The Egyptian Journal of Radiology and Nuclear Medicine (2016) 47, 421–430

Egyptian Society of Radiology and Nuclear Medicine

The Egyptian Journal of Radiology and Nuclear Medicine

www.elsevier.com/locate/ejrnm
www.sciencedirect.com

ORIGINAL ARTICLE

Approach of multi-slice computed tomography (MSCT) in assessment of transcatheter aortic valve implantation (TAVI)

Mohamed Aboul-fotouh Mourad *

Radiology Department, Faculty of Medicine, Minia University, Minia, Egypt

Received 23 January 2016; accepted 16 March 2016
Available online 30 March 2016

KEYWORDS

Aortic stenosis;
Multislice CT;
Transcatheter aortic valve implantation

Abstract *Objectives:* For better approach and optimum benefit from cardiac CT in pre-procedural assessment of the transcatheter aortic valve implantation (TAVI).
Materials and methods: 120 patients underwent cardiac CT examination and echocardiography for preoperative assessment of the aortic root measurements and vascular root evaluation.
Results: In coronal view, the mean diameter of the aortic annulus was 26.3 ± 2.3 mm while in single oblique sagittal view it was 23.9 ± 2.0 mm. Mean Agatston score of aortic calcifications was 786 ± 1324. The mean diameter of the aortic annulus by echocardiography was 22.1 ± 2.5 mm.
Conclusion: Cardiac CT is considered a valuable approach for optimum positioning of the aortic valve in conjunction with echocardiography to avoid undesirable complications and reducing the mortality rate.

1. Introduction

Degenerative valvular heart disease, especially aortic stenosis (AS), is a major cause of morbidity and mortality in the older age group (1,2). If left untreated, symptomatic, severe aortic stenosis is associated with poor prognosis (3,4). Therefore, surgical aortic valve replacement is indicated in these patients. However, many older patients with AS have multiple co-morbidities with associated increased surgical risk such as pulmonary and hepatic disease, chest deformities or prior radiation therapy, which may interfere with surgical approach (5). For these patients, transcatheter aortic valve implantation (TAVI) is considered the most suitable alternative treatment, with improved outcome compared to surgical and medical management (6). In 2002, the first catheter-based aortic valve implantation was performed in a human (7). As of early 2010, >15,000 procedures have been performed worldwide, mostly confined to patients at high surgical risk (8–10). As of mid-2013, more than 90,000 procedures have been performed worldwide. This procedure has become increasingly common and is an accepted alternative to surgical aortic valve replacement in patients with contraindications to surgery or at high surgical risk (11).

* Address: Minia University Hospital, Minia 61111, Egypt. Tel.: +20 1114707980.
E-mail address: m_aboul.fotouh@yahoo.com.

Peer review under responsibility of The Egyptian Society of Radiology and Nuclear Medicine.

http://dx.doi.org/10.1016/j.ejrnm.2016.03.009
0378-603X

Transesophageal echocardiography and fluoroscopy are useful modalities for percutaneous valve replacement procedures (12–14). However, these modalities may be less accurate due to their 2-dimensional character assuming circular annular orifice through single annular plane (15,16) in contrast to 3-dimensional multislice computed tomography (MSCT) images that can provide high spatial resolution with detailed information on the anatomy of the aortic annulus and the relation of the annulus with the coronary arteries which is important for performing these procedures. Also, accurate positioning of the prosthesis in the aortic annulus to avoid occlusion of the left coronary artery (16) and the covering of the coronary ostia by the upper part of the prosthesis (17).

The purpose of the present study was to get a standard protocol for non-invasive assessment of the aortic root anatomy by MSCT including measurements on the aortic annulus and the relation with the left coronary artery, aortic calcifications, left ventricle thrombus, thoracoabdominal aorta, and iliofemoral arteries assessment.

2. Methods

2.1. Patients

2.1.1. Multislice CT coronary angiography

The study including 120 patients referred for MSCT coronary angiography suspected to have aortic stenosis in the period from December 2013 till December 2014. The hospital's ethics committee approved the protocol of the study.

In all patients, the aortic root could be analyzed on the acquired MSCT scan. The MSCT examinations were performed with a 128-row CT scanner (Aquilion CX, Toshiba Medical Systems, Tokyo, Japan). First step including a prospective coronary calcium scan was performed (collimation 4×3.0 mm, rotation time 320 ms, tube voltage 120 kV, and tube current 200 mA). The scan is also including the aortic calcifications.

For the CT coronary angiogram, a collimation of 128×0.5 mm and a rotation time of ~0.35 s were used. A multi-segment reconstruction algorithm was used, resulting in a temporal resolution of 300 ms depending on heart rate and pitch. The tube current was 400 mA, at 120 kV. Nonionic contrast material (Iopromide 370, Bayer Schering Pharma AG, Germany) was administered in the antecubital vein, in an amount of 80–120 ml depending on the total scan time and a flow rate of 5.0 ml/s.

The scan for aortic root was done with retrospective ECG-gating to avoid motion artifacts and image degradation. While scanning of the thoracoabdominal aorta and ilio-femoral arteries was done with non-ECG synchronization to decrease the pitch aiming to lowering the radiation dose, the scan is extending from the subclavian arteries (if this route will be used) till the common femoral arteries below the level of the femoral heads.

No β-blockers or nitrates needed to achieve lower heart rates in the pre-scanning time as it may increase the symptoms of critical aortic stenosis by depression of the left ventricular systolic function.

Reconstructions in specific phases were described in percent relative to the position in the R–R interval, e.g., a systolic 30%-phase and diastolic 75%-phase for valve area measurements and annular assessment corresponding to echocardiographic guidelines. Retrospective gating also allows 4-D image reconstruction of multiple adjacent reconstructions along the cardiac cycle for evaluation of valvular and ventricular function (18,19).

All data were transferred to separate workstation (vitrea 2, Vital images, Plymouth, Minnesota) for image analysis and post processing as follows:

- *Aortic valve anatomy:* tri or bicuspid.
- *Aortic calcifications:* are subjectively quantified according to Agatston Calcium Score as follows (20,21) Fig. 1:
  - Grade 1: no calcifications.
  - Grade 2: mild calcifications (small separated spots).
  - Grade 3: moderate calcifications (multiple larger spots).
  - Grade 4: heavy calcifications: (extensive cusps calcifications).

Anatomical distribution: at cusps attachment sites, at commissures or edges of the leaflets.

- *Aortic root:* it is considered the main aim of the study including the following:
  - Sinotubular junction.
  - Sinus of Valsalva.
  - Aortic Annulus.
  - Coronary ostia.
  - Coronary leaflets.

The oblique orientation of the aortic valve at the axial view needs manipulation of the images for better valve assessment by reconstructing a coronal and a single oblique sagittal view through the aortic valve. The latter view has same orientation as parasternal long-axis view on transthoracic echocardiogram (16).

Many views are used for anatomical assessment. The coronal and reconstructed single oblique sagittal views assess the aortic root anatomy and the relationship of the aortic annulus, coronary leaflets, and the coronary arteries ostia in the systolic and diastolic phases.

The aortic valve cuspidity and calcifications were assessed in reconstructed double oblique transverse view at the level of the aortic valve.

Coronal, single oblique sagittal, and double oblique transverse views examples are seen in Fig. 2.

- Double oblique transverse view:
  - I. Valve cuspidity.
  - II. Aortic calcifications: including Agatston calcium Score, cusps calcifications and its grading.

- *Coronal and single oblique sagittal view:* for aortic annulus mean diameter by measuring the long axis (maximum) and short axis (minimum).
- Coronal view:
  - Sinus of Valsalva diameter (maximum diameter).
  - Distance between annulus and sinus of Valsalva.
  - Distance between annulus and coronary (Left and Right) osita.
  - Right and left coronary leaflets length.
  - Distance between the left coronary leaflet tip and left coronary ostium.
  - Sinotubular junction diameter (Maximum diameter).

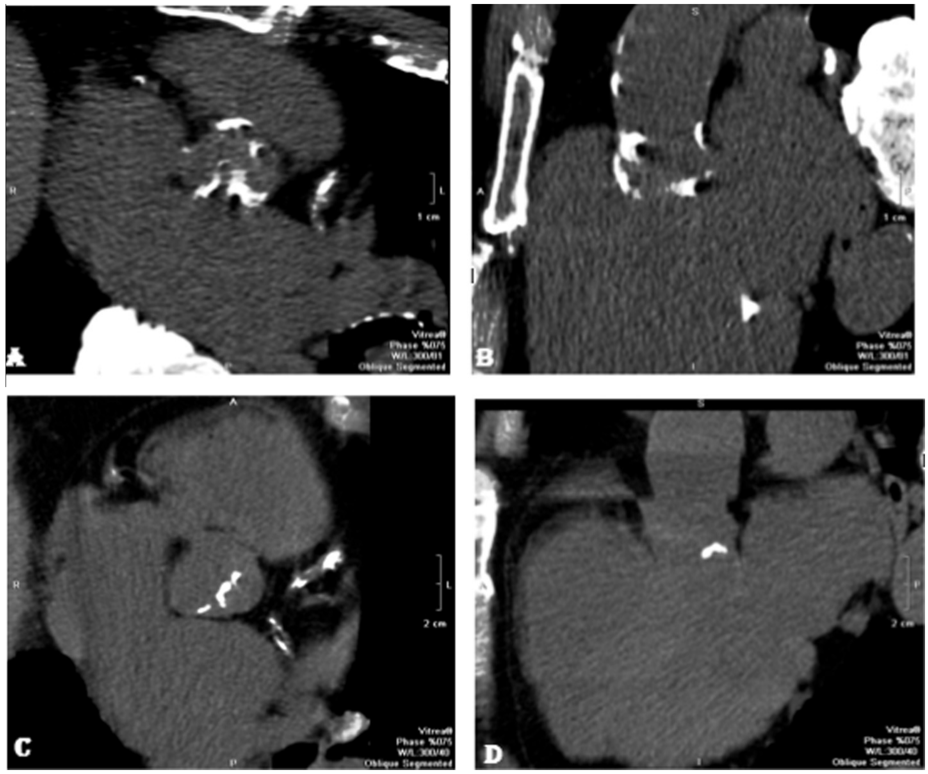

Fig. 1 (A and C) axial views and (B and D) single oblique sagittal views calcium scoring shows aortic valve calcifications.

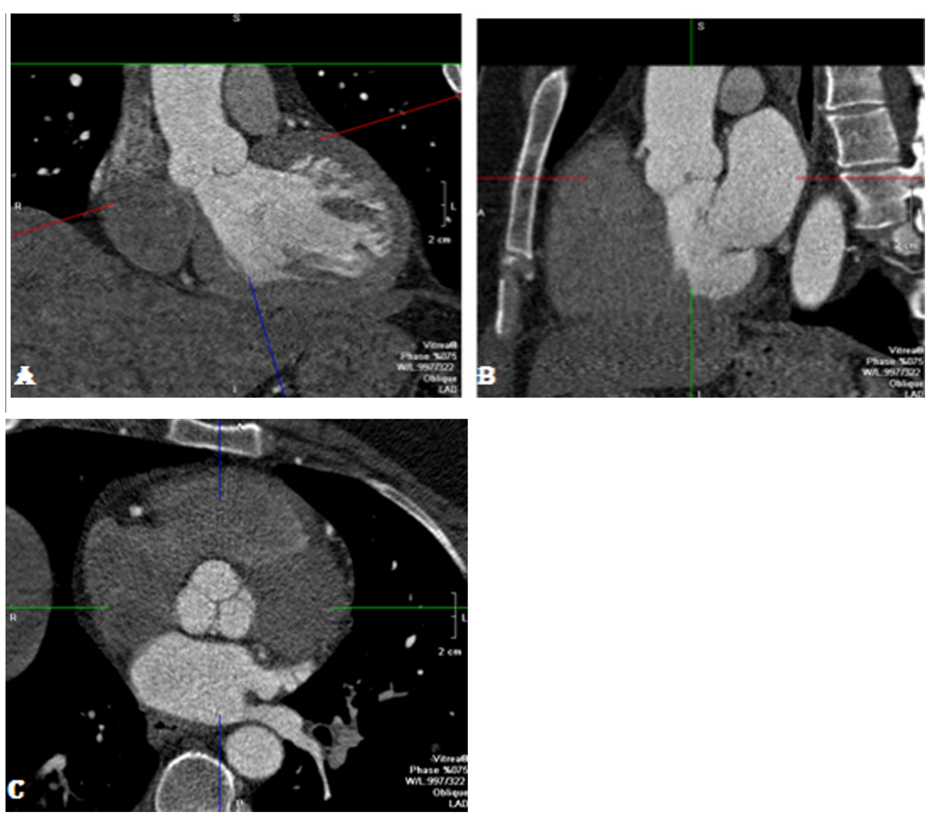

Fig. 2 Used reconstructed views, (A) Coronal view. (B) Single oblique sagittal view. (C) Reconstructed double oblique transverse view.

- Single oblique sagittal view at end-diastole:
  - Left ventricular outflow tract: assesses opposite to aortic annulus plane.
  - Inter-ventricular septum:
    I. Measures of the largest diameter.
    II. Shape; either normal or sigmoid.

– *Left ventricular outflow tract (LVOT):* as previously described.
– *Inter-ventricular septum:* as previously described.
– *Left ventricle: for LV hypertrophy and thrombus:* if present.
– *Thoracic, abdominal aorta and subclavian arteries* (if this is the alternative access route of choice): for diameter, tortuosity, calcifications, emboli, thrombi or aneurysms.
– *Ilio-femoral arteries:* for minimal width bilaterally, tortuosity and calcifications.
– *Extra-cardiac and extra-vascular findings:* to avoid unexpected complications.
– *Suggested fluoroscopic projections angle:*
  I. Cranio-caudal without RAO or LAO angulation.
  II. Straight RAO to LAO without cranial or caudal angulation.
  III. LAO 30° with cranial or caudal angulation, this is suggested by Gurvitch et al. (22).

2.1.2. Echocardiography

Images were obtained using a dedicated small dual-crystal CW 3.5-MHz transducer in the suprasternal and right parasternal (long- and short-axis) and apical (2-and 4-chamber) views using a commercially available system (Xario 100, Toshiba Diagnostic Ultrasound System, Japan). Both gray scale and map and color Doppler were used.

The diameter of the aortic annulus was assessed from the parasternal long-axis view using the shortest diameter of the oval annulus and grading from mild to moderate degrees of aortic stenosis according to the American College of Cardiology/American Heart Association guidelines (2): Mild: Area > 1.5 cm^2, moderate: 1.0–1.5 cm^2, severe: < 1.0 cm^2.

All data are analyzed using SPSS software using Student's *t* test for aortic annulus diameter in different views. Continuous variables were expressed as mean values ± standard deviation and categorical variables are expressed as frequencies and percentages.

3. Results

A total of 120 patients diagnosed or suspected as having aortic stenosis were examined by MSCT coronary angiography and echocardiography. Clinical and demographic data are summarized in Table 1.

– *Aortic valve anatomy:* all patient had tricuspid valve. No bicuspid valves.
– *Aortic calcifications:*
Agatston Calcium Score: Mean Agatston score was 786 ± 1324.
Subjective quantification is as follows:
- Grade 1: 92 patients (77%).
- Grade 2: 18 patients (15%).
- Grade 3: 6 patients (6%).
- Grade 4: 4 patients (4%).

– *Aortic root measures include the following:*
  - Aortic annulus diameter: it was measured in systolic phase (at 30% R–R cardiac cycle). In coronal view, the mean diameter was 26.3 ± 2.3 mm while in single oblique sagittal view it was 23.9 ± 2.0 mm (Fig. 3).
  - Sinus of Valsalva diameter (maximum diameter) was 34.6 ± 3.5 mm (Fig. 4).
  - The mean distance between the aortic annulus and sinus of Valsalva was 18.2 ± 3.2 mm (Fig. 5).
  - The mean distance between annulus and left and right coronary ostia was 15.3 ± 3.1 mm and 17.6 ± 3.5 mm respectively (Figs. 6 and 7).
  - Mean length of left coronary leaflets was 16.2 ± 2.6 mm (Fig. 8).
  - Mean length of right coronary leaflets was 15.4 ± 3.0 mm (Fig. 8).
  - The mean distance between the tip of left coronary leaflet and left coronary ostium was 13.8 ± 3.1 mm (Fig. 9).
  - Sinotubular junction diameter (Maximum diameter) was 30.2 ± 3.6 mm.

– *Left ventricular outflow tract:* mean diameter was 20.5 ± 2.3 mm (Fig. 10).
– *Inter-ventricular septum:* mean diameter was 12.7 ± 2.8 mm. All patients show normal shape of the septum except two patients showing sigmoid septum (Fig. 10).
– *Left ventricle:* no definite left ventricular thrombus could be identified in the examined patients; some patient shows LV hypertrophy (Fig. 11).
– *Extra-cardiac and extra-vascular findings:* one patient shows aortic aneurysm (Fig. 12).
– *Multiple fluoroscopic projections angle:* (Fig. 13).
– *Echocardiography:* The aortic annulus mean diameter was 22.1 ± 2.5 mm. The aortic stenosis is grading as 72% mild stenosis, 17% moderate stenosis and 11% severe stenosis (see Table 2).

4. Discussion

Annulus measurements are usually assessed by transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE) in addition to 3-dimensional imaging including MSCT, MRI as well as C-arm. Because of the lack of exposure and visualization of the operative field, transcatheter valvular procedures rely on image guidance for patient selection, pre-procedural planning, and intra-operative decision-making (23,24).

Accurate assessment and measurement of the aortic annulus is the critical point of view for accurate selection of

Table 1 Demographics and risk factors of studied patients.

Age	61 ± 12.5	
Sex	Male 76/Female 44	
Hypertension	77	64%
CAD	63	52%
CABG	13	11%
Smoking	53	44%
Diabetes Mellitus	44	36%
Hypercholesterolemia	47	39%

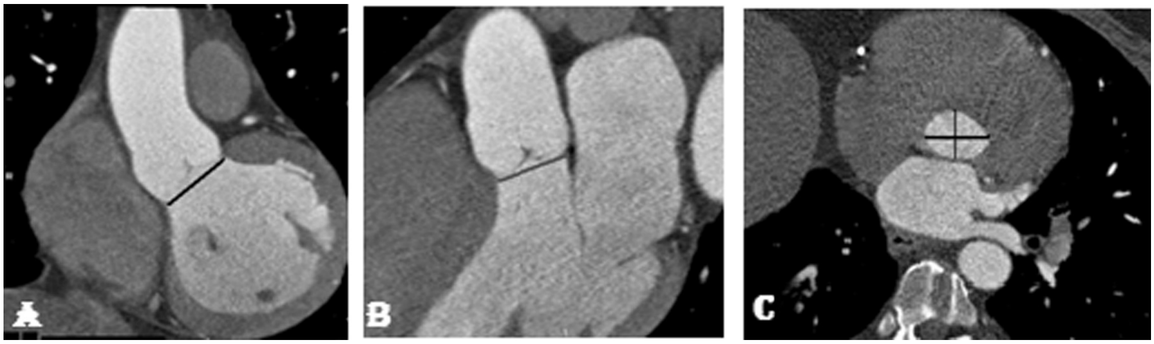

Fig. 3 Aortic annulus diameter in (A) coronal view, (B) single oblique sagittal view and (C) reconstructed double transverse views (black lines).

Fig. 4 The sinus of Valsalva maximum diameter in coronal view (black line).

Fig. 6 Distance between annulus and left coronary ostium (black line).

Fig. 5 The distance between the aortic annulus (lower black line) and the level maximum diameter of the sinus of Valsalva (upper black line).

prosthesis size and type to prevent undesirable complications including valve damage (25). These measurements have been historically performed by using two-dimensional transthoracic echocardiography (TTE), calibrated aortic angiography, or transesophageal echocardiography (TEE). But discordance has occurred between these measurements. Limitations of these 2-dimensional techniques arise from the fact that the annulus has an oval, not a circular, shape (26,27,28) while the two-dimensional echocardiography, either transthoracic or transesophageal, will measure a single diameter which is the shorter diameter of the oval aortic annulus (17).

Echocardiography is an operator dependent method measuring the annulus diameter as a circular orifice in contrast to 3-dimensional CT reconstruction of the ellipsoidal shaped annulus with detailed assessment of its minimum, maximum as well as mean diameter. Echocardiography can provide complementary data about the optimum prosthesis size.

The annulus has anatomical and clinical definitions, and anatomically it is a crown-shaped 3-dimensional structure formed by the lowest three points of the aortic valve cusps extending from the left ventricle distally to the sinotubular junction. Clinically, the annulus is defined as the lowest level of the insertion of the valve cusps into the aortic root (29).

Fig. 7 Distance between annulus and right coronary ostium (black line).

Fig. 8 The length of the left and right coronary leaflets (black lines).

The optimal positioning of the transcatheter aortic prosthesis is the main goal along with valve deployment within the native aortic annulus. If the valve is deployed at higher level, it may increase the possibility of para-valvular regurgitation, aortic injury or embolization. The low positioning may increase the possibility of para-valvular regurgitation, heart block, mitral dysfunction and embolization into the left ventricle. Also the size of the valve is critical and should be optimized to avoid rupture if small in size which may be fatal or para-valvular regurgitation if large in size (25,26).

To avoid paravalvular leak, is required that the covered portion of the prosthesis must be well-apposed to the host valve and inter-leaflet triangles and the ventricular border of the device just under the hinge points of the AV.

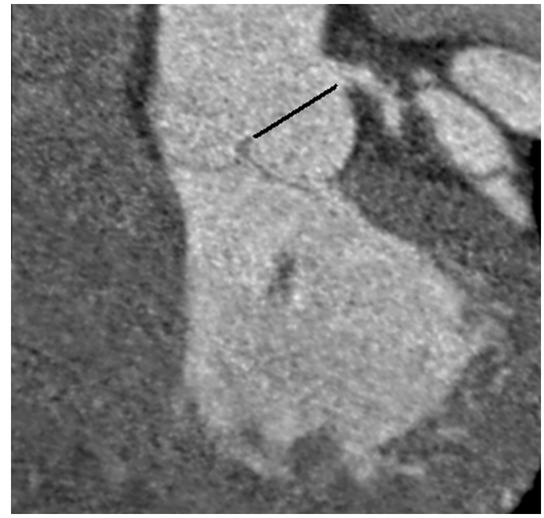

Fig. 9 The distance between left coronary leaflet tip and left main coronary ostium (black line).

Willmann et al. (21) studied 25 patients with severe AS prior to surgical aortic valve replacement. The mean diameter of the annulus assessed by contrast-enhanced CT was 24 ± 2.0 mm. When compared with surgery, the mean diameter was 23.8 ± 0.2 mm with mild overestimation of the diameter by 0.7 mm (21). This study is nearly similar to our results.

Laurens et al. (16) studied 169 patients with and without aortic stenosis using 64-slice computed tomography. In systolic phase, mean aortic diameter of aortic annulus in coronal and single oblique sagittal views was 26.5 ± 2.9 and 24.2 ± 2.6 mm respectively. In the diastolic phase, mean diameter of the aortic annulus on the coronal and reconstructed single oblique sagittal view was 26.3 ± 2.8 and 23.5 ± 2.7 mm respectively. This study represents no significant difference between the measurements in the systolic and diastolic phases. Our study shows similar results for aortic annulus diameter; the mean diameter was 26.3 ± 2.3 mm in coronal view while in single oblique sagittal view it was 23.9 ± 2.0 mm.

This study (16) also showed maximal diameter of Valsalva's sinus in diastole on coronal view was 32.4 ± 4.0 mm. The mean distance between annulus level and maximal diameter of Valsalva's sinus was 17.2 ± 2.9 mm. The maximal diameter of the sinotubular junction was 28.2 ± 3.2 mm. The mean distance between annulus level and the sinotubular junction was 20.3 ± 3.3 mm. The mean distance between the aortic annulus and the left coronary ostium was 14.4 ± 2.9 mm, and the mean distance between the aortic annulus and right coronary ostium was 17.2 ± 3.3 mm. These results are similar to our study with no significant differences, and the subtle differences may argue to use 128-slice scanner with different reconstructions.

Jatene et al. (30) evaluated the anatomical characteristics of the aortic valve in 100 healthy fixed human hearts. There were small variations regarding the position of the respective ostium in relation to the correspondent Valsalva's sinus. The mean distance between left and right coronary ostia and the bottom of Valsalva's sinus was 13.3 and 14.8 mm respectively (30). This study is little different from our study. These measurements are of critical importance because if the distance

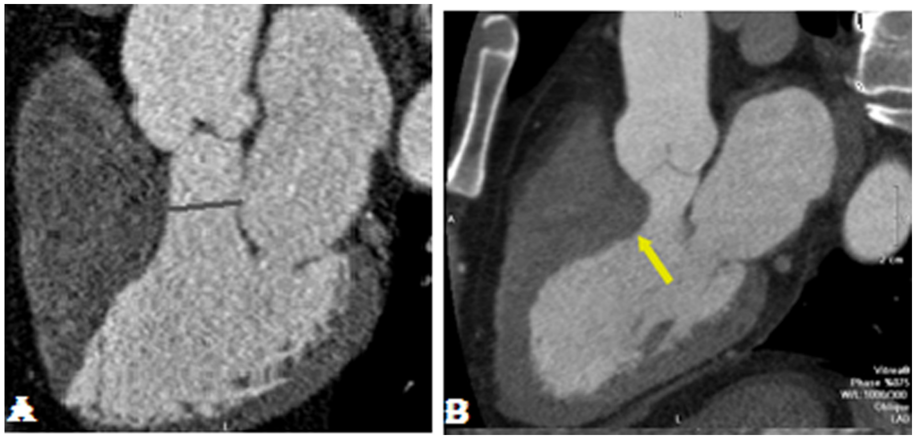

Fig. 10 The single oblique sagittal view shows (A) the left ventricular outflow tract (gray line). (B) The sigmoid inter-ventricular septum (yellow arrow) in another patient with consequent narrowing of the LVOT.

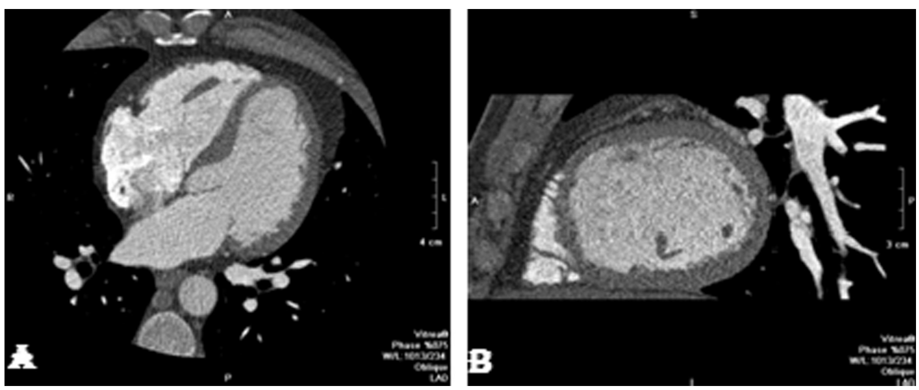

Fig. 11 (A) Axial and (B) short axis views show the left ventricular hypertrophy.

between the annulus and the coronary ostium is smaller than the lower two-thirds of the prosthesis, coronary occlusion is highly suspicious. Our measurements could be used with Jatene et al. (30) as a guide because no definite established criteria available at this time to exclude patients for risk of coronary occlusion. Instead, a safety 14 mm distance between coronary osita and leaflets insertion is advised. The length of aortic cusps and calcifications extension should be taken into consideration also (31).

In these patients, peri-deployment placement of a guidewire in the left main should be considered to ensure access in case of complications if an obstructive portion of the valve frame or the sealing cuff is placed directly over a coronary ostium (32).

Kazui et al. (33) studied the anatomy of the aortic root in 25 patients without aortic root, valve disease or previous myocardial infarction using 16-slice computed tomography (CT) reported aortic annulus diameter in the systolic and diastolic phases was 22.5 ± 2.2 and 22.1 ± 2.2 mm respectively. This study shows little difference than our results which may be explained by pathological effect.

According to many studies no definite fixed figures could be considered as a standard for aortic root measurements to follow but a large variability is noticed.

MSCT allows detailed assessment of the aortic valve type and calcifications. The aortic valve is composed of tricuspid star-shaped systolic opening, to a lesser extent a bicuspid valve with eccentric slit-like opening (6).

A major advantage for MSCT in conjunction with transthoracic echocardiography, is the accurate quantitative evaluation of aortic valve calcification including calcium score for assessment of aortic stenosis severity (34). Also, MSCT can detect precise localization of calcifications extending from commissure to anterior mitral leaflet base and mitral annulus. The prosthesis may be unable to pass the native extensively calcified aortic valves in percutaneous valve replacement (35).

Development of post-procedural paravalvular aortic regurgitation (AR) is one of the potential problems associated with TAVI especially in the presence of extensive aortic calcifications (36).

Severity of atheroma at the most diseased aortic segment has been established as a predictor of pre and post-operative complications, as well of adverse long-term outcome. In other words, the presence of significant aneurysm (Fig. 12) is considered a TAVI contraindication. TAVI may be associated with high rate of clinically silent cerebral embolism (72.7%) (37,38).

The assessment of root orientation is critical for precise positioning of the stent/valve along the centerline of the aorta and perpendicular to the valve plane. The current standard approach is based on the identification of X-ray root angiograms in 1 or preferably 2 orthogonal planes before the

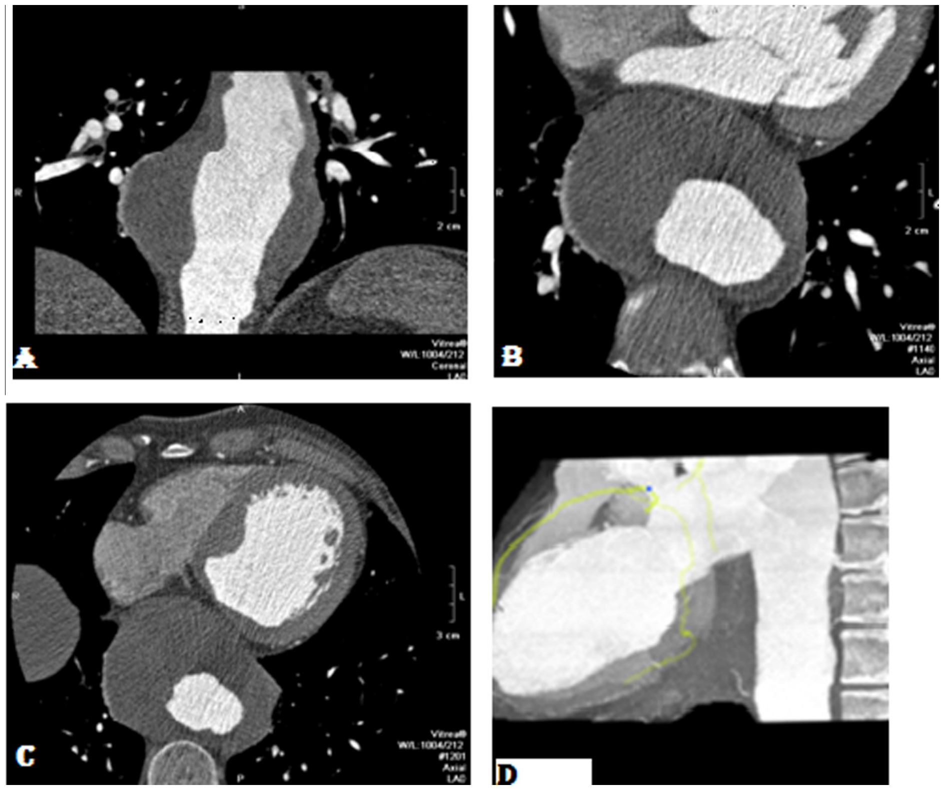

Fig. 12 Ascending aortic aneurysm and the left ventricular hypertrophy. (A) Coronal reconstruction view. (B and C) Axial views. (D) Volume rendering (VR) view.

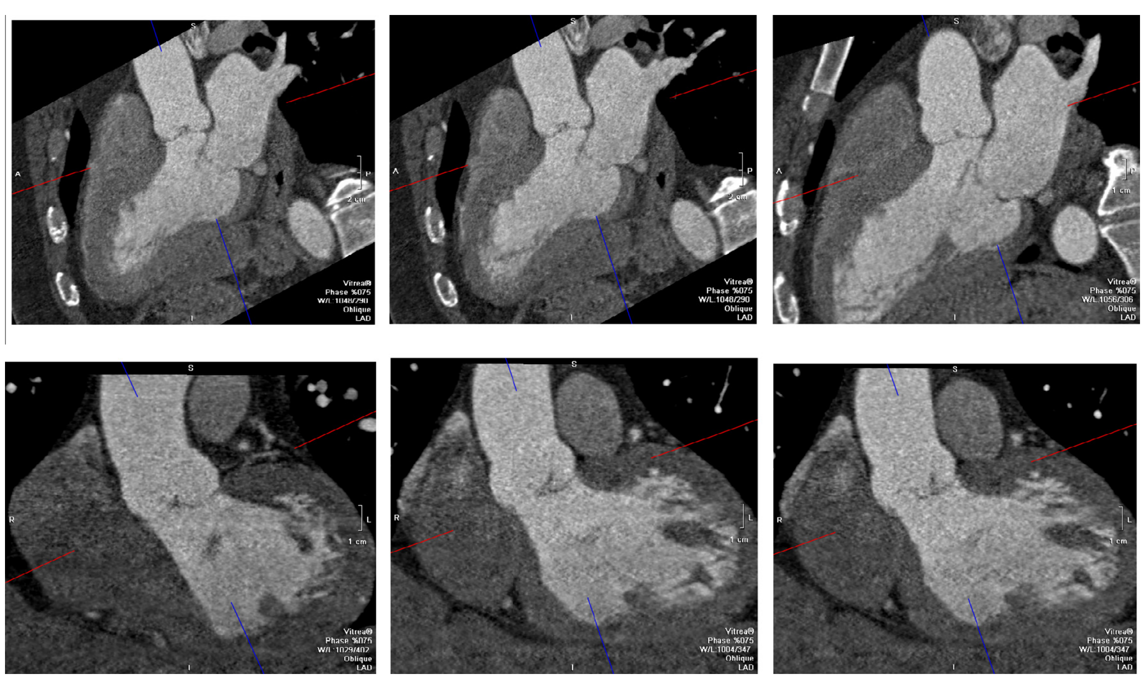

Fig. 13 Multiple projections for root angulation depending on the transverse double oblique multi-planar reconstruction in different LAO positions by adjusting the cross-bars in the transverse double-oblique view.

procedure after repeated root injections. Kurra et al. (39), demonstrate that a pre-procedural MDCT angiography of the aortic root allows prediction of the angulation of the root angiogram, which could facilitate the angiographic procedure and reduce the number of root injections, procedure time and contrast administration. The potential advantage of MDCT is the 3D nature of the image dataset, which after fast acquisition allows off-line reformations along unrestricted

Table 2 The aortic root measurement analysis dilemma and used reconstruction views.

		Coronal view	Oblique sagittal view
Aortic annulus diameter:	CT	26 ± 2.3	23.9 ± 2.0
	Echo	22.1 ± 2.5	
Sinus of Valsalva:			
• Maximum diameter		34.6 ± 3.5	
• Distance between sinus of Valsalva and aortic annulus		18.2 ± 3.2	
Coronary ostia;			
Distance between the annulus and left coronary ostium		15.3 ± 3.1	
Distance between the annulus and left coronary ostium		17.6 ± 3.5	
Coronary leaflets;			
Left coronary leaflet length		16.2 ± 2.6	
Right coronary leaflet length		15.4 ± 3.0	
Tip of the left coronary leaflet and left coronary ostium		13.8 ± 3.1	
Sinotubular junction maximum diameter		30.2 ± 3.6	
Left ventricular outflow tract			20.5 ± 2.3
Inter-ventricular septum			12.7 ± 2.8

planes (39). Double oblique transverse multiplanar reconstructions are performed at aortic root level and then rotated through a series of many angles (Fig. 13).

Comprehensive assessment of vascular accesses route is critical including the assessment of luminal diameter for delivery sheaths, calcifications locations and shape such as circumferential or horse shoe calcifications, tortuosity, aneurysms and pseudo-aneurysms.

Significant atherosclerotic peripheral artery disease is common in the high-risk patient population currently evaluated for percutaneous aortic valve insertion reaching up to 33%. Computed tomography allows identification of patients with iliofemoral anatomy unfavorable for the transfemoral approach to percutaneous aortic valve insertion. In such patient alternative access approaches may include surgical side-graft on the iliac arteries, transaxillary, or transapical access (40).

Post-procedural imaging relies primarily on echocardiography, which allows assessment of the valve and valvular dysfunction. MSCT allows assessing stent-valve including the circularity, expansion and apposition and its relationship to annulus and coronary artery (41). The stents are also examined for stent fracture (42).

5. Conclusion

Most of the aortic stenosis patients are elderly group, which have much comorbidity, so they need rapid and detailed assessment in a one single and rapid examination, which is provided by MSCT including pre and post procedural assessment. It is beneficial to explore the non-visualized operative field, and to guide pre-procedural planning as well as intraoperative decision-making. It also provides detailed anatomic measurements of aortic annulus, root, valve and coronary ostia, vascular access route and orientation of the annulus plane. CT should be used in conjunction with echocardiography and angiography aiming for optimum selection of candidates, pre and post procedural planning with long term follow-up.

Future studies should apply dose modulation with iterative image reconstruction techniques to decrease radiation dose using high dual source scanners (256–320 slices) with prospective triggering. These facilities may improve safety and potential application of TAVI in aortic stenosis management.

Funding

No funding applied.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

Disclosure: The authors declare no conflict of interest.

References

(1) Nkomo VT, Gardin JM, Skelton TN, et al. Burden of valvular heart diseases: a population-based study. Lancet 2006;368:1005–11.
(2) Bonow RO, Carabello BA, Chatterjee K, et al. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing Committee to Revise the 1998 guidelines for the management of patients with valvular heart disease) developed in collaboration with the Society of Cardiovascular Anesthesiologists endorsed by the Society for Cardiovascular Angiography and Interventions and the Society of Thoracic Surgeons. J Am Coll Cardiol 2006;48:e1–e148.
(3) Iung B, Baron G, Butchart EG, et al. A prospective survey of patients with valvular heart disease in Europe: The Euro Heart Survey on Valvular Heart Disease. Eur Heart J 2003;24:1231–43.
(4) Kapadia SR, Goel SS, Svensson L, et al. Characterization and outcome of patients with severe symptomatic aortic stenosis referred for percutaneous aortic valve replacement. J Thorac Cardiovasc Surg 2009;137:1430–5.
(5) Tornos P, Iung B, Permanyer-Miralda G, et al. Infective endocarditis in Europe: lessons from the Euro heart survey. Heart 2005;91:571–5.
(6) Schoenhagen P, Hausleiter J, Achenbach S, et al. Computed tomography in the evaluation for transcatheter aortic valve implantation (TAVI). Cardiovasc Diagn Ther 2011;1(1):44–56.
(7) 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;106:3006–8.
(8) Svensson LG, Dewey T, Kapadia S, et al. United States feasibility study of transcatheter insertion of a stented aortic valve by the left ventricular apex. Ann Thorac Surg 2008;86:46–55.
(9) Grube E, Schuler G, Buellesfeld L, et al. Percutaneous aortic valve replacement for severe aortic stenosis in high-risk patients using the second- and current third-generation self-expanding CoreValve prosthesis: device success and 30-day clinical outcome. J Am Coll Cardiol 2007;50:69–76.

(10) Walther T, Simon P, Dewey T, et al. Transapical minimally invasive aortic valve implantation: multicenter experience. Circulation 2007;116, I240-5.
(11) Holmes Jr, Mack MJ, Kaul S, et al. ACCF/AATS/SCAI/STS expert consensus document on transcatheter aortic valve replacement. J Am Coll Cardiol 2012;59:1200–54.
(12) Cribier A, Eltchaninoff H, Tron C, et al. Treatment of calcific aortic stenosis with the percutaneous heart valve: mid-term follow-up from the initial feasibility studies: the French experience. J Am Coll Cardiol 2006;47:1214–23.
(13) Webb JG, Chandavimol M, Thompson CR, et al. Percutaneous aortic valve implantation retrograde from the femoral artery. Circulation 2006;113:842–50.
(14) Grube E, Laborde JC, Gerckens U, et al. Percutaneous implantation of the Core Valve self-expanding valve pros- thesis in high-risk patients with aortic valve disease: the Siegburg first- in-man study. Circulation 2006;114:1616–24.
(15) Ng A, Delgado V, van der Kley F, 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 Imag 2010;3:94–102.
(16) Tops LF, Wood DA, Delgado V, et al. Noninvasive evaluation of the aortic root with multislice computed tomography: implications for transcatheter aortic valve replacement. J Am Coll Cardiol Img 2008;1:321–30.
(17) Achenbach s, Delgado V, Hausleiter J, et al. SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). J Cardiovasc Comput Tomogr 2012;6:366–80.
(18) Chenot F, Montant P, Goffinet C, et al. Evaluation of anatomic valve opening and leaflet morphology in aortic valve bioprosthesis by using multidetector CT: comparison with transthoracic echocardiography. Radiology 2010;255:377–85.
(19) Feuchtner GM, Alkadhi H, Karlo C, et al. Cardiac CT angiography for the diagnosis of mitral valve prolapse: comparison with echocardiography 1. Radiology 2010;254:374–83.
(20) Rosenhek R, Binder T, Porenta G, et al. Predictors of outcome in severe, asymptomatic aortic stenosis. N Engl J Med 2000;343:611–7.
(21) Willmann JK, Weishaupt D, Lachat M, et al. Electrocardiographically gated multi-detector row CT for assessment of valvular morphology and calcification in aortic stenosis. Radiology 2002;225:120–8.
(22) Gurvitch R, Wood DA, Leipsic J, et al. Multislice computed tomography for pre-diction of optimal angiographic deployment projections during transcatheter aortic valve implantation. JACC Cardiovasc Intervent 2010;3(11):1157–65.
(23) Messika-Zeitoun D, Serfaty JM, Brochet E, et al. Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation. J Am Coll Cardiol 2010;55:186–94.
(24) Wood DA, Tops LF, Mayo JR, et al. Role of multislice computed tomography in transcatheter aortic valve replacement. Am J Cardiol 2009;103:1295–301.
(25) Al Ali AM, Altwegg L, Horlick EM, et al. Prevention and management of transcatheter balloon-expandable aortic valve malposition. Catheter Cardiovasc Intervent 2008;72:573–8.
(26) Altiok E, Koos R, Schroder J, et al. Comparison of two-dimensional and three-dimensional imaging techniques for measurement of aortic annulus diameters before transcatheter aortic valve implantation. Heart 2011;97:1578–84.
(27) Gurvitch R, Webb JG, Yuan R, et al. Aortic annulus diameter determination by multidetector computed tomography: reproducibility, applicability, and implications for transcatheter aortic valve implantation. JACC Cardiovasc Interv 2011;4:1235–45.
(28) Feltes Gisela, Núñez-Gil Iván J. Practical update on imaging and transcatheter aortic valve implantation. World J Cardiol 2015;7 (4):178–86.
(29) Akhtar M, Tuzcu EM, Kapadia SR, et al. Aortic root morphology in patients undergoing percutaneous aortic valve replacement: evidence of aortic root remodeling. J Thorac Cardiovasc Surg 2009;137:950–6.
(30) Jatene MB, Monteiro R, Guimaraes MH, et al. Aortic valve assessment. Anatomical study of 100 healthy human hearts. Arq Bras Cardiol 1999;73:75–86.
(31) Litmanovich DE, Ghersin E, Burke DA, et al. Imaging in Transcatheter Aortic Valve Replacement (TAVR): role of the radiologist. Insights Imag 2014;5:123–45.
(32) Masson JB, Kovac J, Schuler G, et al. Transcatheter aortic valve implantation: review of the nature, management, and avoidance of procedural complications. JACC Cardiovasc Interv 2009;2:811–20.
(33) Kazui T, Izumoto H, Yoshioka K, Kawazoe K. Dynamic morphologic changes in the normal aortic annulus during systole and diastole. J Heart Valve Dis 2006;15:617–21.
(34) Cueff C, Serfaty JM, Cimadevilla C, et al. Measurement of aortic valve calcification using multislice computed tomography: correlation with haemodynamic severity of aortic stenosis and clinical implication for patients with low ejection fraction. Heart 2011;97:721–6.
(35) Korosoglou G, Mueller D, Lehrke S, et al. Quantitative assessment of stenosis severity and atherosclerotic plaque composition using 256-slice computed tomography. Eur Radiol 2010;20:1841–50.
(36) Latsios G, Gerckens U, Buellesfeld L, et al. "Device landing zone" calcification, assessed by MSCT, as a predictive factor for pacemaker implantation after TAVI. Catheter Cardiovasc Interv 2010;76:431–9.
(37) Kurra V, Lieber ML, Sola S, et al. Extent of thoracic aortic atheroma burden and long-term mortality after cardiothoracic surgery: a computed tomography study. JACC Cardiovasc Imag 2010;3:1020–9.
(38) Ghanem A, Müller A, Nähle CP, et al. Risk and fate of cerebral embolism after transfemoral aortic valve implantation: a prospective pilot study with diffusion-weighted magnetic resonance imaging. J Am Coll Cardiol 2010;55:1427–32.
(39) Kurra V, Kapadia SR, Tuzcu EM, et al. Pre-procedural imaging of aortic root orientation and dimensions: comparison between X-ray angiographic planar imaging and 3-dimensional multidetector row computed tomography. JACC Cardiovasc Interv 2010;3:105–13.
(40) Kurra V, Schoenhagen P, Roselli EE, et al. Prevalence of significant peripheral artery disease in patients evaluated for percutaneous aortic valve insertion: preprocedural assessment with multidetector computed tomography. J Thorac Cardiovasc Surg 2009;137:1258–64.
(41) Delgado V, Ng AC, van de Veire NR, et al. 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;31:1114–23.
(42) Leipsic J, Gurvitch R, LaBounty TM, et al. Multidetector computed tomography in transcatheter aortic valve implantation. JACC: Cardiovasc Imag 2011;4:416–29.