Imaging techniques in aortic valve and root surgery

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Chapter 1:

General introduction
The role of multimodality imaging in the selection of patients for aortic valve repair

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Summary

Aortic valve sparing surgery for aortic regurgitation and/or aortopathy serves as an alternative to aortic valve and root replacement. One of the advantages of aortic valve sparing surgery over conventional replacement is that there is no need for life-long anticoagulation, which is particularly attractive in young patients who may receive a mechanical prosthesis otherwise. However, successful aortic valve repair requires high expertise. At present, reparability is determined intraoperatively by direct surgical inspection. Preoperative imaging techniques might improve the patient selection for aortic valve repair. The mechanism of aortic regurgitation, aortic valve morphology and calcification and aortic root dimensions are all of importance when aortic valve repair is considered. The present review focuses on the role of imaging techniques in determining aortic valve reparability.

Introduction

Aortic valve repair for aortic regurgitation and valve-sparing aortic root replacement for aortic root and ascending aorta aneurysm or dissection are feasible and safe alternative techniques to aortic valve replacement and tubular graft implantation. However, successful and durable aortic repair requires high expertise. In contrast to mitral valve repair for mitral valve regurgitation, where the pre-procedural and surgical exploration of the valvular pathology and the surgical techniques are more standardized,[1] aortic valve repair techniques are more heterogeneous. In addition, since the introduction of the remodeling and reimplantation techniques by Drs. Yacoub and David, respectively, several modifications of the techniques have been developed according to the experience of the centers.[2-4] Accurate characterization of the underlying pathology and mechanism of aortic regurgitation is crucial for selection of patients in who aortic valve repair techniques and valve-sparing aortic root replacement will be successful resulting in a durable competent aortic valve.

The present review article focuses on the role of non-invasive imaging to characterize the underlying mechanism of aortic regurgitation and selection of patients who are candidates for surgical aortic valve repair/valve-sparing aortic root replacement techniques

Aortic valve and root anatomy

The aortic root has a complex anatomy consisting of several components as shown in Figure 1. The aortoventricular junction, also called the annulus, is described as a virtual basal ring which separates the left ventricular outflow tract from the aortic root. It is defined by the circumference described by the nadirs of the aortic valve cusp attachments. The sinus of Valsalva consists of three bulges of the aortic wall. The coronary arteries arise from two of the sinuses, the right coronary sinus and the left coronary sinus. The remaining sinus is termed the non-coronary sinus and is spatially related with the interatrial septum. The morphology of the sinuses allows the formation of flow vortices during the left ventricular ejection to reduce the stress on the aortic valve cusps and support coronary flow.[5] The sinotubular junction is the circumference that supports the peripheral attachments of the aortic cusps and separates the aortic root from the ascending aorta.

The aortic valve consists of three semilunar cusps, commissures and intercusps triangles. The aortic cusps are termed according to their corresponding sinus as the left coronary cusp, right coronary cusp and non-coronary cusp. They are attached to the aortic root wall in a semilunar fashion forming the intercusps triangles. The apices of these triangles demark the commissures, defined as the areas where the attachments of the cusps have a parallel course for a short distance. In the general population, 1-2% has a bicuspid aortic valve (BAV) defined by the presence of two commissures and two equally sized cusps without a raphe or, more frequently, three cusps with two of them fused by a raphe.[6,7] Fusion of the left coronary and

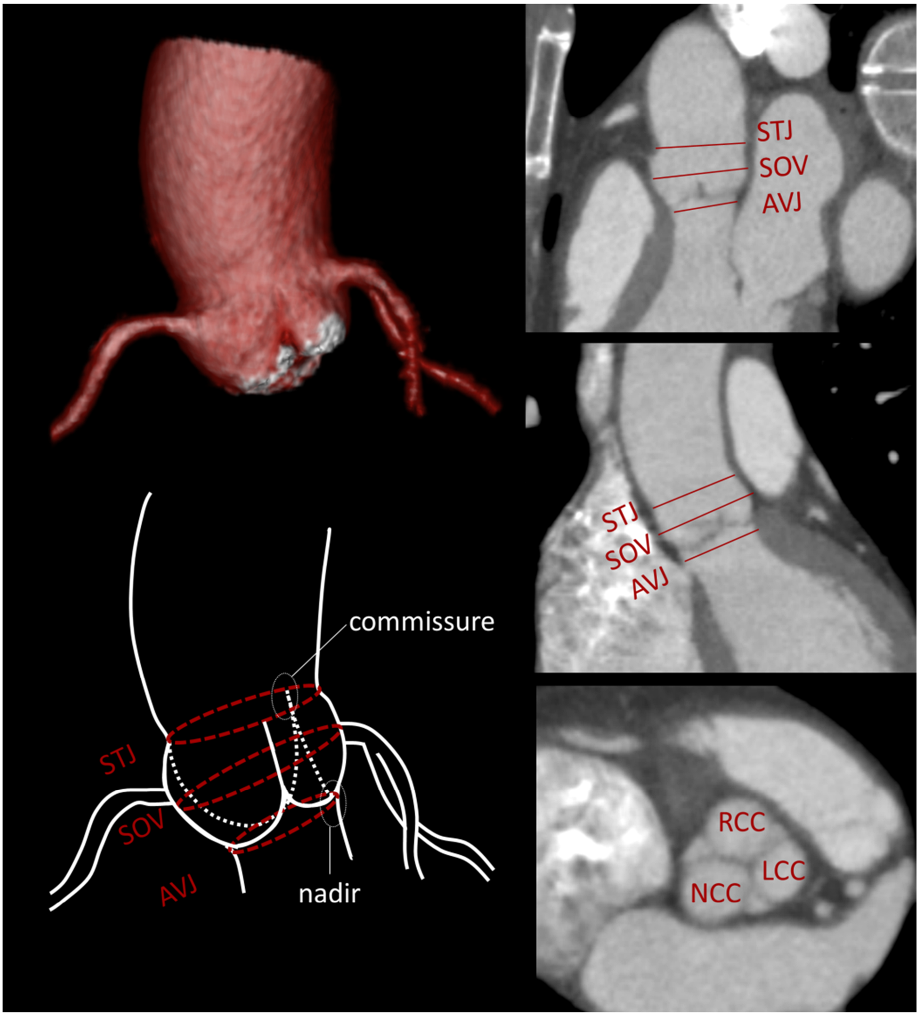

Figure 1. Anatomy of the aortic valve and root.
AVJ: aortoventricular junction, LCC: left coronary cusp, NCC: non-coronary cusp, RCC: right coronary cusp, SOV: sinus of Valsalva, STJ: sinotubular junction

right coronary cusp or right coronary and non-coronary cusp are the most frequent phenotypes.[7] The posterior aspect of the aortic root is supported by fibrous tissue (membranous part of the membranous septum) in its 50% of the circumference, whereas the anterior aspect is surrounded by the left ventricular myocardium.This has important implications for aortic valve repair techniques.

Similarly, successful and durable aortic valve repair requires accurate characterization of the specific geometry of the aortic root. The sinotubular junction is usually 10-15% smaller than the aortoventricular junction or aortic annulus, whereas at the level of the valve commissures, the diameter of the aortic root is comparable to that of the aortic annulus. The height of the aortic cusps (from the apex of the intercusp triangle to the nadir of the cusp) is 12-18 mm. The non-coronary sinus and its corresponding cusp are larger than the left and right counterparts. These dimensions have been largely studied and formulae to size the tubular graft used in aortic valve repair have been developed to ensure appropriate coaptation of the aortic cusps.[8-12]

Mechanisms of aortic regurgitation

Aortic regurgitation comprises 10% of all moderate to severe valvular heart diseases, being the prevalence of moderate to severe aortic regurgitation in the general population of 0.5%.[13,14] Aortic regurgitation is caused by malcoaptation of the aortic valve cusps, which results either from intrinsic cusp damage or from aortic root dilation.[15] Valvular causes of aortic regurgitation include aortic valve degeneration, congenital malformation of the aortic valve (with BAV being the most common abnormality), rheumatic valvular disease (particularly in developing countries) and infective endocarditis.[14,15] Non-valvular causes of aortic regurgitation include aortic root aneurysm (whether or not in the context of connective tissue disease such as Marfan syndrome), aortic dissection and aortitis.[15]

Similarly to the classification of mitral regurgitation mechanisms, a repair-oriented classification system has been developed to describe the mechanism of aortic regurgitation.[16] Based on the motion of the aortic cusps, the underlying mechanism of aortic regurgitation can be classified as: type 1 characterized by normal motion of the cusps and malcoaptation due to dilatation of the aortic root involving the sinus of Valsalva, type 2 characterized by excessive cusp motion causing prolapse an type 3 characterized by restrictive motion of the cusps (Figure 2). Some of these mechanisms may coexist. Type 1 aortic regurgitation is frequently caused by aortic root aneurysm or aortic dissection, developed due to longstanding hypertension, connective tissue disease or in the context of BAV, whereas the underlying pathology in type 2 and type 3 aortic regurgitation is valvular dysfunction most often due to valve degeneration, congenital malformation and infective endocarditis.[16]

Aortic valve repair techniques

To restore the competence of the aortic valve, the several surgical approaches aim at correcting the underlying mechanism of aortic regurgitation. In type 1 aortic regurgitation, restoration of the normal dimensions of the aortic root is necessary and can be performed with one of the valve-sparing aortic root reconstruction techniques. In patients with aortic root dilation, either the remodeling technique or the reimplantation technique can be performed. In the remodeling technique, the aortic sinuses are resected along the commissures and a Dacron graft with neosinuses is implanted.[17] In the reimplantation technique, the entire aortic root until the aortoventricular junction is resected and replaced by a Dacron graft and the native aortic valve is reimplanted.[18] In both the remodeling and reimplantation techniques, the coronary arteries are reimplanted in the neo-aortic root. In the last decades, several modifications of these techniques have been proposed. The remodeling technique can be extended with a subvalvular annuloplasty ring in order to stabilize the aortoventricular junction.[3,4] Another modification of remodeling is the sleeve technique in which coronary keyholes are created in the neo-aortic root to prevent reimplantation of the coronary arteries.[19]

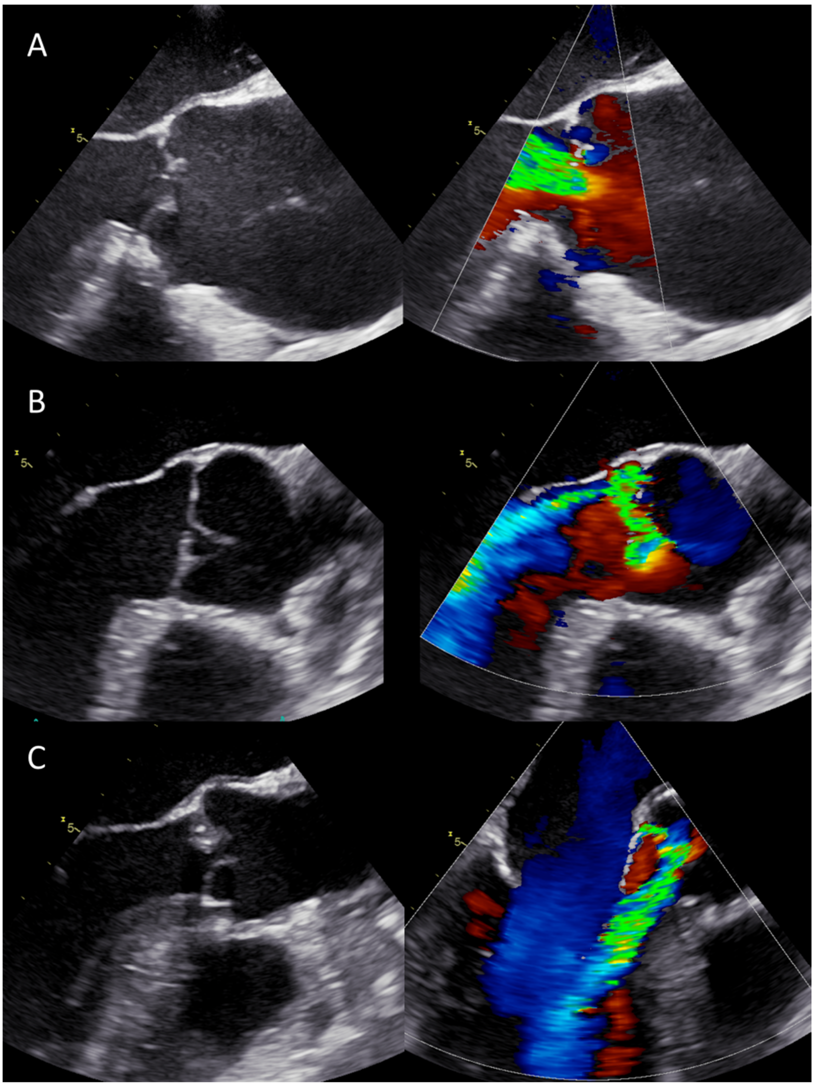

Figure 2. Mechanisms of aortic regurgitation.
A: aortic regurgitation type 1 due to aortic root dilation. B: aortic regurgitation type 2 due to leaflet prolapse. C: aortic regurgitation type 3 due to cusp restriction.

Moreover, the reimplantation technique uses currently a tailored graft with neosinuses or a prefabricated Valsalva-graft (David-V) to provide more physiological hemodyamics.[2] In patients with ascending aorta dilation without aortic root dilation, supracoronary ascending aorta replacement using a Dacron graft and remodeling of the sinotubular junction to prevent residual aortic regurgitation are commonly performed.[18]
Type 2 aortic regurgitation, due to excessive cusp motion, can be repaired using different leaflet repair techniques. When there is prolapse of one of the leaflets, central cusp plication or triangular resection can be performed.[20]. In addition or separately, resuspension of the free edge of the leaflet can be performed. A running suture is passed along the cusp free margin. A cusp defect or large fenestration can be repaired using a pericardial patch sewn into the cusp.[21] In patients with poorly aligned commissures, a subcommissural annuloplasty using three sutures is added.[22]
Type 3 aortic regurgitation results from aortic valve restriction. Frequently, the aortic cusps are thickened and calcified reducing the feasibility of successful and durable repair.[16] Therefore, in patients with this type of regurgitation, aortic valve replacement is the surgical approach of first choice.
In experienced centers, aortic valve repair has shown low early mortality rates (1.1-3.6%) and a 10-year survival rates ranging between 75% and 95%.[16,23-27] Freedom from reoperation and aortic regurgitation recurrence rates at 10 years are 90% and 80%, respectively.[16,23-28] The 5-year survival is better after aortic valve repair (96%) compared to aortic valve replacement with biological prosthesis (89%) and mechanical prosthesis (82%; p=0.02). This may be explained by the lower operative risks of patients who are referred for aortic valve repair compared to that of patients undergoing aortic valve and aortic root replacement.[29]
Several studies have compared the outcomes between different aortic valve repair techniques. David et al. showed that the remodeling technique is marginally associated with a three times higher risk of reoperation than the reimplantation technique (p=0.07).[27] Additionally, in patients with BAV, connective tissue disease or acute type A aortic dissection, freedom from reoperation at follow-up is generally higher after reimplantation approach compared with the remodeling technique.[24,30,31] There is no difference in 8-year freedom from reoperation and 5-year freedom from aortic regurgitation recurrence (92% and 89% and 84% and 90%, respectively)among patients undergoing isolated valve-sparing root replacement or combination of this technique with additional leaflet repair.[32] However, when leaflet repair is applied as an isolated technique, significant worse freedom from reoperation at 10 years follow-up is observed (70%) compared to supracoronary ascending aorta replacement (93%) and remodeling technique (89%; p<0.001).[33] In patients undergoing supracoronary ascending aorta replacement in whom additional subcommissural annuloplasty is performed, the 5-year

freedom survival from aortic regurgitation was better (94%) compared with that of patients in whom this procedure was not performed (58%, p=0.02).[34]

Multimodality imaging in aortic valve repair

Imaging of the aortic valve and root plays an important role in decision-making of patients with aortic regurgitation who may be candidates for aortic valve repair techniques. Different imaging techniques such as 2-dimensional transthoracic and transesophageal echocardiography (2DTTE and 2DTEE), 3-dimensional transesophageal echocardiography (3DTEE), multi-detector row computed tomography (MDCT) and cardiac magnetic resonance (CMR) can be used to assess aortic regurgitation severity, aortic regurgitation mechanism, aortic valve reparability and aortic root dimensions (Table 1).

Table 1. Imaging modalities to assess several aspects of aortic regurgitation.

	2DTTE	2DTEE	3DTEE	MDCT	CMR
Aortic regurgitation severity	++	++	++	-	++
Aortic regurgitation mechanism	+	+	+	-	+/-
Aortic root dimensions	+/-	+/-	+	++	++
Aortic valve reparability	+/-	++	+	+	+

2DTEE: two-dimensional transesophageal echocardiography, 2DTTE: two-dimensional transthoracic echocardiography, 3DTEE: three-dimensional transesophageal echocardiography, CMR: cardiac magnetic resonance, MDCT: multidetector row computed tomography.

Quantification of aortic regurgitation.

Echocardiography is the imaging technique of first choice to grade aortic regurgitation. Current guidelines recommend a multiparametric approach using multiple views (parasternal long axis view and apical views) and several qualitative, semi-quantitative and quantitative parameters of regurgitant volume and/or fraction as displayed in table 2.[35,36] Colour Doppler imaging is used to grade aortic regurgitation semi-quantitatively, measuring jet area and jet width ratio (ratio between regurgitant jet width and left ventricular outflow tract width). However, these methods are not recommended when several aortic regurgitation jets are observed.[35] A more quantitative approach can be followed by measuring the vena contracta width, which is defined as the width of the regurgitant jet as it transverses the aortic valve. A vena contracta width of <3mm corresponds with mild aortic regurgitation, 3-6 mm with moderate and >6mm with severe aortic regurgitation. Using continuous wave Doppler of the regurgitant jet, the measurement of a pressure half time <200 ms, indicates the presence of severe aortic regurgitation.[35] In addition, diastolic flow reversal in the descending aorta, measured with pulsed wave Doppler is strongly associated with severe aortic regurgitation. Moreover, quantitative measurement of the effective regurgitant orifice area and regurgitant volume using the proximal isovelocity surface area (PISA) method is highly recommended when feasible, especially in patients with intermediate vena contracta values (between 3 and 6 mm). Aortic regurgitation is considered severe when the effective regurgitation orifice area is ≥30mm^2 or regurgitant volume is ≥60 ml.[37] However, this method is less feasible when the effective orifice area is not circular (prolapse of one of the cusps) or in very eccentric regurgitant jets.[38]

With the development of 3-dimensional echocardiographic techniques, newer methods to grade aortic regurgitation have been proposed. In particular patients with eccentric jets and multiple jets may benefit from three dimensional assessment of the regurgitant jet. A vena contracta area >0.6cm^2 on 3DTEE indicates the presence severe aortic regurgitation and correlates well with aortic regurgitant fraction on CMR.[39,40] Direct measurement of PISA

Table 2. Echocardiographic parameters to assess severity of aortic regurgitation.

	Mild	Moderate	Severe
Qualitative			
Aortic valve morphology	Normal/abnormal	Normal/abnormal	Abnormal/flail/large coaptation defect
Colour flow aortic regurgitation jet width	Small in central jets	Intermediate	Large in central jets, variable in eccentric jets
Continuous wave signal of aortic regurgitation jet	Incomplete/faint	Dense	Dense
Diastolic flow reversal in descending aorta	Brief, protodiastolic flow reversal	Intermediate	Holodiastolic flow reversal (end-diastolic velocity >20 cm/s)
Semi-quantitative			
Vena contracta width	<3 mm	Intermediate	>6 mm
Pressure half-time	>500 ms	Intermediate	<200 ms
Quantitative			
Effective regurgitant orifice area	<10 mm^2	10-29 mm^2	≥30 mm^2
Regurgitant volume	<30 ml	30-59 ml	≥60 ml

Adopted from Lancellotti et al.[37]

without geometric assumptions is possible with 3DTEE and seems superior to two-dimensional PISA.[41] In patients with inadequate echocardiographic quality, CMR should be used to assess aortic regurgitation severity.[42] Aortic regurgitant fraction >33% on CMR which is defined as the proportion of the regurgitant volume relative to the forward stroke volume identifies patients who progressed to symptoms and surgery.[43] Additionally, effective regurgitant orifice area can be measured on gated MDCT in diastolic phase. An aortic regurgitant orifice area of 0.04-0.25 cm^2 corresponds with mild aortic regurgitation, 0.37-0.44 cm^2 with moderate aortic regurgitation and 0.81-1.05 cm^2 with severe aortic regurgitation.[44,45] Several small studies show good correlation between regurgitant orifice area on MDCT and aortic regurgitation grade on 2DTTE; however this imaging technique is associated with important radiation dose and low temporal resolution and therefore is not an imaging technique of first choice to grade aortic regurgitation.

Assessment of aortic regurgitation mechanism and factors associated with reparability.
At present, aortic valve reparability is assessed intraoperative by direct surgical inspection. Aortic regurgitation mechanism is an important factor in determining whether the aortic valve is or not reparable.[16] Besides aortic valve calcification, aortic valve morphology and aortic root diameter play an important role in determining reparability. Next to the intraoperative inspection, imaging modalities can be used to assess reparability. In Figure 3, the aortic valve and root on MDCT and 3DTEE are shown in comparison to direct surgical inspection.

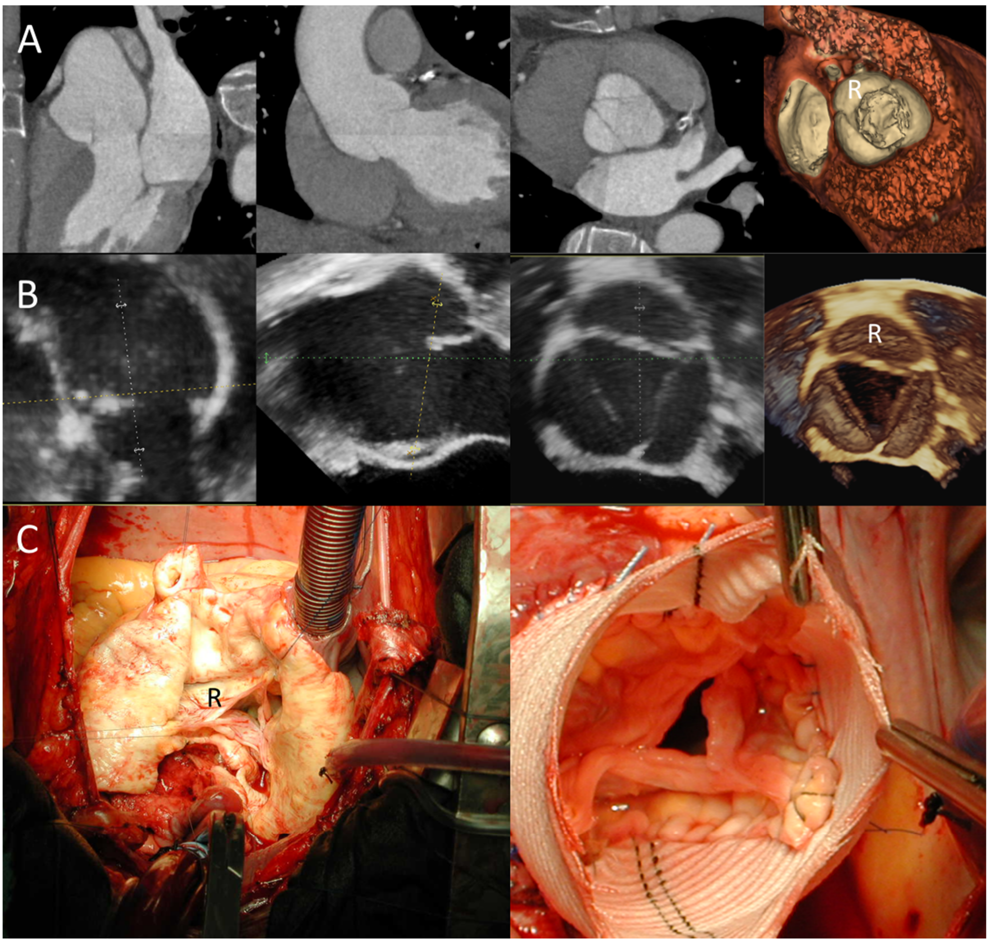

Figure 3 Assessment of the aortic valve and root with multi-detector row computed tomography (A), 3-dimensional transesophageal echocardiography (B) and surgical view (C: before and after reimplantation technique).
The images are rotated to match the surgical view. R indicates right-coronary cusp.

An important advantage of imaging techniques over direct surgical inspection is that the cusp motion can be observed throughout the cardiac cycle. In addition, preoperative imaging can be used at the heart team discussion to decide whether or not aortic valve repair seems feasible and which technique is the most appropriate. Table 3 summarizes factors associated with reparability and the preferred imaging modality to assess these factors.
The mechanism of aortic regurgitation can be assessed with 2DTEE. First, the jet direction is classified as central or eccentric. Central jets are associated with normal cusp mobility and aortic root dilatation whereas eccentric jets are observed in excessive cusp mobility.[46] Moreover, a transverse fibrous band in addition to an eccentric jet characteristically identifies a prolapsing cusp.[16] There is a good agreement between identification of the aortic regurgitation mechanism by 2DTEE and direct surgical inspection with a kappa of 0.90.[47]
In addition, the tissue characteristics of the aortic cusps have an important impact on the durability of the repair. Freedom from recurrent aortic regurgitation grade >2 is significantly impaired after repair in type 3 aortic regurgitation, which is characterized by thickened and restrictive cusps, in comparison with type 1 and type 2 aortic regurgitation (hazard ratio: 2.6, 95% confidence interval: 1.1-11.6, p=0.03).[16] Therefore repair is not recommended in type 3 aortic regurgitation.

Table 3. Factors associated with aortic valve reparability and the preferred imaging modality

Factors associated with aortic valve reparability	Preferred imaging modality
Type 1 and 2 aortic regurgitation	2D/3DTEE
No or only small aortic annular or commissural calcification	2D/3DTEE, MDCT
Bicuspid aortic valve	
with commissural orientation >160°	2D/3DTEE, (gated MDCT)
with eccentric jet without commissural or cusp thickening	2D/3DTEE
with large cusp pliability and small coaptation deficiency index	2D/3DTEE
Aortoventricular junction <28 mm	MDCT, 3DTEE

2DTEE: two-dimensional transesophageal echocardiography, 3DTEE: three-dimensional transesophageal echocardiography, MDCT: multidetector row computed tomography.

In contrast, preoperative severity of aortic regurgitation is not associated with reparability.[32] Patients with aortic regurgitation grade ≥3 need leaflet repair as often as patients with aortic regurgitation grade <3 with comparable freedom from reoperation at 8 years (90±7% vs. 89±11%, respectively; p=0.7).[32] Calcifications of the aortic valve cusps are also important determinants of the success of aortic valve repair. In moderately calcified valves (grade <3), when the calcifications are confined to the free margin, repair is considered feasible.[47] Calcifications in the body of the cusp or interfering with cusp mobility are considered non-reparable.[47] In addition, higher grades of aortic valve commissural and annular calcification, assessed with MDCT, are associated with non-reparability.[48]

In addition, aortic valve morphology has been associated with aortic valve reparability. Echocardiography can demonstrate the presence of BAV with precision.[49,50] The diagnosis of BAV is made when there are two leaflets in systole with two commissures framing an ellipsoid orifice.[37] Moreover, ECG-gated contrast enhanced MDCT is highly accurate to differentiate between tricuspid aortic valves and BAV.[51] CMR can also be used to assess aortic valve morphology.[52] Aortic valve repair techniques provide in general good outcomes in BAV-patients operated by experienced surgeons.[53,54] BAV-patients with an eccentric regurgitant jet, without commissural or cusp thickening on the preoperative 2DTEE are more likely to undergo successful aortic valve repair.[55] Furthermore, greater tissue pliability, defined by tissue normality index on 2DTEE ((diastolic cusp area – systolic cusp area) / diastolic cusp area), and lower coaptation deficiency index, defined on 2DTEE as the sum of conjoint cusp height and reference cusp height relative to diastolic aortic annulus diameter, have been associated with higher rates of successful valve repair in patients with incompetent BAV.[21] On the other hand, BAVs are less often reparable when there is a commissural orientation <160° and preoperative aortic regurgitation grade ≥3.[56]
Aortic root diameter is also of interest in determining reparability. Patients with an aortoventricular junction of >28mm have more often recurrent aortic regurgitation grade >2 and higher risk of reoperation if no additional surgical techniques are employed to restore the dimensions of this aortic root component.[56-58] Figure 4 describes a flowchart which can be used to determine whether or not an incompetent aortic valve is reparable.

Associated aortic root aneurysms.

Due to increased risk of aortic rupture, the presence of associated aortic root aneurysms of >55 mm indicate surgery irrespective of the aortic regurgitation severity.[59] Lower thresholds of 50 mm or 45 mm are applied in BAV or connective tissue disease with additional risk factors such as positive family history of aortic dissection, fast growth of the ascending aorta (>3 mm/year), severe aortic regurgitation or desire for pregnancy.[59]
Aortic root dimensions are evaluated on transthoracic echocardiography as part of routine cardiac evaluation. The aortic root diameter is measured at 3 predefined levels: aortoventricular junction, sinus of Valsalva and sinotubular junction on long axis views during end-diastole.[46,60] Upper normal limits are defined at each level separately for men (aortoventricular junction: 31 cm, sinus of Valsalva: 40 cm and sinotubular junction: 36 cm) and women (aortoventricular junction: 26 cm, sinus of Valsalva: 36 cm and sinotubular junction: 32 cm).[60]

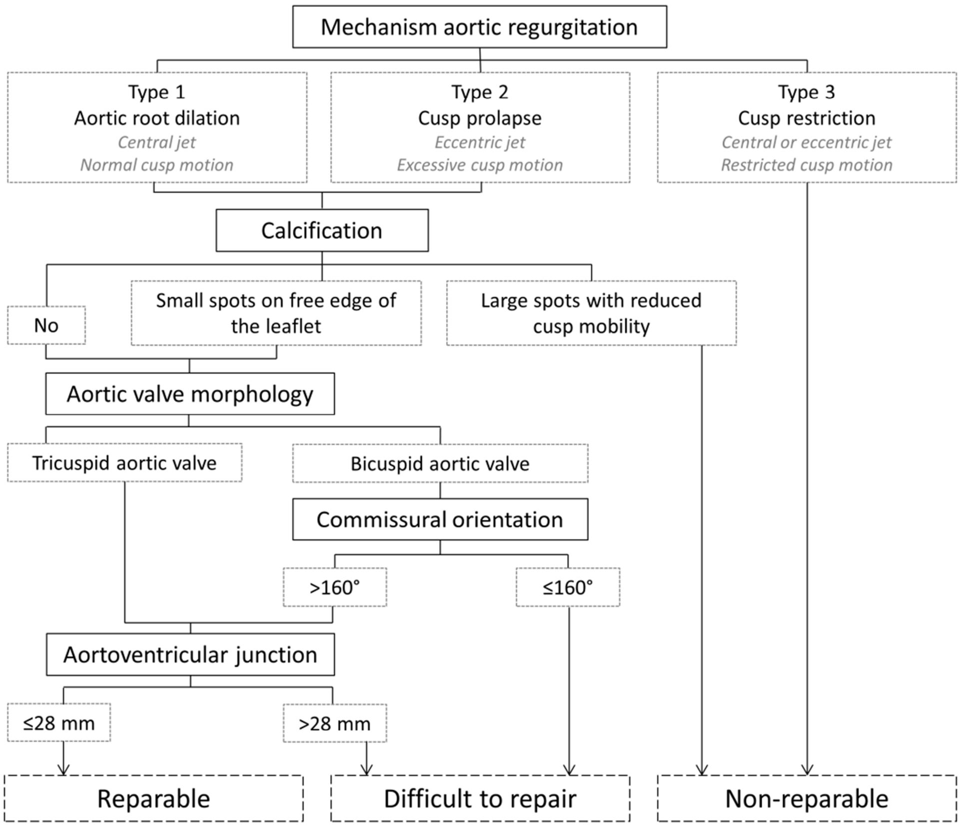

Figure 4 Flowchart to determine aortic valve reparability.

Measurements on 2-dimensional echocardiography significantly underestimate the aortic root diameter in comparison to automated measurements on 3DTEE, CMR and MDCT.[61] Therefore 3-dimensional imaging modalities are preferred over 2-dimensional modalities in the assessment of the aortic root diameter. In 3-dimensional imaging techniques the maximum diameter should be measured perpendicular to the centreline of the vessel using multiplanar reconstruction.[59,62] There is no consensus on whether the aortic wall should be included in the measurement of the aortic diameter and on whether the measurement should be performed in systole or diastole.[59] Echocardiography uses the leading edge-to-leading edge technique whereas MDCT and CMR use the inner edge-to-inner edge technique.[63] In addition, visualization and quantification of dynamic flow patterns with 4-dimensional (4D) flow magnetic resonance imaging (MRI) have shown promising in predicting the development of aortic disease in patients with aortic valve disease (Figure 5). Vectors plots and particle traces (streamlines and pathlines) are the most common approaches to visualize 4D flow data.[64] Vector plots represent the actual velocity data at a given moment in time, streamlines connect

these vectors with imaginary lines that illustrate the instantaneous flow field and pathlines represent blood flow over time and are calculated by releasing imaginary particles intro the flow field and tracking their position across the cardiac cycle.
Quantitative assessment of dynamic flow patterns includes wall shear stress and flow displacement. High wall shear stress states and flow displacement have been associated with aortic dilatation, particularly in patients with BAV.[65,66]

Conclusion

Surgical aortic valve repair demands high experience and surgical skills. In contrast to mitral valve repair where the surgical repair techniques are more standardized, surgical aortic valve repair is more heterogeneous and requires an advanced knowledge on the anatomy, geometry and dynamics of the aortic root. In the evolution of surgical aortic valve repair techniques, cardiac imaging has been an important adjuvant to better select the patient in whom this treatment will be durable and to modify the techniques in order to attain a more physiological function of the replaced aortic root.

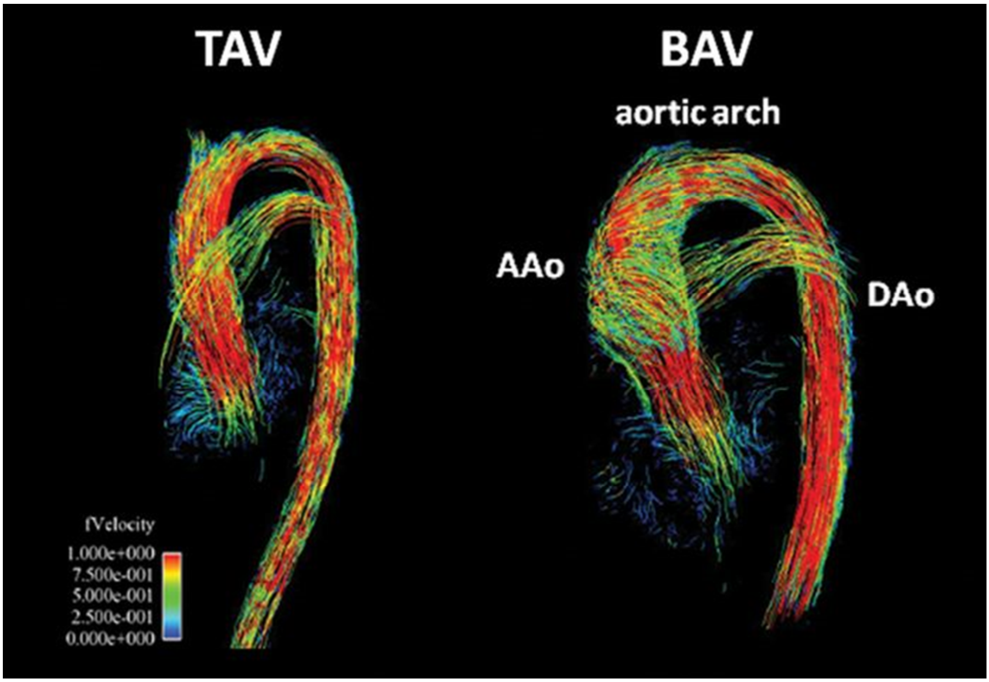

Figure 5. 4D flow MRI of the aortic valve and aorta.
Comparison of 4D flow MRI streamlines of the aortic flow in a patient with tricuspid aortic valve (TAV) and a patient with bicuspid aortic valve (BAV). Reproduced from Meierhofer et al.66 with permission from the Oxford University Press.

Objective and outline of the thesis

The primary objective of this thesis is to improve patient selection for valve-sparing aortic root reconstructive surgery using imaging techniques. This thesis can be divided into two parts. The first part focuses on imaging in patients with aortic regurgitation and/or aortopathy to evaluate disease progression and to determine reparability of the aortic valve in surgical patients. The second part describes the effect of aortic valve and root surgery on left ventricular performance and aortic dilation.

Part I: preoperative evaluation of patients with aortic regurgitation and/or aortopathy

In Part Ia, the progression of disease in patients with aortic regurgitation and/or aortopathy is evaluated. Chapter 2 describes the changes in aortic valve geometry in dilated aortic roots evaluated using three-dimensional transesophageal echocardiography. Chapter 3 focuses on the effect of aortic regurgitation on mitral valve geometry in relation to the presence of mitral regurgitation. Chapter 4 evaluates the effect of statin therapy on aortic root dilation in patients with bicuspid aortic valves. Part Ib consists of two chapters discussing different preoperative imaging techniques in the selection of patients for valve-sparing root replacement techniques. The use of multidetector row computed tomography in determining aortic valve reparability is described in Chapter 5. In Chapter 6, the additional value of echocardiography in selection of the appropriate graft size in valve-sparing root replacement using the reimplantation technique is evaluated.

Part II: postoperative evaluation of patients after aortic valve and root surgery

In Part IIa, the effects of aortic valve and root surgery on the left ventricle are described. The occurrence of postoperative left ventricular reverse remodeling is compared between acute aortic regurgitation and chronic aortic regurgitation in chapter 7. In chapter 8, distinction is made between left ventricular reverse remodeling after repair and replacement of the aortic valve and/or root. Chapter 9 focuses on the changes in left ventricular volumes and function after different surgical techniques for acute type A aortic dissection. In chapter 10, the prevalence of conduction disturbances and its effect on the left ventricle after aortic valve replacement is discussed. Part IIb describes aortic dilation after aortic valve and root surgery. Chapter 11 compares aortic root dilation after replacement of a bicuspid and a tricuspid aortic valve. Lastly, in chapter 12, dilation of the native descending thoracic aorta after surgery for acute type A aortic dissection is evaluated. The final chapters describe a general summary, conclusions and future perspectives.

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