Transcatheter aortic valve implantation: role of multimodality cardiac imaging

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ABSTRACT

Current evidence based on more than 8000 high-risk patients with severe aortic stenosis has demonstrated that transcatheter aortic valve implantation (TAVI) is a feasible alternative to surgical aortic valve replacement in selected patients. Despite current promising results on hemodynamic and clinical improvements, there are several unresolved safety issues such as the frequency of vascular complications, post-procedural paravalvular leak, atrioventricular heart block and stroke. Multimodality cardiac imaging may help to minimize these complications and may play a central role before (optimizing patient selection, selection of appropriate prosthesis size and anticipating the procedural approach), during, and after TAVI (evaluating the immediate and long-term procedural results). The present article reviews the state-of-the-art of TAVI procedures and the role that multimodality cardiac imaging plays before, during and after TAVI.
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INTRODUCTION

Valvular heart diseases represent an important public health problem in Western countries and degenerative aortic stenosis is the most frequent type of valvular heart disease.1,2 Recent registries and population-based studies have demonstrated that the clinical spectrum of the aortic valve stenosis has changed from rheumatic to degenerative etiologies, and often seen in elderly patients with high prevalence of cardiovascular risk factors and comorbidities.2,3 Surgical aortic valve replacement is the definitive therapy for patients with symptomatic, severe aortic stenosis.4,5 However, in elderly patients with left ventricular dysfunction and associated comorbidities, the operative mortality and morbidity risks may outweigh the benefits of surgical aortic valve replacement. Consequently, surgery is often denied in over one third of those patients.3

Transcatheter aortic valve implantation (TAVI) has emerged as feasible and effective treatment for high-risk patients with symptomatic, severe aortic stenosis. Since the first-in-man experience in 2002, several centres worldwide have reported promising results in over 8000 high-risk patients with procedural success rates around 95% and 30-day mortality rates ranging from 5% to 18%.6,7 Despite satisfactory short- and mid-term hemodynamic results, TAVI procedures still face several important safety issues: 1) vascular complications, 2) long-term consequences of paravalvular leaks, 3) stroke and 4) atrioventricular heart block and need for pacemaker implantation. Accurate patient selection with exact characterization of the vascular anatomy, aortic annular sizing and LV evaluation may minimize the risk of those complications by helping to select the appropriate prosthesis size and the procedural approach. A multi-disciplinary team involving clinical, imaging and interventional cardiologists, cardiac surgeons and anaesthesiologists is crucial to optimize the patient selection and the procedural results. In addition, multimodality cardiac imaging, including 2- and 3-dimensional echocardiography, multidetector computed tomography (MDCT) and magnetic resonance (MRI), may constitute the best approach to evaluate candidates to TAVI. Similarly, these imaging techniques provide invaluable information during the valve implantation procedure to guide the intervention, and after the procedure to evaluate the positioning, deployment and function of the prosthesis.

In this article, the state-of-the-art of TAVI procedures and the role that multimodality cardiac imaging plays before, during and after TAVI will be reviewed.

Transcatheter aortic valve prosthesis and implantation techniques

At present, the 2 most commonly implanted transcatheter aortic valves are the balloon-expandable Edwards Sapien valve (Edwards Lifescience, Irvine, CA) and the self-expandable CoreValve Revalving system (CoreValve Inc., Irvine, CA) (Table 1). The Edwards Sapien valve consists of 3 bovine pericardial leaflets mounted within a balloon-expandable stainless steel stent. The bottom third of the prosthesis is covered by a fabric sealing cuff that reduces paravalvular leaks. This device is currently available in 23 mm and 26 mm sizes, and requires either the 22F or 24F delivery sheaths for the transfemoral approach or the 26F delivery sheath for the transapical approach. The CoreValve Revalving system consists of 3 porcine pericardial leaflets mounted and sutured in a self-expandable...
ninetinol stent. This valve has 3 different functional levels with different radial and hoop strengths. The upper one third, with a low radial force, anchors in the aorta above the coronary ostia. The middle portion contains the valve leaflets and the lower one third level is covered by a skirt of pericardium that prevents paravalvular aortic regurgitation. Two different sizes are currently available: 26 mm and 29 mm sizes that require an 18F delivery system for the transfemoral approach (Table 1). The first-in-man experience with implantation of this self-expandable prosthesis via transapical approach has been reported and a 21F delivery system was used.8

Table 1. Transcatheter aortic valve prosthesis

The transfemoral or transapical approaches are usually performed in the cardiac catheterization laboratory or hybrid operating rooms under general anaesthesia and with transesophageal echocardiographic and fluoroscopic guidance. Particularly, an hybrid operating room may be the optimal environment to perform these procedures since it may meet the demands of traditional cardiologic and surgical procedures (mobile fluoroscopy, sufficient space for transesophageal echocardiography, surgical and catheterization equipment, cardiopulmonary by-pass and ventricular support capabilities and complete anaesthetic equipment).7,9 During the transfemoral approach, the common femoral artery is surgically exposed at the beginning of the procedure while the transapical approach uses a left anterior mini-thoractomy and needle puncture of the left ventricular apex without cardiopulmonary bypass. Balloon valvuloplasty of the native aortic valve is initially performed during rapid right ventricular pacing in order to minimize cardiac output and stabilize the balloon during inflation (Figure 1). Thereafter, the transcatheter aortic valve is positioned within the aortic root
by using the valvular calcium on fluoroscopy as reference landmarks, the location of the aortic cusps on aortography, or under the guidance of transesophageal echocardiography (Figure 1). When appropriate positioning of the prosthesis is achieved, the transcatheter aortic valve is deployed under rapid ventricular pacing. Immediately after deployment, the function of the prosthesis is evaluated by aortography or transesophageal echocardiography. Important parameters to evaluate include the transvalvular gradient, presence of paravalvular leak, and patency of the coronary ostia (Figure 1). In cases of moderate to severe paravalvular leaks, repeat dilatation of the prosthesis with a larger balloon could be performed.

**Figure 1. Transcatheter aortic valve implantation procedure.** The figure illustrates an example of transcatheter aortic valve implantation through transapical approach. First, the aortic valve is crossed with the guide wire (panel A) and the waist of the balloon is positioned at the aortic valve annulus level (panel B). Fluoroscopy uses calcifications of the non-coronary leaflet as anatomical landmarks (panel A, arrows). After balloon valvuloplasty (panel B, arrows), the prosthesis is placed at the level of the aortic annulus and subsequently deployed (panel C). Thereafter, the prosthesis is released and the function is evaluated. In addition, the patency of the coronary ostia is also confirmed (panel D, arrow).

**Clinical experiences: feasibility, safety and short- and mid-term outcomes**

The feasibility of TAVI procedures has been demonstrated in several studies that included over 8000 high-risk patients with symptomatic, severe aortic stenosis. Most recent series reported procedural success rates ranging from 94-97% (Table 2). Improved selection of candidates, procedural learning curve and the development of new lower profile devices are undoubtedly related to this high procedural success rate. These factors have also
favourably influenced the peri-procedural and short-term mortality, key safety parameters in all current TAVI studies. With the Edwards Sapien valve, 30-day mortality rates have significantly decreased from 14.3% in early series to 8.3% from the latest experiences. With the CoreValve ReValving system, similar reductions in 30-day mortality rates have been reported (from an initial 40% 30-day mortality using the 25F devices to 10.8% with the more recent 18F devices). Bearing in mind the high operative risk of these study populations with a logistic EuroSCORE ≥20%, these early results are encouraging and compare favourably with high-risk surgery.

In regards to late outcomes, one recent series that included 168 high-risk patients reported the 12- and 24-month survivals as 74% and 61%, respectively. These late outcomes were primarily determined by associated comorbidities rather than by adverse valve-related events. In addition, when compared to no intervention or balloon valvuloplasty, TAVI procedures had superior long-term outcome with 1-year survival of 78% vs. 53% and 58% respectively. Finally, the improvements in valvular hemodynamics with immediate reductions in transaortic valve pressure gradients after

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Table 2. Feasibility and safety of transcatheter aortic valve implantation techniques

<table>
<thead>
<tr>
<th>Studies (Ref)</th>
<th>Edwards Sapien valve</th>
<th>CoreValve ReValving system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>305</td>
<td>50</td>
</tr>
<tr>
<td>Age, years</td>
<td>81.8</td>
<td>82 ± 7</td>
</tr>
<tr>
<td>LogEuroSCORE (%)</td>
<td>26.4</td>
<td>28</td>
</tr>
<tr>
<td>Aortic valve area (cm²)</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>53 ± 15</td>
<td>NA</td>
</tr>
<tr>
<td>Procedural approach</td>
<td>Trans-femoral</td>
<td>Trans-femoral</td>
</tr>
<tr>
<td>Procedural success (%)</td>
<td>95</td>
<td>86</td>
</tr>
<tr>
<td>Procedural mortality (%)</td>
<td>0.3</td>
<td>2</td>
</tr>
<tr>
<td>30-day outcomes (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td>6.4</td>
<td>12</td>
</tr>
<tr>
<td>Stroke</td>
<td>3.4</td>
<td>4</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vascular complications (%)</td>
<td>7.4</td>
<td>NA</td>
</tr>
<tr>
<td>Aortic regurgitation ≥3+ (%)</td>
<td>NA</td>
<td>13</td>
</tr>
<tr>
<td>Pacemaker (%)</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Abbreviations: LVEF = left ventricular ejection fraction
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TAVI are followed by improvements in clinical status, New York Heart Association functional class and quality-of-life scores.17

In light of this evidence, TAVI procedures are considered feasible. On-going randomized, multi-center trials, such as the PARTNER [Placement of AoRTic traNscathetER] US and PARTNER EU trials will help establish the indications and success of TAVI procedures, and will determine the future dissemination of these procedures. In this regard, multimodality cardiac imaging may play a central role helping to increase the procedural success rate and to reduce the number of complications by optimizing patient selection, planning the procedural strategy, and selection of the appropriate type and size of transcatheter prosthesis to implant. In addition, cardiac imaging is crucial to guide the positioning and deployment of the prosthesis and to evaluate the immediate results. Finally, cardiac imaging should evaluate the mid- and long-term results by monitoring the prosthesis function and position.

Multimodality cardiac imaging before TAVI

Confirmation of aortic stenosis severity and assessment of the procedural feasibility are key steps in the selection of potential candidates for TAVI.

Aortic stenosis severity and aortic valve morphology

Echocardiography is the preferred method to assess the severity of aortic stenosis. Based on Doppler techniques, the aortic valve area and the mean and maximum transvalvular systolic gradient can be calculated. According to current guidelines,4,5 severe aortic stenosis is defined by an aortic valve area <1 cm² and/or mean transvalvular gradient >40-50 mmHg.

In addition, the anatomy and morphology of the aortic valve and aortic root should be evaluated. The presence of bicuspid anatomy may have important clinical implications (Figure 2). Indeed, the prevalence of bicuspid valve in patients with symptomatic, severe aortic stenosis and aged >80 years is considerable (28%).18 Therefore, this subgroup of patients may potentially be referred for TAVI. Although initial successful experiences,19 current recommendations suggest the presence of bicuspid aortic valves as a contraindication for TAVI procedures due to a high likelihood of unfavourable prosthesis deployment.7,20 In addition, bicuspid valve anatomy is frequently associated with aortic root dilatation that may challenge the TAVI procedure.21 Indeed, an aortic root dimension >45 mm at the sino-tubular junction is a contraindication for self-expandable prosthesis implantation.7

Furthermore, the assessment of the extent and location of valvular calcifications may be of importance to anticipate potential procedural complications such as unfavourable deployment of the prosthesis and subsequent valvular regurgitation, embolization of bulky calcifications and subsequent stroke, or occlusion of one of the coronary ostia by a severely thickened and calcified valve leaflet (Figure 2).17,20 For example, Zegdi and co-workers described the positioning and deployment of self-expandable transcatheter aortic valve prosthesis in 35 patients with symptomatic, severe aortic stenosis.20 In 21% of the patients with tricuspid valve anatomy, a triangular deployment of the prosthesis was observed. This less favourable prosthesis deployment could be explained by the cal-
cified leaflet's rigidity that prevented adequate displacement of the leaflets and proper prosthesis deployment.20 Furthermore, the triangular deployment resulted in gaps between the external surface of the stented valve and the inner surface of the native aortic valve. These gaps were exclusively located at the level of the commissures and coincided with the location of the paravalvular leaks.

Transthoracic echocardiography is the technique of choice to evaluate all these issues. However, in presence of suboptimal acoustic window, transesophageal echocardiography may help to define the aortic valve anatomy. Recently, MDCT and MRI have emerged as valuable imaging techniques to evaluate the anatomy and function of the aortic valve.22-24 Excellent agreements between MDCT, MRI and echocardiography for the assessment of valve morphology and aortic valve area have been reported.23 These 3-dimensional imaging techniques provide exact characterization of the aortic valvular anatomy. In particular, MDCT provides clear and accurate visualizations and quantifications of valvular calcifications, which is of importance in anticipating the results of the prosthesis deployment (Figure 2).

**Figure 2. Assessment of aortic valvular anatomy and calcifications.** Transesophageal echocardiography permits exact visualization of the anatomy of the aortic valve: tricuspid (panel A) or bicuspid (panel B). In addition, valvular calcifications can be visualized as hyperechogenic thickened leaflets (arrow). However, MDCT may be the imaging technique of choice to evaluate accurately valvular calcifications (panel C and D, arrows). MDCT enables exact characterization of valvular anatomy (tricuspid, panel C / bicuspid, panel D) and visualization location (free edge of the leaflets, commissures or hinge points) of valvular calcium.

Abbreviations: LA = left atrium; RV = right ventricle.
Assessment of feasibility of TAVI procedures

To assess the feasibility of TAVI, the following factors should be evaluated: measurement of the aortic annulus, assessment of coronary artery anatomy, evaluation of left ventricular function and evaluation of the aorta and peripheral arteries with special attention to size, calcifications and tortuosity of the arteries.

One of the key points of TAVI procedures is the selection of the prosthesis size. Prosthesis size selection depends on accurate aortic valve annulus sizing and is crucial to minimize potential procedural complications such as paravalvular leaks or prosthesis migration. At present, no gold standard method to measure the aortic valve annulus has been established. Currently, 2-dimensional transthoracic or transesophageal echocardiography are the most widely used techniques to estimate aortic valve annulus size. However, transthoracic echocardiography significantly underestimates the aortic valve annulus size as compared to transesophageal echocardiography with a mean difference of 1.36 mm (95% confidence interval -4.48 mm to 1.75 mm). In addition, 2-dimensional
Echocardiography assumes a circular aortic valve annulus, thereby introducing an important error for valve area calculations and for aortic valve annulus sizing. In this regard, 3-dimensional imaging techniques may provide a more accurate assessment of shape and size of the aortic valve annulus. Recent studies have demonstrated the value of MDCT to assess the morphology and size of the aortic valve annulus. In a series of 169 patients, including 19 patients with aortic stenosis, MDCT demonstrated an oval shape of the aortic valve annulus with the coronal diameter larger than the sagittal diameter (26.3 ± 2.8 mm vs. 23.5 ± 2.7 mm). These findings may have important implications on prosthesis size selection. However, at present, there are no prospective studies comparing the impact of different valvular annulus sizing methodologies on the selection of the prosthesis size and the procedural results.

The presence of congenital coronary anomalies or significant coronary artery disease amenable to percutaneous coronary intervention should be evaluated before TAVI. Invasive coronary angiography is the preferred method to assess the coronary anatomy and, in case of severe coronary artery disease, percutaneous coronary intervention can be performed in the same procedure. However,
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MDCT is also a valuable technique to accurately assess the coronary anatomy and to evaluate the position of the coronary ostia relative to the aortic valve annulus plane (Figure 4). Particularly, the distance between the coronary ostia and the aortic valve annular plane has important clinical implications for TAVI as the risk of coronary ostium occlusion by one of the aortic leaflets increases when the height of the coronary ostium decreases. Recently, in 169 patients scanned with MDCT, Tops and co-workers demonstrated a large variability in the height of the coronary ostia, ranging from 7.1 mm to 22.7 mm. Therefore, the assessment of the distance between the aortic valve annulus plane and the coronary ostia may be of interest in order to avoid potential fatal complications such as occlusion of the coronary ostia and myocardial infarction.

In addition, left ventricular dimensions and function should be evaluated. The presence of severe left ventricular dysfunction may challenge the TAVI procedure due to an increased risk of hemodynamic instability. Moreover, the assessment of left ventricular wall thickness, mainly at the septum and the apex, has important implications. The presence of previous apical myocardial infarction and apical wall thinning may contraindicate the transapical approach due the high risk of left ventricular tearing. In addition, the presence of left ventricular thrombus is an established contraindication for TAVI and may be evaluated with contrast echocardiography.

Finally, the size, tortuosity and extent of peripheral arterial calcifications will determine the procedural approach. Small diameter (< 6-9 mm) and severe tortuosity and calcifications of the peripher-
eral arteries are contraindications for a transfemoral approach. In addition, the presence of porcelain aorta may preclude the transfemoral approach due to the risk of embolization of calcified plaques. Invasive angiography is the reference method to evaluate the ilio-femoral artery system. However, MDCT also provides detailed imaging of the extent of calcification and tortuosity along the course of the ilio-femoral arteries and abdominal and thoracic aorta, and permits cross-sectional diameter measurements (Figure 5). In patients with renal insufficiency, MRI without gadolinium contrast is an alternative to MDCT to characterize the aorto-ilio-femoral system. Magnetic resonance angiography provides accurate assessments of the stenosis severity of iliac arteries. In addition, true-fast imaging with steady-state free precession sequence acquisitions allow characterization of the vessel wall with atherosclerosis and arterial wall thrombosis detected on high quality images.

Role of cardiac imaging during TAVI
As previously described, the TAVI procedure includes several sequential steps that can be guided by different imaging modalities in order to minimize the number of procedure-related complications. Fluoroscopy and transesophageal echocardiography are commonly used to guide the TAVI procedure. First, the aortic valve is crossed with the guide wire and the waist of the balloon is positioned at the aortic valve annulus level. During these initial stages, fluoroscopy uses calcifications of the non-coronary cusp as anatomical landmarks whereas transesophageal echocardiography permits direct visualization of the aortic valve (at 30-50° short-axis and 110-130° long-axis views of the aortic valve) (Figure 6).
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Thereafter, balloon aortic valvuloplasty is performed under rapid right ventricular pacing. After successful balloon aortic valvuloplasty, the motion of the aortic cusps, transaortic pressure gradients and the presence and severity of aortic regurgitation can be evaluated with echocardiography. Following that, positioning and deployment of the transcatheter prosthesis are performed. The delivery catheter is guided retrogradely (transfemoral approach) or antegradely (transapical approach) across the aortic valve by fluoroscopy or transesophageal echocardiography using the same initial landmarks. Failure to cross the aortic valve with the delivery catheter or prosthesis has been reported in 2.3-6% of the cases.32,33 Exact positioning of the prosthesis valve is crucial to avoid complications such as prosthesis misdeployment and consequent paravalvular leak or prosthesis migration. In a recent series of 50 patients with severe aortic stenosis undergoing TAVI (Edwards Sapien valve), the use of transesophageal echocardiography together with fluoroscopy resulted in a higher rate of successful valve deployment compared to those procedures without transesophageal echocardiography guidance (89% vs. 77%, p = 0.36).25

Finally, the function of the deployed prosthesis should be assessed by confirming immediate reduction in the transaortic pressure gradients and identification of significant paravalvular or valvular aortic regurgitation. In cases of moderate to severe paravalvular leaks, post-dilatation of the deployed prosthesis using larger balloons maybe needed. At present, recent studies have reported a low incidence of moderate to severe paravalvular regurgitation (1-3%) whereas the incidence of mild paravalvular regurgitation is higher (50%).14,25,33

In addition, transesophageal echocardiography may be useful to diagnose procedural complications such as cardiac tamponade, coronary occlusion or aortic dissection.
Role of cardiac imaging to evaluate mid- and long-term results of TAVI

At follow-up, the position, deployment and function of the prosthesis should be assessed, together with left ventricular function and other hemodynamic indices that reflect the performance of the implanted prosthesis. Transthoracic echocardiography is the imaging modality of choice to evaluate all these issues. However, the low spatial resolution and poor acoustic windows may limit its accuracy in evaluating prosthesis position and deployment. In this regard, MDCT may provide accurate information on positioning and deployment of the prosthesis and may help to understand the underlying mechanisms of paravalvular leaks when present. The presence of bulky calcifications may prevent a favourable deployment of the prosthesis and a snug seal, leading to significant paravalvular leak (Figure 7).20 As previously mentioned, the incidence of moderate to severe valvular regurgitation is low (1-3%) whereas the presence of mild valvular regurgitation is not uncommon (50%).7 Recent studies have demonstrated that mild paravalvular leaks remain stable over time (1-year follow-up).33 However, the long-term impact of moderate to severe paravalvular leaks remains unclear and additional studies are needed to identify complications such as the occurrence of low-grade hemolysis.

In addition, the long-term durability of the prosthesis will need to be studied in light of recent case reports of ingrowths and thrombosis of the prosthesis.34,35

CONCLUSIONS

The number of transcatheter aortic valve implantation procedures has dramatically increased in the last decade. Current evidence has demonstrated that TAVI is a feasible procedure that provides hemodynamic and clinical improvement to patients with severe aortic stenosis and high operative risk. However, further research and technical developments are warranted in order to minimize complications such as vascular injury, paravalvular leak, atrioventricular block and stroke. In addition, studies are needed to elucidate the long-term durability of transcatheter prosthesis. Multimodality cardiac imaging is important in order to achieve the highest procedural success rates while minimizing the frequency of complications. Good patient selection requires accurate evaluation of aortic stenosis severity, aortic annulus sizing and peripheral vascular assessment. Echocardiography, MDCT and MRI are complementary imaging techniques that provide a comprehensive assessment. During the TAVI procedure, combination fluoroscopy and transesophageal echocardiography constitutes the best approach in guiding the procedure. Finally, at follow-up, echocardiography permits the evaluation of the mid- and long-term prosthesis hemodynamics whereas MDCT may be of value in characterizing the position and deployment of the prosthesis.
EXPERT COMMENTARY AND FIVE-YEAR VIEW

The Euro Heart Survey on Valvular Heart Disease recently showed that over 30% of high-risk patients with symptomatic, severe aortic valve stenosis were not referred or denied for surgery. Older age, depressed left ventricular systolic function and associated co-morbidities were the main reasons that determine the decision making of these patients. The advent of TAVI procedures, with the first-in-man experience in 2002, provided a novel therapeutic option for those patients. Indeed, recent clinical experiences, including more than 8000 high-risk patients with symptomatic, severe aortic valve stenosis, have demonstrated the feasibility of TAVI procedures, with acceptable mortality rates. Accurate patient selection and high procedural experience are crucial to achieve high success rates and low complication rates. Multimodality imaging plays a central role in patient selection, procedural guiding and evaluation of immediate and long-term follow-up results. Aortic valve annular size is the key issue to select the prosthesis size; 3-dimensional imaging techniques may be preferred over 2-dimensional techniques since they provide exact characterization of the aortic valve annular shape and size. Particularly, MDCT permits evaluation of the geometry and size of the aortic valve annulus and, furthermore, provides exact information on extent and location of valvular calcifications, aortic root dimensions and spatial relationship with the surrounding structures. In addition, accurate assessment of peripheral arterial system and aorta is crucial to determine the feasibility of the transfemoral approach. In this regard, MDCT and MRI (for patients with renal failure) are valuable imaging techniques to evaluate this aspect. During the TAVI procedure, fluoroscopy plays a central role to guide the procedure. However, transesophageal echocardiography is a valuable imaging technique to evaluate the immediate results of the TAVI procedure and to diagnose potential complications. Finally, at long-term follow-up, evaluation of function, positioning and deployment of the transcatheter prosthesis is mandatory. Transthoracic echocardiography may be the imaging modality of choice to evaluate these issues. However, 3-dimensional imaging techniques such as MDCT may be of value to better characterize the positioning and deployment of the prosthesis.

With the development of smaller transcatheter valve and delivery system profiles, the number of complications is expected to decrease and the TAVI procedure will become even more minimally invasive. In addition, based on recent clinical experience and upon the results of the ongoing multicenter trials, it is expected that, in the next years, the indications for TAVI will expand, including less high-risk patients. Additional studies using multimodality imaging to select the patients undergoing TAVI procedures, to guide the procedure and to evaluate the results at follow-up will provide the basis to define the role of these imaging techniques in this field. In addition, multimodality imaging will provide information on the hemodynamic performance of these devices at long-term follow-up, providing also valuable data for the design of new devices.
REFERENCES


