Percutaneous transarterial aortic valve replacement. A practical tutorial for radiologists and how to approach special situations.

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Learning objectives

The aim of this exhibit is:

1- To review clinical indications and technique in Percutaneous transarterial aortic valve replacement (TAVR).

2- To review the role of radiologists in the evaluation and planning previous to procedure.

3- To describe step-by-step the interpretation of Computed Tomography pre-procedure.

4- To discuss special situations regarding TAVR placement.

Background

Introduction

Transarterial Aortic Valve Replacement (TAVR) is a complex procedure performed with increasing frequency and demands a multidisciplinary approach.

Cardiovascular radiologists must be perfectly trained for the pre-procedure imaging assessment, basic technique and potential complications.

General radiologists must be at least sensitized to the requirements and the main role of imaging in this procedure.

TAVI procedure is used in the treatment of critic aortic stenosis in the setting of high surgical risk.

Aortic Stenosis

Aortic stenosis is the most frequent valvular disease in the western countries.¹

Most of the patients are older than 60 years old. The prevalence of the disease is highly associated with old age, and as the population age increases so the frequency of aortic stenosis.²
When the aortic stenosis turns symptomatic, the mortality rate increases exponentially, with reported mortality rates of 50% and 75% at 2 and 3 years, respectively.\textsuperscript{3}

Surgical repair has shown that increases survival compared to the age group.

Surgical valve replacement is a relatively safe procedure with mortality rates of 2-5\%, nevertheless this numbers rise to 5-15\% in older patients.

Thus, as many as 33\% of the patients with aortic stenosis above 75 years-old are not considered for surgical valve replacement.\textsuperscript{3,4}

The first TAVR procedure was performed for the first time in 2002.\textsuperscript{5}

Today, TAVR procedure is the standard course of treatment in those patients with high surgical risk with absolute contraindication for surgery and a valid alternative in patients with relative contraindications and high surgical risk.\textsuperscript{6}

Known factors associated with increasing surgical risk for valvular replacement are: fragility, history of radiation therapy, porcelain aorta, severe liver or lung disease, thoracic deformities, kidney failure, reduced left ventricular systolic function and advanced age.\textsuperscript{7}

Clinical controlled trials have showed consistent improvement, with transaortic systolic gradients around 10 mm Hg and valvular areas between 1.2 and 1.9 cm\(^2\) after the procedure.\textsuperscript{8} The PARTNER 1B study reported survival rates of 69\% in patients with absolute contraindication for surgery and 76\% in those patients with relative contraindications, this corresponds to 20\% absolute reduction in mortality in the first year compared to medical treatment.\textsuperscript{9}

Paravalvular leak is the most frequent complication, the severity is mild to moderate in the majority of patients and relatively well tolerated in long term follow-up. Nevertheless, has shown impact in prognosis.\textsuperscript{9} The main factor predicting paravalvular leak is inaccurate measure of the valvular plane and the selection of an undersized valve.\textsuperscript{10}
Fig. 1: Bright-blood sequence, three chamber view in a patient with critical aortic stenosis, note the high flow jet through the aortic valve during systole.

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Findings and procedure details

TAVR systems

Currently there are two main options for TAVR procedure:

- Edwards SAPIEN Transcatheter Heart Valve (Edwards Lifesciences, Irvine, CA, USA).
- Medtronic CoreValve ReValving System (Medtronic, Minneapolis, MN, USA). Fig. 2 on page 9

While SAPIEN valve is placed with active expansion with a catheter balloon, the CoreValve system is self-expandable. Fig. 3 on page 18

Once placed, SAPIEN system can not be moved or adjusted, while CoreValve system can be moved or removed up to certain point.\textsuperscript{11}

Objective of non-invasive imaging

Interventional cardiologists use anatomic landmarks to place the valve directly in the aortic annulus. Potential complications are paravalvular leak, coronary ostia occlusion, aortic rupture and atrioventricular block.

A precise evaluation previous to the procedure including diagnostic invasive angiography in order to exclude obstructive coronary artery disease, echocardiography and Computed Tomography are usually performed.

Due to its high spatial resolution and nearly isotropic nature, Computed tomography is an excellent diagnostic modality for the purposes of TAVR planning.

The objectives of CT evaluation previous to the procedure are:

1. Vascular access planning. Vascular access options include femoral arteries, subclavian arteries, transaortic and transapical.
2. Assessment of the size, conformation and calcium distribution in the aortic root.
3. Valve size selection.
4. Contributes overall to procedure planning and provides a vascular route map.

The ideal imaging modality should provide accurate and reproducible measures of the aortic annulus and aortic root diameters to prevent paravalvular leak, embolization of the valve and aortic rupture.

CT can also provide information about the height and localization of the coronary ostia to prevent occlusion, the signs to look for that have been associated with ostium occlusion are: a prominent valve adjacent to the ostium, a low ostium (less than 12 mm from the valve plane) and a shallow coronary cusp.

The calcium distribution and severity has been associated with risk of aortic rupture, particularly when is located in the outflow tract of the left ventricle below the valve plane.\textsuperscript{12}

CT provides information about the diameter, calcium extension and distribution in femoral and subclavian arteries to select the best approach for intervention.

**Computed Tomography acquisition protocols**

Imaging protocol should guarantee motion free, high quality imaging of the aortic annulus during systole, thus a gated (retrospective with no dose modulation) angiographic phase restricted to the heart is acquired. Fig. 4 on page 10

Multi-phase sequences with 1 mm slice thickness are the optimal images for aortic annulus measurement.\textsuperscript{13}

For evaluation of thoracoabdominal aorta, a standard angiographic phase from the neck to the femoral arteries is performed after the first scan, high-pitch protocols are preferred.

**Aortic root measures and selection of the valve size**

First, you most clearly identify the components of the aortic root: Aortic annulus, commissures, coronary cusps, aortic leaflets and sinotubular junction. Fig. 6 on page 12

The aortic leaflets have a semilunar configuration, from the sinotubular junction to the left ventricle outflow tract, this disposition defines two virtual elliptical planes: 1) at sinotubular
junction and 2) at the hinge-point of the leaflets, the is considered the plane of the aortic annulus. Fig. 7 on page 12

To guarantee an accurate measures the aortic annulus, the plane of measure must be perfectly transversal and oriented at the hinge-point of the leaflets.

*Aortic annulus size:*

The aortic annulus is elliptic. Measurement should be performed in maximum opening of the aortic annulus between 20-45% phases.

Three measures must be performed to select the valve size:

1. Major and minor diameters.
2. Diameter calculated from the measured area.
3. Diameter calculated from the measured perimeter.

\[
d = \frac{p}{3.1416}
\]

\[
d = \sqrt{\frac{a}{3.1416 \times 2}}
\]

**Fig. 10**

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The rest of measurements in the aortic root include: distance from right and left coronary ostia to valvular plane, diameter at coronary sinuses (from cusp to commissure), height
of the coronary sinuses, diameter at sinotubular junction and ascending aorta. Fig. 8 on page 13  Fig. 9 on page 14

Access planning

Thoracoabdominal aorta must be fully described, reporting standard diameters, areas of angulation, thrombi, dissection flaps or any other finding that might affect the delivery of the valve.

Femoral and subclavian arteries must be evaluated in diameter, grade of calcification and tortuosity. For reporting, the minimum internal diameter should be used. Fig. 11 on page 15

Special situations

Some considerations in special considerations should be recognized.

Bicuspid valve

Bicuspid aortic valves have a larger annulus size, sinus of Valsalva and ascending aorta dimensions. Also more frequently have eccentric annular calcification. Fig. 13 on page 18

Valve-in-valve procedure

There are some heterogeneous case reports with diverse prosthetic valves, overall, it appears to be a safe procedure in selected patients. Fig. 13 on page 18

Images for this section:
**Fig. 1:** Bright-blood sequence, three chamber view in a patient with critical aortic stenosis, note the high flow jet through the aortic valve during systole.

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**Fig. 2:** TAVR systems.


**Fig. 4:** Axial views in multiphase imaging, acquired with retrospective protocol without radiation dose modulation. Full dose is maintained through the cardiac cycle to guarantee high quality images during systole. For measurements, the maximum opening should be selected, usually between 20-40% of the cycle.

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Fig. 5: Full thoracoabdominal aorta evaluation, from the neck to femoral arteries.

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Fig. 6: Anatomic structures in the aortic root. Measurements of the aortic annulus should be performed in the virtual ring at the hinge-point of the leaflets (green ring). Yellow ring corresponds to sinotubular junction. RCA, right coronary artery; LM, Left Main coronary artery; NCC, non-coronary cusp; RCC, right coronary cusp; LCC, left coronary cusp.

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Fig. 7: In order to guarantee a true plane crossing the aortic annulus, after orientation with the aortic root, when scrolling down (from A to C), all coronary cusps should be fall out of plane simultaneously.

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**Fig. 8:** Diameters at aortic annulus (red line), coronary sinus (green line), sinotubular junction (blue line) and ascending aorta (yellow line).

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Fig. 9: Measurements of the aortic annulus, A) minimum and maximum diameters, B) area/perimeter, C) Height of the coronary ostia.

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**Fig. 11:** Evaluation of vascular access in CT. Diameter, tortuosity and calcium distribution must be reported.

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Fig. 12: Volumetric reformats of the full aorta can provide an overall evaluation of aorta morphology and severity of atherosclerotic disease. Note in this patient an aberrant right subclavian artery (arrow).
Fig. 3: TAVR procedure, Edwards SAPIEN system. A) Opacification at the aortic root to corroborate optimal angulation for delivery of the valve. B) TAVR delivery system ascending in the right iliac artery. C, D) Placement of valve. E) Expansion of the valve.
Fig. 13: TAVR procedure in a patient with prosthetic aortic valve (A) dysfunction, valve-in-valve procedure. B) TAVR delivery system coursing in the aortic arch. C, D, E) Gradual expansion and delivery of the valve. F) Final result.

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d = \frac{p}{3.1416}

d = \sqrt{a / 3.1416 \times 2}
Fig. 10

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Conclusion

TAVR procedure is being performed with increasing frequency and demands a multidisciplinary approach.

CT is a highly available and robust diagnostic modality for evaluation previous to TAVR procedure.

Radiologists must be familiarized with CT imaging for planning of TAVR procedure and recognize the relevant role of imaging in the success of the intervention.

Personal information

References


