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

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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.

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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).
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 \( \times \) 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 \( \times \) 0.5 mm and a rotation time of \(~\sim 0.35\) 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 \( \beta \)-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 cuspidy.
    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) ostia.
    - 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.
Aortic stenosis according to the American College of Cardiology oval annulus and grading from mild to moderate degrees of parasternal long-axis view using the shortest diameter of the map and color Doppler were used. Diagnostic Ultrasound System, Japan). Both gray scale and using a commercially available system (Xario 100, Toshiba (long- and short-axis) and apical (2-and 4-chamber) views 3.5-MHz transducer in the suprasternal and right parasternal.

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.

# Subjective quantification is as follows:
- Mild: Area > 1.5 cm², moderate: 1.0–1.5 cm², severe: < 1.0 cm².
- Agatston Calcium Score: Mean Agatston score was 786 ± 1324.
- Single oblique sagittal view at end-diastole:
  - Left ventricular outflow tract: assesses opposite to aortic annulus plane.
  - Inter-ventricular septum:
    - Measures of the largest diameter.
    - 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).

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.

<table>
<thead>
<tr>
<th>Demographic/Risk Factor</th>
<th>Frequency</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Age</td>
<td>61 ± 12.5</td>
<td></td>
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<tr>
<td>Sex</td>
<td>Male 76/Female 44</td>
<td>64%</td>
</tr>
<tr>
<td>Hypertension</td>
<td>77</td>
<td></td>
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<tr>
<td>CAD</td>
<td>63</td>
<td>52%</td>
</tr>
<tr>
<td>CABG</td>
<td>13</td>
<td>11%</td>
</tr>
<tr>
<td>Smoking</td>
<td>53</td>
<td>44%</td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>44</td>
<td>36%</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>47</td>
<td>39%</td>
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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. 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. 5  The distance between the aortic annulus (lower black line) and the level maximum diameter of the sinus of Valsalva (upper black line).

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

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...
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 are 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
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

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

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

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