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MDCT IMAGING BEFORE TRANSCUTANOUS AORTIC VALVE IMPLANTATION: RATIONALE AND MEASUREMENTS

L. Ardies[1], Th. Vancauwenberghe[1], T. De Beule[1], M. de Booij[2], P.K. Vanhoenacker[1]

Since its introduction in 2002, transcatheter aortic valve implantation (TAVI) has assumed growing importance in the treatment of patients with severe aortic stenosis (AS), because it offers a much less invasive alternative for those in high risk for surgery. Good early results and advances in percutaneous valve technology have led to a substantial increase in procedural success rate and number of patients undergoing this less invasive treatment.
Pre-procedural screening of several anatomic factors to assess the feasibility of this technique is important. Multi-detector row computed tomography (MDCT) is the technique of choice in assessing these factors. This technical note aims to describe and illustrate the key elements that need to be evaluated before the procedure.

Key-word: Aortic valve.

Aortic valve stenosis is one of the most frequent causes of valvular disease in the elderly population and is often associated with other cardiovascular comorbidities causing these patients to be at high risk for surgery. A study by lung et al. (1) showed us that about 33% of patients with severe AS and severe symptoms are high-risk candidates for surgery. This emphasizes the need for a minimal invasive technique in this population of patients. Since its first use in 2002 (2), TAVI has become a good alternative for high-risk patients. Procedural success rates between 93-95% and low 30 day mortality rate (3) have led to a dramatic increase in percutaneous procedures and development of new devices.

Although TAVI is less invasive than conventional valve replacement, it needs an accurate preprocedural workup and patient selection to minimize complications and maximize success. Cardiovascular imaging plays an important role in screening and optimal patient evaluation.

At the moment 2 TAVI technologies have received CE-approval (Fig. 1): the CoreValve technology and the Cribier Edwards SAPIEN valve. The CoreValve technique uses a self-expanding valve with an 18 French delivery system, which allows access to the femoral or subclavian artery. The Edwards SAPIEN on the other hand is a balloon-expendable valve with a 24-26 French delivery system, thus only suitable for a retrograde transfemoral or anterograde transapical approach.

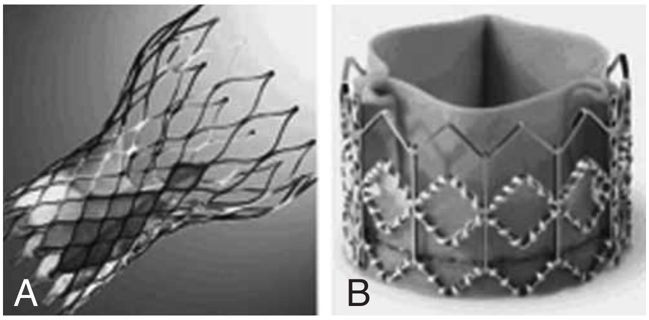

Fig. 1. — A. CoreValve. B. Edwards SAPIEN

Pre-operative imaging

As mentioned before, preprocedural TAVI planning heavily relies on imaging for patient selection and sizing (4). However, to date there isn't a gold standard for evaluating the aortic valve (5). Echocardiography has emerged as the method of choice in evaluating hemodynamic status and severity of aortic stenosis. However, transthoracic echocardiography may lead to suboptimal results in patients with poor acoustic windows (thick or deformed chest walls, small hearts, obesity, and pulmonary disease). In addition, echocardiography is very operator dependent and limited in quantifying aortic valve calcification, since only indirect signs, such as increased echogenicity and thickening of the aortic valve leaflets are usable. Further, echocardiography is limited by its 2-dimensional character, making it difficult to make correct calculations of the aortic root diameters. Due to the complex anatomy of the aortic root and annulus an adequate 3D imaging modality is required for accurate reproduction of aortic root and annulus measurements (6). Multidetector computed tomography (MDCT) has the advantage of providing reproducible 3-dimensional images with a high spatial and temporal resolution, emerging it as a promising method for non-invasive valve and coronary imaging. Further MDCT has the merit of evaluating peripheral artery and thoracic aorta anatomy and morphology and revealing several incidental nonvascular findings. Still, the major drawback of using MDCT for imaging is the limitation in repetitive scanning because of the hazardous radiation, although development of the new generation MDCT's has led to significant reduction in radiation dose (7-9).

Scan protocol

All our pre-TAVI examinations are performed with a 128 multi-detector row computed tomography (CT) scanner (Somatom Definition Flash, Siemens Erlangen, Germany), upgraded to allow low-dose acquisitions (Caredose4D, Siemens). Collimation was 128 x 0,6 mm. Tube voltage was 120 kV and current 340 mAs. At our institution we seper-

From: 1. Department of Radiology and Imaging, OLV Ziekenhuis, Aalst, Belgium and 2. Department of Radiology, Atrium MC Parkstad, Heerlen, The Netherlands.
Address for correspondence: Dr L. Ardies, M.D., OLV Ziekenhuis Aalst, Moorselbaan 164, B-9300 Aalst, Belgium. E-mail: lenz_ardies@hotmail.com

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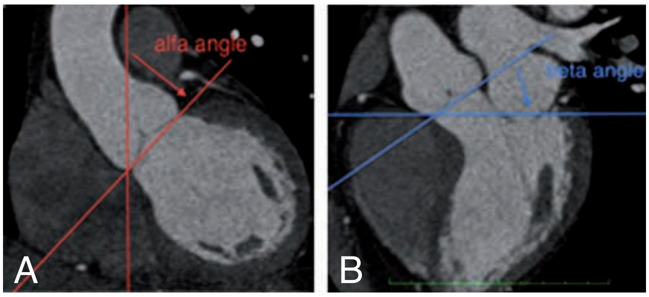

Fig. 2. — A: The lateral angulation (alpha angle, red line), measured on the coronal view. B: The cranio-caudal angulation (beta angle, blue line), measured on the sagittal view.

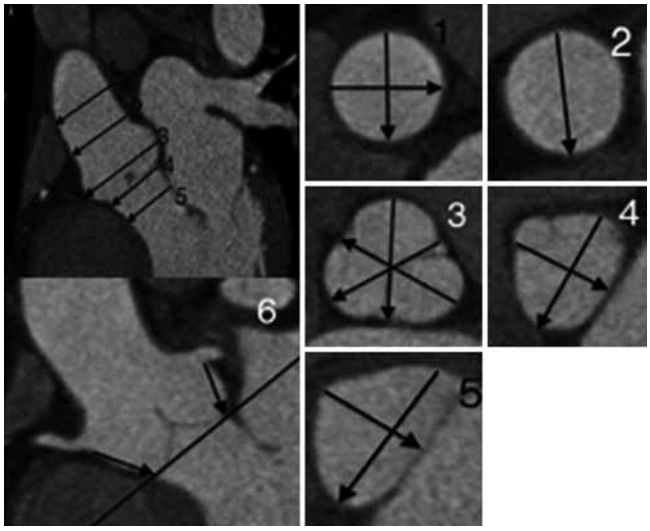

Fig. 3. — Double oblique transverse view, 1: Ascending aorta maximum diameter, 2: Sino-tubular junction maximum diameter, 3: Sinus of Valsalva maximum diameter, 4: Aortic valve annulus maximum and minimum diameter. 5: double oblique transverse view, left ventricle outflow tract maximum and minimum diameter. 6: coronal view in systole of the height of the coronary ostia relative to the aortic valve annular plane.

atly aqcuire images of the the heart and iliac arteries, instead of scanning them in one volume. Cardiac images are obtained with prospective triggering at the 70% phase of R-R cardiac cycle to ensure minimum motion artifacts, under electrocardiographic gating and with longitudinal coverage of the entire thoracal aorta. Gantry rotation time was 280 ms. For the aqcuisition of the iliac arteries, we use a longitudinal coverage of the infrarenal aorta, iliac and common femoral arteries and a gantry rotation time of 500 ms.

A bolus of 100 ml contrastmedium (Iopromide 370 mg/ml <Ultravist, Bayer Schering Pharma AG, Berlin, Germany>) was given intravenously at 5 ml/s for scanning of the heart, followed by a second bolus of 20 ml for scanning of the infrarenal aorta and iliacs. To ensure optimal contrast enhancement bolus tracking was used at the aorta ascendens level, with the trigger at 100 HU. No beta-blockers were administered.

Computed data were processed using a B30f medium-smooth kernel. Thickness of reconstructed images was 0.6 mm. Data were sent to an external workstation (Vitrea Core 1.3, Vital) where images were analyzed.

Image analysis

We first measured the angulation of the aortic valve plane, combining the lateral angulation calculated from the coronal plane, and cranio-caudal angulation from the sagital view, as described by Decramer et al (10) (Fig. 2).

To measure the aortic annulus diameter we used a 2-step method. The first step was based on a double oblique transverse view with reconstruction of a plane including the aortic root, the left ventricular outflow tract, and the left atrium and ventricle (3-chamber view), where we could measure the diameter of the annulus at the hinge points of the leaflets. Second, we obtained a slice perpendicular to the aortic root and measure the diameters of the ascending aorta, the sino-tubular junction, the sinus of Valsalva, the aortic valve annulus and the left ventricle outflow tract (Fig. 3).

Contribution of MDCT to preoperative screening and presurgical work-up

Adequate sizing and probe selection are required for correct apposition of the prosthesis into the native aortic root leading to optimal prosthesis stability post-deployment and minimal potential paravalvular leakage or prosthesis migration. Due to the complex anatomy of the aortic root and aortic annulus an accurate 3D imaging technique will be mandatory to acquire sufficient data for reliable reconstruction of the aortic anatomy. In contrary to 2D TTE and TEE, MDCT offers superb spatial and temporal resolution needed for precise reconstruction of the several anatomic dimensions important for preprocedural TAVI planning (11).

Several studies (12,13) have revealed that the annulus has an oval shape instead of a circular one, which might help explain differences in measured aortic annular diameters using TEE, TTE and calibrated angiography (14). These findings suggest that minimum and maximum diameters should be taken in the axial plane to calculate the mean diameter or area of the aortic valve annulus providing more accurate selection of the prosthesis size. Determining inclination of the aortic valve (angle α and β) (Fig. 2) will also be of importance for successful percutaneous aortic valve replacement. Defining the correct plane with MDCT avoids having multiple “trial and error” angiographic series before the optimal plane is found.

Exact anatomical knowledge of the aortic root is needed for accurate positioning of the prosthesis in the aortic annulus, especially when using the corevalve prosthesis, as an extremely narrow or wide aortic root might be a contraindication for this type of probes (15). Measurements of the aortic root dimensions include maximum diameters of the ascending aorta, the sino-tubular junction, the sinus of Valsalva, and maximum and minimum diameters of the aortic valve annulus and the left ventricle outflow tract (Fig. 3).

It is also important to measure the height of the coronary ostia relative to the aortic valve annular plane to avoid covering of the coronary ostia by the upper part of the prosthesis or one of the native leaflets (Fig. 3) (15,16).

Furthermore, location and quantifying the degree of aortic valve calcifications (Fig. 6) is important,

Fig. 4. — MDCT images. A. Normal iliofemoral arteries, (B) Circumferential iliofemoral calcification. (C) Severe iliofemoral tortuosity. B and C are illustrations of iliac arteries which are considered as a contra-indication for TAVI placement, as they don't allow safe passage of the prosthesis into the aorta and increase the risk of local vascular complications and formation of emboli.

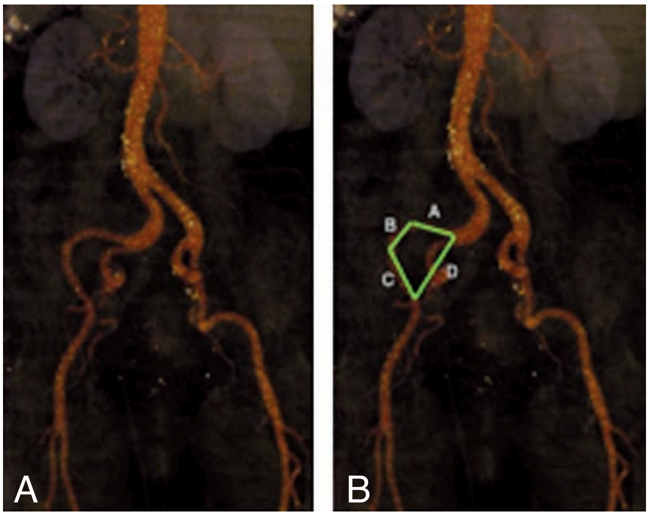

Fig. 5. — Example of a tortuosity index that exceeds 1.5 (= total length of the external iliac artery (lines ABC) divided by the shortest possible distance between the common iliac artery and the femoral artery (line D), indicating that the course of the iliac artery is too tortuous for the prosthesis to safely pass the iliac artery.

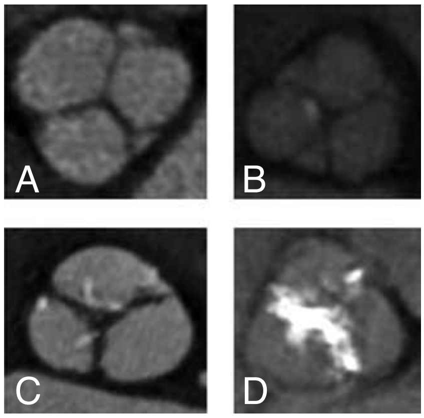

Fig. 6. — The axial reformat, showing us the 3 aortic cusps in one plane. A: normal valve without calcifications. B: mild calcifications. C: moderate calcifications. D: severe calcifications, which hamper the prosthesis deployment and increase the risk of paravalvular leakage.

because heavily calcified valves may hamper the prosthesis in crossing the native valve in percutaneous valve replacement or may interfere with stent expansion and cause paravalvular leakage (17). Willmann et al describes a good correlation between nonenhanced and contrast-enhanced CT and surgical findings, with regard to quantification of the degree of aortic valve calcification (18).

As mentioned above, precise preoperative workout will not only reduce procedural complications, it will also speed up the TAVI procedure and minimize the amount of contrast used during the procedure. One bolus of contrast on ventriculogram/aortogram will be sufficient in most cases, hereby effectively reducing the dose of contrast from an average of 250 ml to 60 ml (10).

Preoperative anatomic screening variables

Further knowledge of vascular anatomy and existing comorbidities is needed in determining which way of access is most desirable. MDCT is the imaging modality of choice for evaluating these variables.

First the luminal diameters, tortuosity and wall calcifications of the ilio-femoral arteries should be accurately assessed (Fig. 4, 5). Concentric or circumferential calcifications and complex plaques with thrombus formation are considered as relative contra-indications for the trans-femoral approach, as they hamper the advancement of the catheter and increase the risk of inducing emboli (19). Extremely tortuous and small iliacs (diameter smaller than 6 mm) are also a contra-indication, because they don't allow safe manipulation of the rigid catheter past the iliac artery into the aorta and hereby enlarge the risk of local vascular complications (19). To make an estimation of the tortuosity of an iliac artery we can calculate it's tortuositiy index, which is total length of the external iliac artery divided by the shortest possible distance between the common iliac artery and the femoral artery (Fig. 5) (20).

In such cases, a transapical approach can be considered, hereby access to the left ventricle is achieved through a minithoracotomy with needle puncture, which is a viable alternative for patients who also have advanced peripheral vascular disease, but might be contraindicated in patients with lung disease, pericardial calcifications, extensive epicardial fat, previous left ventricular surgery and dysmorphic chest anatomy (19, 21). This TAVI approach may become an attractive alternative in the future, especially if the incidence of cerebrovascular accidents is significantly smaller compared to the retrograde approach. Another valuable alternative in patients with unsuitable femoral access includes the subclavian approach with high success rates showed by several small studies (21).

Second, MDCT may serve as an alternative to invasive coronary angiography to rule out significant coronary artery disease, as most practitioners feel compelled to assess coronary anatomy ahead of valve surgery, as severe coronary artery disease might be a relative contraindication (4). As expected, coronary calcifications are very frequent in patients with aortic valve stenosis.

Complications related to percutaneous valve implantation

The fast growing number of patients treated with TAVI and data provided by longer follow-up studies have resulted in a better knowledge of the complications. Again MDCT is an important tool in preventing the majority of these complications. A detailed insight in vascular anatomy can reduce vascular injuries, such as aortic rupture and iliac perforation. Obtaining accurate measurements of the aortic root and annulus will prevent valve malpositioning, which can lead to coronary obstruction, significant paravalvular leakage and prosthesis migration.

Other complications, such as cardiac perforation and tamponade, conduction abnormalities, myocardial infarction, and stroke with a reported rate of 3% to 9% (11), are procedure related and are therefore more difficult to prevent.
Concluding, a detailed evaluation of different anatomical variables is mandatory before any implant.

Conclusion

TAVI has become a widely accepted alternative to conventional open-heart surgery for selected high-risk patients with severe symptomatic aortic stenosis. As techniques and devices evolve, the procedure will become suitable for a wider range of candidates. Pre-surgical work-up is of major importance in reducing complications related to the procedure. Due to its superb spatial and temporal resolution and accurate 3D imaging, MDCT is emerging as the best preprocedural imaging modality, and will inevitably play a vital role in facilitating the selection and evaluation of candidates. So, radiologists should familiarize themselves in using MDCT as a standard work-up tool preceding the TAVI procedure to succeed future demands.

References

1. Cribier A., Eltchaninoff H., Bash A., et al.: Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. *Circulation*, 2002, 106: 3006-3008.
2. Iung B., Cachier A., Baron G., Messika-Zeitoun D., Delahaye F., Tornos P., Gohlke-Barwolf C., Boersma E., Ravaud P., Vahanian A., et al.: Decision making in elderly patients with severe aortic stenosis: why are so many denied surgery? *Eur Heart J*, 2005, 26: 2714-2720
3. Zajarias A., Cribier A.G.: Outcomes and safety of percutaneous aortic valve replacement. *J Am Coll Cardiol*, 2009, 53: 1829-1836.
4. Vahanian A., Alfieri O., Al-Attar N., Antunes M., Bax J., Cormier B., Cribier A., De Jaegere P., Fournial G., Kappetein A.P., et al.: Transcatheter valve implantation for patients with aortic valve stenosis: a position statement from the European Association of Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur Heart J*, 2008, 29: 1463-1470.
5. Messika-Zeitoun D., Serfaty JM., Brochet E., Ducrocq G., Lepage L., Detaint D., Hyafil F., Himbert D., Pasi N., Laissy JP., Iung B., Vahanian A.: Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation. *J Am Coll Cardiol*, 2010, 19, 55: 186-194.
6. Assessment of the aortic annulus by multi-slice computed tomography, contrast aortography and trans-thoracic echocardiography in patients referred for transcatheter aortic valve implantation. AT, Ci S, N P, A M, Nm VM, Rj N, Rj VG, Ml G, Pw S, Ppt DJ. Catheter Cardiovasc Interv. 2010 Sep 7. [Epub ahead of print]
7. Achenbach S., Marwan M., Ropers D., Schepis T., Pflederer T., Anders K., Kuettner A., Daniel W.G., Uder M., Lell M.M.: Coronary computed tomography angiography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. *Eur Heart J*, 2010 Feb, 31 (3): 340-6. Epub, 2009 Nov 5.
8. Sommer W.H., Albrecht E., Bamberg F., Schenzle J.C., Johnson T.R., Neumaier K., Reiser M.F., Nikolaou K.: Feasibility and radiation dose of high-pitch acquisition protocols in patients undergoing dual-source cardiac CT. *AJR*, 2010, 195: 1306-1312.
9. Duarte R., Bettencourt N., Costa J.C., Fernandez G.: Coronary computed tomography angiography in a single cardiac cycle with a mean radiation dose of approximately 1 mSv: initial experience. *Rev Port Cardiol*, 2010, 29: 1667-1676.
10. Decramer I., Vanhoenacker P.: Multidetector computed tomography guidance for percutaneous aortic valve implantation. EuroIntervention May 2008 http://www.pcronline.com/eurointervention/authors/?authorId=1599.
11. Shultz C., Moelker A., Tzikas A., Rossi A., van Geuns RJ., de Feyter P., Serruys P., de Jeagere P., et al.: Cardiac CT: necessary for precise sizing for transcatheter aortic implantation. *EuroIntervention*, 2010, 6: 6-13.
12. Messika-Zeitoun D., Serfaty J.M., Brochet E., Ducroq G., Lepage L., Detaint D., Hyafil F., Himbert D., Pasi N., Laissy J.P., et al.: Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation. *J Am Coll Cardiol*, 2010, 55: 186-194.
13. Tops L.F., Wood D.A., Delgado V., Schuijf J.D., Mayo J.R., Pasupati S., Lamers F.P., van der Wall E.E., Schalij M.J., Webb J.G., Bax J.J.: Noninvasive evaluation of the aortic root with multislice computed tomography: implications for transcatheter aortic valve replacement. *J Am Coll Cardiol Img*, 2008, 1: 321-330.
14. Smid M., Ferda J., Baxa J., Cech J., Hajek T., Kreuzberg B., Rokyta R.: Aortic annulus and ascending aorta: comparison of preoperative and periperative measurement in patients with aortic stenosis. *Eur J Radiol*, 2010, 74: 152-155.
15. Delgado V., Schuijf J., Bax J.: Preoperative aortic valve implantation evaluation: multimodality imaging. *EuroIntervention*, 2010, 6: 38-47.
16. Webb J.G., Chandavimol M., Thompson C.R., Ricci D.R., Carere R.G., Munt B.I., Buller C.E., Pasupati S., Lichtenstein S.: Percutanous aortic valve implantation retrograde from the femoral artery. *Circulation*, 2006, 113: 842-850.
17. Delgado V., Ng A.C., van de Veire N., van der Kley F., Schuijf J.D., Tops L.F., de Weger A., Tavilla G., de Roos A., Kroft L.J., Schalij M.J., Bax J.J.: Transcatheter aortic valve implantation: role of multi-detector row computed tomography to evaluate prosthesis positioning and deployment in relation to valve function. *Eur Heart J*, 2010, 31: 1114-1123.
18. Willmann J.K., Weishaupt D., Lachat M., Kobza R., Roos J.E., Seifert B., Luscher T.F., Marincek B., Hilfiker P.R.: Electrocardiographically gated multi-detector row CT for assessment of valvular morphology and calcification in aortic stenosis. *Radiology*, 2002, 225: 120-128.
19. Kaleschke G., Seifarth H., Kerckhoff G., Reinecke H., Baumgartner H.: Imaging decision-making for transfemoral or transapical approach of transcatheter aortic valve implantation. *EuroIntervention*, 2010, 6: 20-27.
20. Hellinger J.C.: Endovascular Repair of Thoracic and Abdominal Aortic Aneurysms: Pre- and postprocedural Imaging. *Tech Vasc Interv Radiol*, 2005, 8: 2-15.
21. del Valle-Fernandez R., Martinez C.A., Ruiz C.E.: Transcatheter aortic valve implantation. *Cardiol Clin*, 2010, 28: 155-168.