EuroIntervention

Imaging decision-making for transfemoral or transapical approach of transcatheter aortic valve implantation

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The authors have no conflict of interest to declare.

This paper also includes accompanying supplementary data published at the following website: www.eurointervention.org

KEYWORDS
Preprocedural evaluation, imaging, transapical, transfemoral, transcatheter aortic valve implantation, aorto-iliac angiography, CT-angiography, aortic annulus, aortic root, calcification, tortuosity, complications

Abstract

Transcatheter aortic valve implantation has been shown to be a feasible alternative to surgical aortic valve replacement in selected high-risk patients. Although, being less invasive, catheter techniques remain associated with the potential of serious complications. Procedural success and avoidance of such complications critically depends on careful patient selection and comprehensive preprocedural evaluation of vascular access, cardiac and aortic root anatomy. This article reviews the role of currently available imaging modalities for appropriate patient selection and decision between transfemoral and transapical approach.

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Introduction

Since its first in human use in 2002[1], transcatheter aortic valve implantation (TAVI) has rapidly evolved. Currently, more than 8,000 procedures have been performed in selected high-risk patients with severe calcific aortic stenosis (AS) demonstrating outcomes that compare overall favourably with the outcome of conventional valve replacement as predicted by validated operative risk assessment tools[2-5]. Two TAVI systems have so far achieved the CE mark and are commercially available in Europe: the balloon-expandable Edwards valve (Edwards Lifesciences, Irvine, CA, USA) allowing either retrograde transfemoral or antegrade transapical application and the self-expanding CoreValve ReValving system (Medtronic Inc., Minneapolis, MN, USA) designed primarily for the retrograde transarterial (femoral, alternatively subclavian) approach. Although TAVI is less invasive than conventional valve replacement, it remains associated with the potential of a number of serious complications including femoral artery, iliac artery and aortic injury, stroke, prosthesis embolisation, coronary obstruction, paravalvular regurgitation, mitral valve injury, annular and aortic root rupture, cardiac perforation, heart block and acute renal failure[6]. Procedural success and avoidance of complications largely depends on careful patient selection that besides assessment of clinical patient characteristics primarily focuses on anatomical issues. With this regard, imaging modalities including transthoracic (TTE) and transesophageal (TEE) echocardiography, multislice computed tomography (CT), magnetic resonance imaging (MRI) and invasive angiography have gained a key role for patient screening. Current experience demonstrates different strengths and limitations of these techniques suggesting a multimodality approach of cardiovascular imaging for optimal patient evaluation. This article aims to demonstrate diagnostic pathways that comprehensively guide the selection of patients for TAVI and the decision between the transfemoral and transapical approach.

Patient selection and eligibility for TAVI: general considerations

Current ESC guidelines on the management of valvular heart disease do not yet include specific recommendations concerning indication, patient selection or technical aspects of TAVI[7]. Since their publication in 2007 this technique has however seen wide clinical application[2-4] being one reason why the guidelines will shortly require revision. A joint position statement from the European Association of Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI)[8] was published in 2008 describing basic technical aspects of TAVI and providing preliminary recommendations for its use and further development. Patient eligibility for TAVI includes clinical and anatomical criteria. Indications for intervention as described in the current guidelines referring to surgical valve replacement[7] must also be met when TAVI is considered (severity of AS, presence of symptoms, risk factors of worse outcome in asymptomatic patients). Nevertheless, improvement of quality of life will predominate in the decision to intervene rather than prognostic considerations in elderly patients with significant comorbidities. Significantly increased surgical risk, primarily defined by a logistic EuroSCORE >20% or STS-Score >10%[8,9] or by conditions such as porcelain aorta or previous chest radiation is the currently recommended prerequisite for choosing TAVI as an alternative to surgery[8]. However, the reliability of currently used scoring systems has been questioned in isolated aortic valve replacement and suggested to overestimate the actual risk[10]. On the other hand, patients older than 80 years particularly in the presence of frailty may rather be considered for TAVI even with lower scores[11]. In any case, the decision should be made by a multidisciplinary team including cardiologists, cardiac surgeons and anaesthesiologists. Patients who fulfil the clinical criteria for TAVI must, in a next step, be carefully evaluated with regard to technical and anatomical requirements for the catheter based procedure. Since the transfemoral approach is the least invasive and allows the fastest recovery it is generally preferred when applicable. Because of the large sheath size (at least 18 Fr) suitability of the femoral and iliac arteries but also the aorta must be evaluated with regard to lumen diameters, tortuosity, and extent of disease (calcification, obstruction, complex plaques). Less commonly, the transapical access may be limited by chest abnormalities after previous surgery, by anatomic variations, abnormal intra-thoracic heart axis or apical thrombi. Both, transfemoral and transapical implantation require evaluation of the heart and the aortic root including anatomy of the aortic valve, annulus size, size and anatomy of the aortic root (sinuses), distance between annulus and coronary arteries, left ventricular outflow tract morphology and length of the ventricle[6]. All these characteristics are best provided by multimodality cardiovascular imaging that plays therefore a key role for patient selection and the decision between transfemoral and transapical approach as well as for procedural success and safety.

Vascular access

Entry site, vessel course and tortuosity, luminal diameter and degree of calcification or obstruction determine the success or failure of the transfemoral approach. Assessment of the vascular access is therefore the key information for the decision between transfemoral and transapical approach.

Simple and commonly available ultrasound of the femoral arteries can provide information about vessel wall thickness, calcification, plaque burden and diameter. Sonography is usefulness to assess wall morphology[12] and was evaluated in comparison with conventional angiography, with good results[13]. Especially the ventral vessel wall is of critical importance for sheath insertion and vascular closure after the TAVI procedure. (Figure 1)

Along with preprocedural invasive coronary angiography and haemodynamic evaluation, overview angiography of the iliac and femoral arteries can be used as a first screening modality to determine potential suitability for transfemoral TAVI. In particular, a definitely unsuitable vessel status can be ruled out. Although single plane angiography has been reported to provide useful information on vessel diameter, calcification and tortuosity before TAVI[14], biplane technique (anterior-posterior and 60-80° oblique projections with 15-20 ml with 12-15 ml/sec flow rate) is obviously superior for evaluation of vessel course and eccentric lumen reduction. (Figure 2)

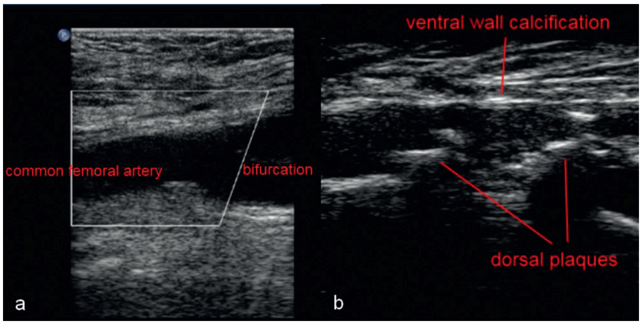

Figure 1. Ultrasound images. (a) Common femoral artery with almost no calcification in a 84 years old patient with suitable diameter for transfemoral approach (later successfully treated with a 26 mm Edwards SAPIEN valve) (b) Heavily calcified common femoral artery of a 74 years old patient with typical dorsal plaques reducing arterial lumen and ventral wall calcification (later on successfully treated with 26 mm Edwards SAPIEN valve via transapical approach).

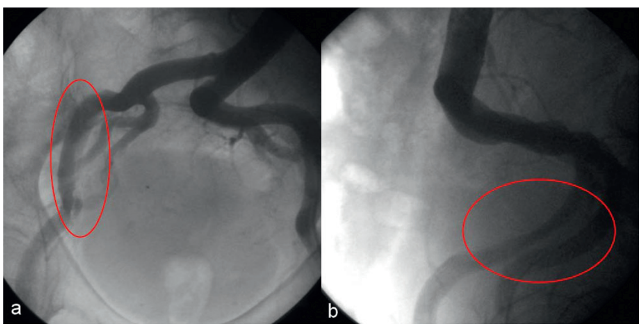

Figure 2. Invasive angiography. (a) Anterior-posterior projection of an aorto-iliac angiogram with tortuous arteries and dissection caused by the wire during preprocedural invasive evaluation. No flow compromise was observed and no treatment was necessary. The dissection was no longer detectable by CT after two weeks and the patient was successfully treated by transfemoral approach from the right common femoral artery later on. Suitable vessel diameters and low degree of calcification made the femoral access possible despite tortuosity. (b) Lateral (LAO 80°) projection of the aorto-iliac angiogram with the dissection already shown in panel a. The dissected segment is longer than expected from the anterior-posterior projection.

The required minimum lumen diameters for the two TAVI systems are shown in Table 1. Although a limit for vessel angulation of 40 degrees has also been recommended[15], it must be kept in mind that the ability to straighten a tortuous vessel with a stiff guidewire and advancing of the sheath without significant risk of dissection or even vessel perforation depends not only on the angle but largely on the vessel quality. Diseased arteries may may not be suitable be suitable with significantly less angulation. Apical access should be preferred in this case.

CT-angiography has proven to have high diagnostic value for peripheral arterial disease[16-18] and is the most comprehensive approach for complete 2D and 3D vessel imaging. It should be performed for further evaluation, if angiographic screening during invasive evaluation suggests suitability for transfemoral access and in any case if an overview angiography is not available. The CT scan provides full information not only about the degree of calcification but also about plaque allocation (e.g., circular wall, intraluminal calcium spur). Non-calcified and mildly but non-circularly calcified arteries may be stretched by the sheath in the situation of borderline vessel diameters. CT allows precise lumen measurements and demonstrates vessel course, ideally in 3D reconstructions of the region of interest[19]. MRI may also be used for angiography of the aorta, iliac and femoral arteries but this modality has major limitations in calcification imaging. CT is therefore preferable and MRI not routinely used in TAVI preprocedural evaluation. (Figures 3 and 4)

Annulus diameter, aortic valve and aortic root morphology

The configuration and anatomical variations of the aortic annulus have gained great interest since the clinical introduction of TAVI. A precise measurement of the annulus diameter is crucial for the decision whether a patient is eligible for TAVI and for the selection of the appropriate prosthesis size. It may be pivotal for consequences like valve embolisation, aortic annulus or root rupture and intolerable paravalvular leakage. Nevertheless, no gold standard for the measurement of this crucial variable could so far be established. Basically the annulus is a virtual basal ring which is defined by the lowest insertion of the aortic valve leaflets, whereas the leaflets themselves, each being attached to the aortic root in a semi-lunar constitution, form a crown-like shape. CT studies have shown that the annulus itself is of oval shape and not circular[20,21], but the clinical impact of this finding on TAVI remains unclear[22]. The two orthogonal diameters from multiplanar reconstruction (long and short axis) that define the oval shape differ from standard echocardiographic imaging planes and tend to be somewhat larger than the measurements by TTE (parasternal long axis view) or TEE (3-chamber view in 110-140°). Using an "echo-like" image reconstruction of CT in a 3-chamber view annulus diameters correlate better with TTE and TEE, but the difference between CT and echo measurements remain larger than between the echo modalities[20]. In contrast to

Table 1. Recommended annulus size and minimum arterial diameter for currently available TAVI valve sizes.

	Medtronic CoreValve 3rd generation		Edwards SAPIEN		Edwards SAPIEN XT	
Valve size	26 mm	29 mm	23 mm	26 mm	23 mm	26 mm¶
Annulus diameter*	20-24 mm	24-27 mm	18-21 mm	21-25 mm	18-21 mm	21-25 mm
Sheath size (TF)	18 Fr	18 Fr	22 Fr	24 Fr	18 Fr	19 Fr
Sheath size (TA)	(21 Fr‡)	(21 Fr‡)	26 Fr	26 Fr	22 Fr	22 Fr
Arterial diameter**	6 mm	6 mm	8 mm	9 mm	6 mm	7 mm

TF: transfemoral; TA: transapical; *recommendations refer to TEE measurements of the annulus diameter; **slightly smaller minimum diameters may be acceptable when good vessel quality allows stretching (see text); ¶29 mm for transapical implantation already developed and available for use later this year; ‡limited experience available

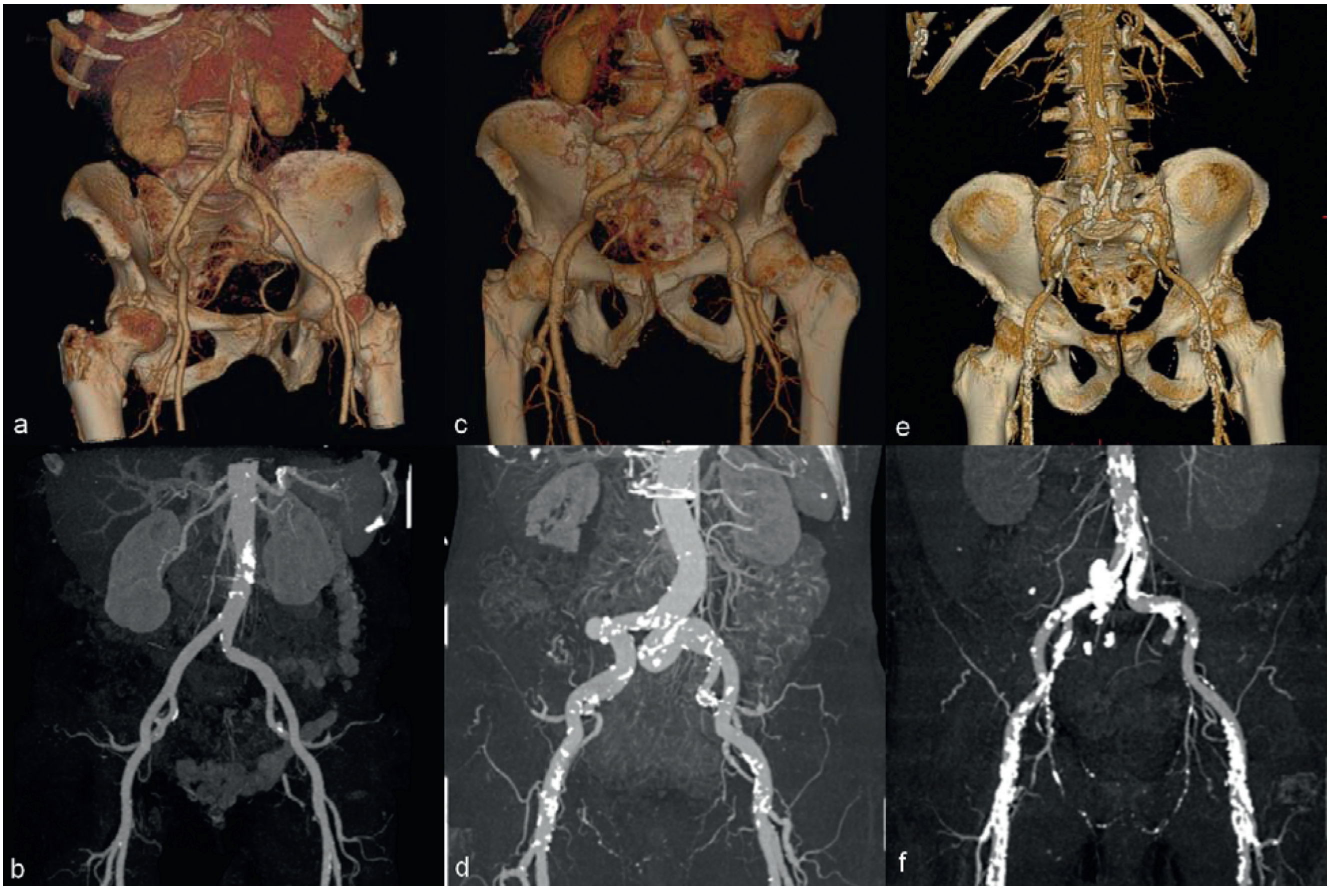

Figure 3. 3D volume rendering and maximum intensity projection reconstructions. (a+b) Reconstructions of non-calcified iliac arteries without relevant tortuosity and with suitable diameters for transfemoral TAVI. (c+d) Reconstructions of massively tortuous iliac arteries with a nearly 180° kinking of the left common iliac artery. (e+f) Reconstructions of heavily calcified iliac and especially femoral arteries unsuitable for transfemoral access.

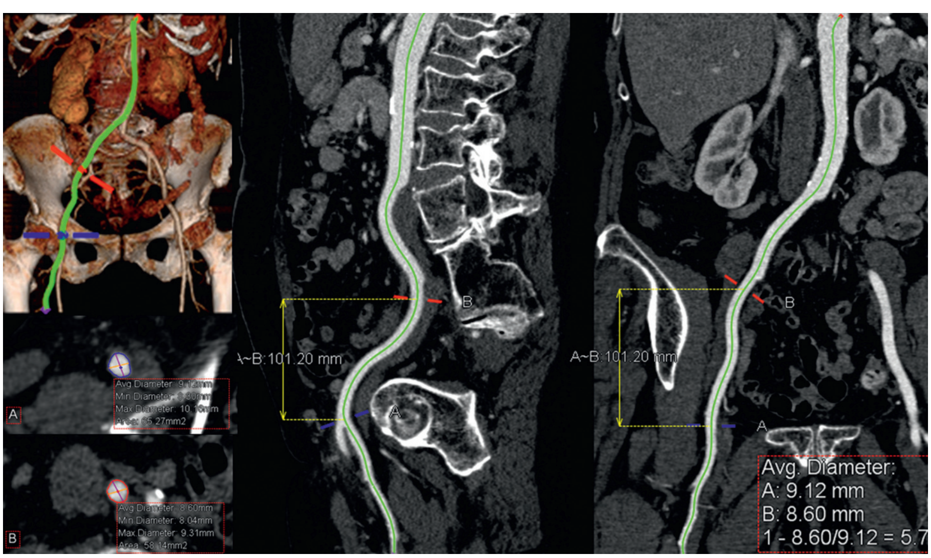

Figure 4. Vessel reconstruction tool. Vessel reconstruction and measurement of lumen diameters in selected areas (Aquarius Intuition Edition 4.4, TeraRecon Inc., San Mateo, CA, USA).

other investigators[23,24] who reported TEE diameters to be slightly (approximately 1 mm) larger than TTE measurements, the same authors did not observe a significant difference between TTE and TEE diameters, but they excluded patients with poor image quality from the analysis.

In clinical practice, TTE allows appropriate screening in the majority of patients. When measurements in the upper range of suitable diameters are found or image quality is insufficient, additional preprocedural TEE is advisable[24]. To date TEE guided implantation while being aware of CT morphology and angiographic findings (including relation of valvuloplasty balloon to the aortic root) provides good clinical results (Figure 5). Furthermore, it has to be emphasised that current recommendations for patient eligibility and for prosthesis size choice refer to TEE diameters. Current recommendations for prosthesis choice with regard to annulus size are summarised in Table 1.

Anatomical characteristics of aortic valve such as bicuspid or tricuspid leaflet configuration and degree of calcification have direct impact on valve deployment. Although successful implantations have been reported, bicuspid valves are currently considered unfavourable for TAVI because of the potential of stent maldeployment[8,25-27]. Although the current techniques of TAVI requires a calcified valve ensuring a stable prosthesis position, severe calcification may interfere with stent expansion and lead to relevant paravalvular leakage[28]. Imaging and allocation of calcification especially in relation to the aortic root can be provided by angiography, echocardiography or CT[19,29,30]. In the case of a small aortic root with poorly developed sinuses, bulky calcifications may perforate the aortic wall with fatal consequences. (Figure 6) Obstruction of the coronary ostia after deployment of the prosthesis is relatively rare[4,5,31] although the distance between the annulus and the coronary ostia was observed to be smaller than the length of aortic valve cusps in almost 50% of patients[21]. A minimum distance of 8 to 10 mm between annulus and coronary ostia is recommended for the SAPIEN valve to minimise the risk of obstruction. Conventional angiography of the aortic root does usually not provide a clear picture of this anatomic relation, but ECG-triggered CT imaging allows precise measurements (Figure 7). It is important to recognise that the risk of coronary ostium obstruction is not simply related to the distance from the annulus but also depends on the root morphology (size of sinuses) and the extent of valve calcification and its mobilisation by the stent. Better imaging

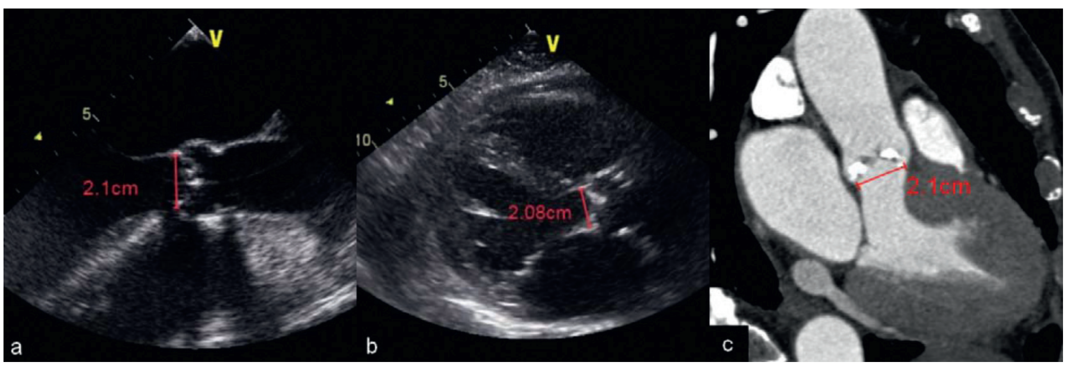

Figure 5. Measurement of the aortic valve annulus with different modalities. Measurements of the aortic valve annulus in (a) TEE, (b) TTE and (c) CT imaging (in an "echo-like" 3-chamber view).

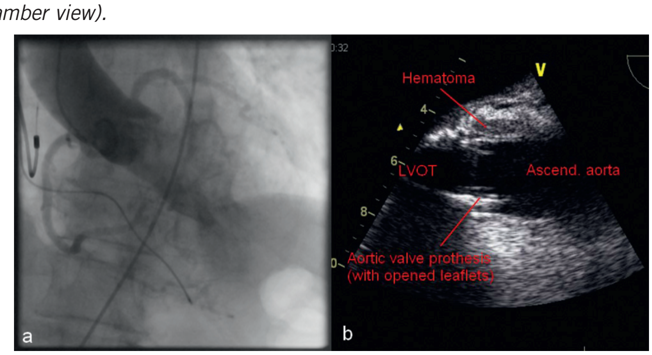

Figure 6. Narrow aortic root and wall haematoma (possible complication of TAVI). Angiogram of a narrow aortic root before TAVI in a patient with bulky calcification of the aortic valve (a). TEE image of an aortic wall haematoma after implantation of an Edwards SAPIEN valve in the same patient (b).

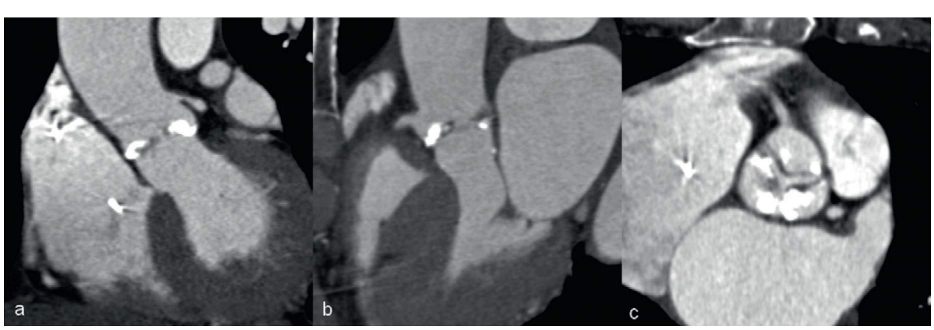

Figure 7. ECG-triggered CT images of the aortic root, valve area and coronary ostia. The distance between left and right coronary arteries and aortic annulus can be appreciated (a+b). Note the calcified right coronary cusp that might obstruct the ostium of the RCA during implantation of the stent prosthesis. (c) shows heavy calcification of all three cusps of the native valve.

criteria and algorithms to predict this risk need to be developed. Prosthesis stent struts may furthermore interfere with guiding catheter intubation (particularly after CorValve implantation), but successful cases of interventional coronary angioplasty of patients pre-treated with TAVI have been described[32,33].

Additional anatomical considerations

Although not well defined, severe hypertrophy of the basal interventricular septum may also interfere with stent employment and may be related to the occurrence of conductance disturbance. Very small ventricles with a length of less than 5 cm between valve and apex may be at increased risk of ventricular damage. Apical thrombi may cause embolic events during transfemoral TAVI and are also a contraindication for transapical intervention. These findings are provided by echocardiography.

Decision between transfemoral and transapical approach

Although the key information for the decision between transfemoral and transapical valve implantation is the suitability of vascular access, several other aspects need to be considered. Severe lung disease makes even a mini-thoracotomy undesirable. Severe pericardial calcification, extensive epicardial fat tissue at the apex, left ventricular epicardial patches and a dysmorphic chest anatomy that makes the apex difficult to reach are rare additional conditions making the apical approach difficult or occasionally impossible. CT is helpful for the evaluation with this regard.

Besides pathology of femoral and iliac arteries, massive kinking of the aorta, a transverse course of the ascending aorta and complex plaques with thrombus formation in the aorta favour the transapical approach. The latter can in general also be performed with smaller amounts of contrast media. This may be an advantage in patients with severe renal failure.

For patients with unsuitable femoral access, alternatives include - besides the transapical implantation-, subclavian, open iliac or ascending aorta approaches, or reconstruction of ilio-femoral axis with stents or grafts. Limited experience exists for these alternatives.

Summary

Cardiovascular imaging, ideally with a multimodality approach, plays a key role in selecting patients for TAVI and the decision between transfemoral and transapical approach. Detailed evaluation of vascular access and anatomical characteristics particularly including aortic valve morphology, annulus size, aortic root morphology and coronary artery ostia location is crucial for procedural success and avoidance of complications. Echocardiography, as the fist line diagnostic tool, provides detailed information not only on aortic stenosis severity, but also on valve morphology, annulus size and the left ventricle, as well as, the diameters of the ascending aorta. Widely available sonography of the femoral arteries can provide first information on arterial disease. Aorto-iliac angiography performed along with invasive coronary angiography and haemodynamic evaluation can be used as a first screening modality to determine the potential suitability for transfemoral TAVI. ECG-triggered CT of the aorta from the aortic root to femoral arteries plays however a key role in image-based decision making providing comprehensive evaluation of the vascular access, aortic root anatomy, annulus size, valve calcification and distance to the coronary ostia. Besides the CT scan may reveal comorbidities such as undiscovered cancer which is not uncommon in elderly patients being evaluated for TAVI. The value of the different imaging modalities for the evaluation of the various anatomical characteristics is summarised in Table 2. Finally, it has to be emphasised that optimal patient evaluation requires a multidisciplinary team of cardiologists, cardiac surgeons and radiologists.

Acknowledgements

The authors would like to thank Dr. Volker Vieth (Department of Radiology, University of Muenster) and Dr. Matthias Meyborg (Department of Cardiology and Angiology, University of Muenster) for their support in the selection and processing of the ultrasound and CT-images.

References

1. Cribier A, Eltchaninoff H, Bash A, Borenstein N, Tron C, Bauer F, Derumeaux G, Anselme F, Laborde F, Leon MB. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. *Circulation.* 2002;106:3006-3008.

2. Piazza N, Grube E, Gerckens U, den Heijer P, Linke A, Luha O, Ramondo A, Ussia G, Wenaweser P, Windecker S, et al. Procedural and 30-day outcomes following transcatheter aortic valve implantation using the third generation (18 Fr) corevalve revalving system: results from the multicentre, expanded evaluation registry 1-year following CE mark approval. *EuroIntervention.* 2008;4:242-249.

3. Walther T, Simon P, Dewey T, Wimmer-Greinecker G, Falk V, Kasimir MT, Doss M, Borger MA, Schuler G, Glogar D, et al. Transapical minimally invasive aortic valve implantation: multicenter experience. *Circulation.* 2007;116:240-245.

Table 2. Role of TTE, TEE, CT, MRI and invasive angiography for TAVI preprocedural evaluation.

Characteristics to be evaluated	TTE	TEE	CT	MRI	Invasive
AS severity	++	+	±	±	+
Valve morphology	+	++	+	±	–
Annulus diameter	+	++	+	+	+
Femoral artery	–	–	++	+	+
Aorta and iliac arteries	–	–	++	+	+
Coronary ostia to aortic annulus distance	±	±	++	+	±
Aortic root morphology	+	+	++	+	+

AS: aortic stenosis; CT: multislice computed tomography; MRI: magnetic resonance imaging; TEE: transesophageal echocardiography; TTE: transthoracic echocardiography; – not useful; ± limited usefulness; + useful; ++ very useful (method of choice)

4. Webb JG, Pasupati S, Humphries K, Thompson C, Altwegg L, Moss R, Sinhal A, Carere RG, Munt B, Ricci D, et al. Percutaneous transarterial aortic valve replacement in selected high-risk patients with aortic stenosis. *Circulation.* 2007;116:755-763.

5. Zajarias A, Cribier AG. Outcomes and safety of percutaneous aortic valve replacement. *J Am Coll Cardiol.* 2009;53:1829-1836.

6. Masson JB, Kovac J, Schuler G, Ye J, Cheung A, Kapadia S, Tuzcu ME, Kodali S, Leon MB, Webb JG. Transcatheter aortic valve implantation: review of the nature, management, and avoidance of procedural complications. *JACC Cardiovasc Interv.* 2009;2:811-820.

7. Vahanian A, Baumgartner H, Bax J, Butchart E, Dion R, Filippatos G, Flachskampf F, Hall R, Iung B, Kasprzak J, et al. Guidelines on the management of valvular heart disease: The Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. *Eur Heart J.* 2007;28:230-268.

8. Vahanian A, Alfieri O, Al-Attar N, Antunes M, Bax J, Cormier B, Cribier A, De Jaegere P, Fournial G, Kappetein AP, et al. Transcatheter valve implantation for patients with aortic stenosis: a position statement from the European Association of Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur Heart J.* 2008;29:1463-1470.

9. Vassiliades TA, Jr., Block PC, Cohn LH, Adams DH, Borer JS, Feldman T, Holmes DR, Laskey WK, Lytle BW, Mack MJ, et al. The clinical development of percutaneous heart valve technology: a position statement of the Society of Thoracic Surgeons (STS), the American Association for Thoracic Surgery (AATS), and the Society for Cardiovascular Angiography and Interventions (SCAI) Endorsed by the American College of Cardiology Foundation (ACCF) and the American Heart Association (AHA). *J Am Coll Cardiol.* 2005;45:1554-1560.

10. Wendt D, Osswald B, Thielmann M, Kayser K, Tossios P, Massoudy P, Kamler M, Jakob H. The EuroSCORE - still helpful in patients undergoing isolated aortic valve replacement? *Interact Cardiovasc Thorac Surg.* 2010;10:239-244.

11. Piazza N, Otten A, Schultz C, Onuma Y, Garcia-Garcia HM, Boersma E, de Jaegere P, Serruys PW. Adherence to patient selection criteria in patients undergoing transcatheter aortic valve implantation with the 18F CoreValve ReValving System. *Heart.* 2010;96:19-26.

12. Wong M, Edelstein J, Wollman J, Bond MG. Ultrasonic-pathological comparison of the human arterial wall. Verification of intima-media thickness. *Arterioscler Thromb.* 1993;13:482-486.

13. Favaretto E, Pili C, Amato A, Conti E, Losinno F, Rossi C, Faccioli L, Palareti G. Analysis of agreement between Duplex ultrasound scanning and arteriography in patients with lower limb artery disease. *J Cardiovasc Med (Hagerstown).* 2007;8:337-341.

14. Eltchaninoff H, Kerkeni M, Zajarias A, Tron C, Godin M, Sanchez Giron C, Baala B, Cribier A. Aorto-iliac angiography as a screening tool in selecting patients for transfemoral aortic valve implantation with the Edwards SAPIEN bioprosthesis. *EuroIntervention.* 2009;5:438-442.

15. Ducrocq G, Francis F, Serfaty JM, Himbert D, Maury JM, Pasi N, Marouene S, Provenchere S, Iung B, Castier Y, et al. Vascular complications of transfemoral aortic valve implantation with the Edwards SAPIEN prosthesis: incidence and impact on outcome. *EuroIntervention.* 2010;5:666-672.

16. Heijenbrok-Kal MH, Kock MC, Hunink MG. Lower extremity arterial disease: multidetector CT angiography meta-analysis. *Radiology.* 2007;245:433-439.

17. Met R, Bipat S, Legemate DA, Reekers JA, Koelemay MJ. Diagnostic performance of computed tomography angiography in peripheral arterial disease: a systematic review and meta-analysis. *JAMA.* 2009;301:415-424.

18. Sun Z. Diagnostic accuracy of multislice CT angiography in peripheral arterial disease. *J Vasc Interv Radiol.* 2006;17:1915-1921.

19. Leipsic J, Wood D, Manders D, Nietlispach F, Masson JB, Mayo J, Al-Bugami S, Webb JG. The evolving role of MDCT in transcatheter aortic valve replacement: a radiologists' perspective. *AJR Am J Roentgenol.* 2009;193:W214-219.

20. Messika-Zeitoun D, Serfaty JM, Brochet E, Ducrocq G, Lepage L, Detaint D, Hyafil F, Himbert D, Pasi N, Laissy JP, et al. Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation. *J Am Coll Cardiol.* 2010;55:186-194.

21. Tops LF, Wood DA, Delgado V, Schuijf JD, Mayo JR, Pasupati S, Lamers FP, van der Wall EE, Schalij MJ, Webb JG, et al. Noninvasive evaluation of the aortic root with multislice computed tomography implications for transcatheter aortic valve replacement. *JACC Cardiovasc Imaging.* 2008;1:321-330.

22. Schultz CJ, Moelker A, Piazza N, Tzikas A, Otten A, Nuis RJ, Neefjes LA, van Geuns RJ, de Feyter P, Krestin G, et al. Three dimensional evaluation of the aortic annulus using multislice computer tomography: are manufacturer's guidelines for sizing for percutaneous aortic valve replacement helpful? *Eur Heart J.* 2009.

23. Fan CM, Liu X, Panidis JP, Wiener DH, Pollack PS, Addonizio VP. Prediction of Homograft Aortic Valve Size by Transthoracic and Transesophageal Two-Dimensional Echocardiography. *Echocardiography.* 1997;14:345-348.

24. Moss RR, Ivens E, Pasupati S, Humphries K, Thompson CR, Munt B, Sinhal A, Webb JG. Role of echocardiography in percutaneous aortic valve implantation. *JACC Cardiovasc Imaging.* 2008;1:15-24.

25. Zegdi R, Ciobotaru V, Noghin M, Sleilaty G, Lafont A, Latremouille C, Deloche A, Fabiani JN. Is it reasonable to treat all calcified stenotic aortic valves with a valved stent? Results from a human anatomic study in adults. *J Am Coll Cardiol.* 2008;51:579-584.

26. Zegdi R, Khabbaz Z, Ciobotaru V, Noghin M, Deloche A, Fabiani JN. Calcific bicuspid aortic stenosis: a questionable indication for endovascular valve implantation? *Ann Thorac Surg.* 2008;85:342.

27. Zegdi R, Lecuyer L, Achouh P, Didier B, Lafont A, Latremouille C, Fabiani JN. Increased radial force improves stent deployment in tricuspid but not in bicuspid stenotic native aortic valves. *Ann Thorac Surg.* 2010;89:768-772.

28. Delgado V, Ng AC, Shanks M, van der Kley F, Schuijf JD, van de Veire NR, Kroft L, de Roos A, Schalij MJ, Bax JJ. Transcatheter aortic valve implantation: role of multimodality cardiac imaging. *Expert Rev Cardiovasc Ther.* 2010;8:113-123.

29. Morgan-Hughes GJ, Owens PE, Roobottom CA, Marshall AJ. Three dimensional volume quantification of aortic valve calcification using multislice computed tomography. *Heart.* 2003;89:1191-1194.

30. Willmann JK, Weishaupt D, Lachat M, Kobza R, Roos JE, Seifert B, Luscher TF, Marincek B, Hilfiker PR. Electrocardiographically gated multidetector row CT for assessment of valvular morphology and calcification in aortic stenosis. *Radiology.* 2002;225:120-128.

31. Wendler O, Walther T, Nataf P, Rubino P, Schroefel H, Thielmann M, Treede H, Thomas M. Trans-apical aortic valve implantation: univariate and multivariate analyses of the early results from the SOURCE registry. *Eur J Cardiothorac Surg.* 2010.

32. Geist V, Sherif MA, Khattab AA. Successful percutaneous coronary intervention after implantation of a CoreValve percutaneous aortic valve. *Catheter Cardiovasc Interv.* 2009;73:61-67.

33. Zajarias A, Eltchaninoff H, Cribier A. Successful coronary intervention after percutaneous aortic valve replacement. *Catheter Cardiovasc Interv.* 2007;69:522-524.

Online data supplement

Video 1 (Case 1). 3D-volume-rendering reconstruction of a patient suitable for transfemoral approach. The arteries show a relatively straight course and no relevant calcification.

Video 2 (Case 1). Axial slices of the angio-CT-scan showing suitable lumen diameters for transfemoral approach.

Video 3 (Case 2). 3D-volume-rendering reconstruction of massively tortuous iliac arteries with nearly 180° degree kinking of left common iliac artery.

Video 4 (Case 2). Axial slices of the angio-CT-scan showing partly calcified and kinked arteries with relatively large lumen diameters

Video 5 (Case 3). 3D-volume-rendering reconstruction of heavily calcified iliac and femoral arteries unsuitable for transfemoral approach. Note the calcified lymph nodes ventral to the aortic bifurcation.

Video 6 (Case 3). Axial slices of the angio-CT-scan showing massively calcified arteries and lumen loss especially in the right common femoral artery.