (including the aortic arch)
- In case of previous sternotomy also include both internal mammary arteries from their origin
- Normally, inject 80-90 ml of contrast agent, similarly to coronary protocol for a 64-detector scanner, which may be reduced to 70 ml or less in case of scanners with more than 128 detectors.
- Generate systolic images (30-40% of the RR cycle) for aortic root measurement analysis, and im ages of the complete cycle (0 to 90% of the RR cycle) for motility and valve function analysis.
To perform peripheral CT angiography at the same time as cardiac CT angiography
- Program acquisition for a second not gated sweep, from the diaphragm to femoral artery bifurcation.
- It is possible that in 64-detector equipments, abdominopelvic image acquisition requires a second IV contrast injection. In this case, it is recommended to separate both acquisitions and perform them at different times (> 48 hours)
- Alternatively, especially in patients with significant renal failure, excellent quality images may be obtained with only 20 ml of contrast agent injected through a 5 Fr pigtail catheter placed in the infrarenal abdominal artery, followed by a bolus injection of 60 ml physiological solution

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 3 A).

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

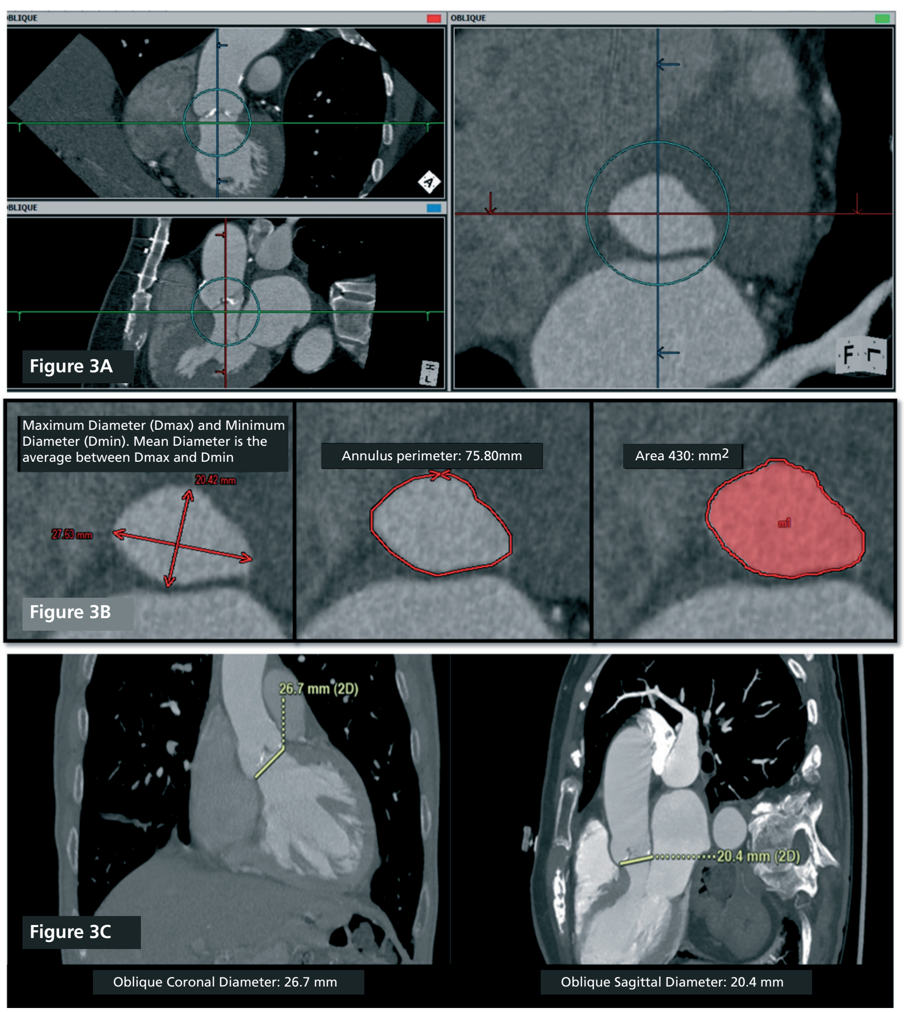

Fig. 3. Tomographic images for aortic annulus identification (**A**), axial plane (**B**) and sagittal and coronal plane dimension measurements (**C**).

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

CoreValve®	Diameter range (mm)	Perimeter range (mm)	Area range (mm2)
23 mm	18-20	56.5-62.8	254.5-314.2
26 mm	20-23	62.8-72.3	314.2-415.5
29 mm	23-27	72.3-84.8	415.5-572.6
31 mm	26-29	81.7-91.1	530.9-660.5
SAPIEN XT®			
23 mm	19-22	60.0-71.0	300-400
26 mm	23-25	72.0-80.5	410-520
29 mm	26-28	81.5-88.0	530-620

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 Matías Sztejfman is a consultant at Medtronic Inc.

REFERENCES

1. Ben-Dor I, Pichard AD, Gonzalez MA, Weissman G, Li Y, Goldstein SA, et al. Correlates and causes of death in patients with severe symptomatic aortic stenosis who are not eligible to participate in a clinical trial of transcatheter aortic valve implantation. Circulation 2010;122:S37-42. http://doi.org/cqsq6p

2. Généreux P, Webb JG, Svensson LG, Kodali SK, Satler LF, Fearon WF, et al. PARTNER Trial Investigators. Vascular complications after transcatheter aortic valve replacement: Insights from the PARTNER (Placement of AoRTic TraNscathetER Valve) trial. J Am Coll Cardiol 2012;60:1043-52. http://doi.org/f2mwmp

3. Joshi SB, Mendoza DD, Steinberg DH, Goldstein MA, Lopez CF, Raizon A, et al. Ultra-low-dose intra-arterial contrast injection for iliofemoral computed tomographic angiography. JACC Cardiovasc Imaging 2009;2:1404-11. http://doi.org/cthtpg

4. Kurra V, Schoenhagen P, Roselli EE, Kapadia SR, Tuzcu EM, Greenberg R. Prevalence of significant peripheral artery disease in patients evaluated for percutaneous aortic valve insertion: preprocedural assessment with multi-detector computed tomography. J Thorac Cardiovasc Surg 2009;137:1258-64. http://doi.org/fwht5j

5. Masson JB, Kovac J, Schuler G, Ye J, Cheung A, Kapadia S, et al. Transcatheter aortic valve implantation: review of the nature, management, and avoidance of procedural complications. JACC Cardiovasc Interv 2009;2:811-20. http://doi.org/dv2xkk

6. Jayasuriya C, Moss RR, Munt B. Transcatheter aortic valve implantation in aortic stenosis: the role of echocardiography. J Am Soc Echocardiogr 2011;24:15-27. http://doi.org/cz9hjs

7. Zamorano JL, Badano LP, Bruce C, Chan KL, Gonçalves A, Hahn RT, et al. EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for valvular heart disease. J Am Soc Echocardiogr 2011;24:937-65. http://doi.org/ch8464

8. Ng AC, Delgado V, van der Kley F, Shanks M, van de Veire NR, Bertini M, et al. Comparison of aortic root dimensions and geometries before and after transcatheter aortic valve implantation by 2- and 3-dimensional transesophageal echocardiography and multislice computed tomography. Circ Cardiovasc Imaging 2010;3:94-102. http://doi.org/fbwj3b

9. Ben-Dor I, Pichard AD, Satler LF, Goldstein SA, Syed AI, Gaglia MA Jr, et al. Complications and outcome of balloon aortic valvuloplasty in high-risk or inoperable patients. JACC Cardiovasc Interv 2010;3:1150-6. http://doi.org/c33j84

10. Piazza N, Lange R, Martucci G, Serruys PW. Patient selection for transcatheter aortic valve implantation: patient risk profile and anatomical selection criteria. Arch Cardiovasc Dis 2012;105:165-73. http://doi.org/qxw

11. Jilaihawi H, Kashif M, Fontana G, Furugen A, Shiota T, Friede G, et al. Cross-sectional computed tomographic assessment improves accuracy of aortic annular sizing for transcatheter aortic valve replacement and reduces the incidence of paravalvular aortic regurgitation. J Am Coll Cardiol 2012;59:1275-86. http://doi.org/f2nck7

12. Généreux P, Head SJ, Hahn R, Daneault B, Kodali S, Williams MR, et al. Paravalvular leak after transcatheter aortic valve replacement: the new Achilles' heel? A comprehensive review of the literature. J Am Coll Cardiol 2013;61:1125-36. http://doi.org/f2f3t4

13. Ribeiro HB, Nombela-Franco L, Urena M, Mok M, Pasian S, Doyle D, et al. Coronary obstruction following transcatheter aortic valve implantation: a systematic review. JACC Cardiovasc Interv 2013;6:452-61. http://doi.org/qxx

14. Samim M, Stella PR, Agostoni P, Kluin J, Ramjankhan F, Budde RP, et al. Automated 3D analysis of pre-procedural MDCT to predict annulus plane angulation and C-arm positioning: benefit on procedural outcome in patients referred for TAVR. JACC Cardiovasc Imaging 2013;6:238-48. http://doi.org/qxz

15. Maluenda G, Araya M, Ibañez-Arenas R. Successful transfemoral aortic valve replacement in a bicuspid aortic stenotic valve: Requirements for a safe implant. Catheter Cardiovasc Interv 2013;82:e826-30. http://doi.org/qx2

16. Kasel AM, Cassese S, Bleiziffer S, Amaki M, Hahn RT, Kastrati A, et al. Standardized imaging for aortic annular sizing: implications for transcatheter valve selection. JACC Cardiovasc Imaging 2013;6:249-62. http://doi.org/qx3