

# Reconstructive surgery of the aortic valve

**Reconstructive surgery of the aortic valve is a safe alternative to aortic valve replacement in many patients with aortic regurgitation, with satisfactory durability and an overall and cardiovascular survival advantage. It is also associated with higher rates of freedom from valve-related and anticoagulation-related events.**

**A**ortic valve replacement has been the standard procedure for the surgical management of aortic valve disease. Reconstructive surgery of the aortic valve has been developed as an advanced approach to the management of aortic root pathology with or without aortic valve regurgitation. This was stimulated by the long-term problems inherent to contemporary aortic valve prostheses (Aicher et al, 2010) and the advantages of using patients' own tissues (Boodhwani and El Khoury, 2014).

Reconstructive surgery of the aortic valve involves a variety of surgical techniques that range from simple commissurotomy to total valve reconstruction. These are tailored according to the specific pathological findings and characteristics in each patient.

## Anatomical features of the aortic root

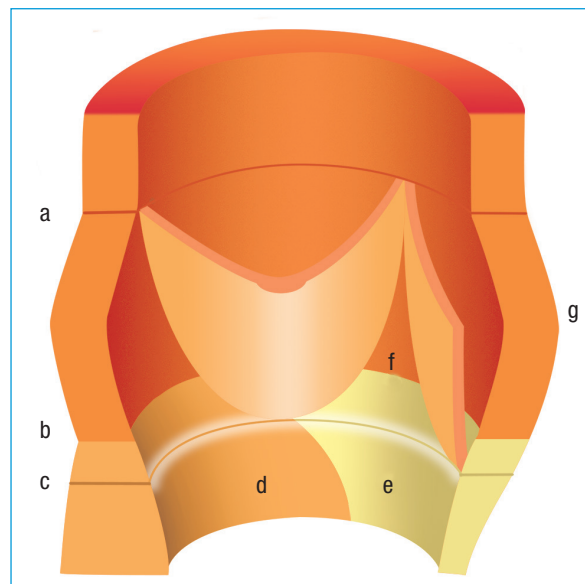
The aortic root consists of two major corresponding components, the functional aortic annulus and the aortic valve cusps. The functional aortic annulus acts as a native stent, and is best described as a cylindrical unit, with the aortoventricular junction at its base, the sinotubular junction at its higher end, and the sinuses of Valsalva as expansions of the cylindrical wall (*Figure 1*).

Each semi-lunar aortic valve cusp is attached to the functional aortic annulus in a scalloped fashion and has a free margin that is slightly longer than the diameter of the aortic annulus. The free margins of the three aortic valve cusps incline at 32° to meet in a central coaptation surface that normally stands at the mid-height of the sinuses of Valsalva (de Kerchove et al, 2015). The highest point where the cusps join – the commissure – is located immediately below the sinotubular junction, and the scalloped cusp attachment lines create an important triangular space underneath each commissure (Sutton et al, 1995)(*Figure 1*).

## Functional classification of aortic regurgitation

Integrity of the anatomical components of the aortic root is required for good valvular function, and alteration of any of these components can disturb aortic valve competence. A functional classification of lesions leading to aortic regurgitation is universally used, and is based on echocardiographic assessment and intraoperative

**Figure 1. Anatomical features of the aortic root. a. Sinotubular junction, (b) anatomical aortoventricular junction, (c) virtual basal aortic ring, (d) muscular septum, (e) membranous septum, (f) subcommissural triangle and (g) sinuses of Valsalva.**



visual inspection (Boodhwani et al, 2009) (*Table 1*). This classification clarifies the mechanisms of aortic valve regurgitation and guides selection of the most appropriate surgical techniques to restore normal valve physiology.

Three main types of aortic valve regurgitation are identified, although some patients may have multiple mechanisms contributing to their aortic dysfunction:

### Type I

Aortic regurgitation associated with normal cusp motion, that is the result of either dilatation of the functional aortic annulus or of cusp perforation. Dilatation of the functional aortic annulus may be encountered in ascending and aortic root aneurysms, such as patients with Marfan syndrome. Cusp perforations may be iatrogenic or sequelae of healed

**Mr Mohammad Bashar Izzat**, Consultant Cardiac Surgeon,  
Department of Surgery, Damascus University Cardiac  
Surgery Hospital, Damascus, Syria ([mbizzat@gmail.com](mailto:mbizzat@gmail.com))

**Table 1. Functional classification of aortic regurgitation**

Class	Mechanism of aortic regurgitation		Common aetiologies
Type I	Normal cusp motion	I (a, b, c) Dilatation of the functional aortic annulus	Ascending aortic aneurysms
		la Sinotubular junction dilatation	Aortic root aneurysms
		lb Sinotubular junction and aortoventricular junction dilatation	Annuloaortic ectasia, in association with other aetiologies
	lc Aortoventricular junction dilatation	Iatrogenic, healed endocarditis	
	Id	Cusp perforation	Cusp prolapse, bicuspid aortic valve, acute or chronic aortic dissection
Type II	Excessive cusp motion		Rheumatic, degenerative
Type II	Reduced cusp motion		

endocarditis. Type I lesions are further categorized into four subtypes based on which root component is dilated (Table 1).

**Type II**

Aortic regurgitation as a result of excessive cusp motion, including cusp prolapses or commissural detachments. Cusp prolapse results from elongation of its free margin with sagging of its body, and commissural detachments are occasionally encountered in acute or chronic aortic dissections. Regurgitation of bicuspid aortic valves usually results from prolapse of the conjoint cusp, most often formed by fusion of the right and left aortic cusps.

**Type III**

Aortic regurgitation as a result of reduced cusp motion. This is most often secondary to rheumatic or degenerative valvular disease. Variable degrees of commissural fusion and cusp thickening, retraction and calcification can be present.

**Selection of suitable patients**

Most patients with aortic valve insufficiency or aortic root aneurysms are potential candidates for reconstructive surgery of the aortic valve. The most important determinant of the possibility of aortic valve reconstruction in any patient is the morphology of aortic valve cusps (Boodhwani and El Khoury, 2014). Thin and mobile cusps with smooth free margins are most suitable, so the best candidates for aortic valve reconstruction are patients who have pathologies of the functional aortic annulus with intact valve cusps (type I lesions), as is the case in moderate dilatations of the ascending aorta or aortic root. The results of surgical reconstruction of the aortic valve are likely to be reliable in these cases. More severe dilatations are often associated with the development of multiple and large cusp fenestrations and may deform valve cusps to a degree that may render the aortic valve unreconstructable (Saczkowski et al, 2013).

While fibrosed and retracted valve cusps can be extended using glutaraldehyde-fixed bovine or autologous

pericardium, significant calcifications of aortic cusps may preclude aortic valve reconstruction, given that decalcification procedures have only demonstrated very short-lived success (Craver, 1990).

**Role of intraoperative echocardiography**

Intraoperative transoesophageal echocardiography is used to guide reconstructive surgery of the aortic valve as it permits precise assessment of aortic root anatomy, as well as functional analysis of the mechanisms and severity of aortic regurgitation (le Polain de Waroux et al, 2007).

Standard transoesophageal echocardiographic assessment begins with measuring aortic root dimensions at four levels (aortoventricular junction, sinuses of Valsalva, sinotubular junction and ascending aorta) and comparing measurements to published normal values. Next, attention is paid to aortic valve cusps. The number of valve cusps, their thicknesses and excursions, and the level of cusp coaptation are noted. Cusp prolapse is identified when its free edge overrides the plane of the aortoventricular junction. In contrast, thickened and rigid valve cusps, often coupled with systolic cusp doming, may indicate restricted motion. Finally, the direction and size of the regurgitant jet is noted. Dilatation of the functional aortic annulus usually results in a central aortic regurgitation jet that runs parallel to the left ventricular outflow tract, while an aortic regurgitation jet resulting from cusp prolapse is eccentric and directed away from the culpable cusp.

Following completion of surgical reconstruction, intraoperative transoesophageal echocardiography allows appraisal of the functional outcome. The anticipated postoperative outcome is an aortic valve which has flexible cusps that open well and coapt fully above the aortoventricular junction without any residual aortic regurgitation (Van Dyck et al, 2010).

**Operative techniques**

The goal of aortic valve reconstruction is to restore the normal cusp coaptation surface through restoring normal dimensions and geometry of the functional aortic annulus

and aortic cusps, while preserving normal mobility of aortic valve cusps (Saczkowski et al, 2013). As highlighted earlier, multiple mechanisms may contribute to aortic regurgitation in any one patient. Optimal surgical reconstruction of the regurgitant valve may therefore require use of more than one technique since each may achieve only partial correction and require reinforcement by others (Boodhwani and El Khoury, 2014).

Broadly speaking, operative techniques for aortic valve reconstruction can be divided into two categories: techniques for reconstruction of the functional aortic annulus and cusp repair techniques.

### Reconstruction of the functional aortic annulus

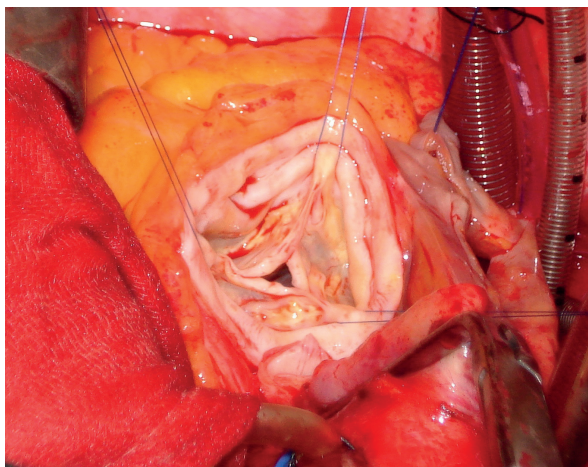
#### Dilatation of the sinotubular junction (type Ia lesions)

Supracoronary aneurysmal dilatation of the ascending aorta results in dilatation of the sinotubular junction with outward displacement of the commissural posts of the aortic valve, preventing valve cusps from coapting during diastole (Figure 2). The sinotubular junction must be normalized to restore valve competence, and is accomplished by replacing the ascending aorta with a tubular Dacron graft that is sutured right at the level of the sinotubular ridge (David et al, 2007).

#### Dilatation of the functional aortic annulus (type Ib lesions)

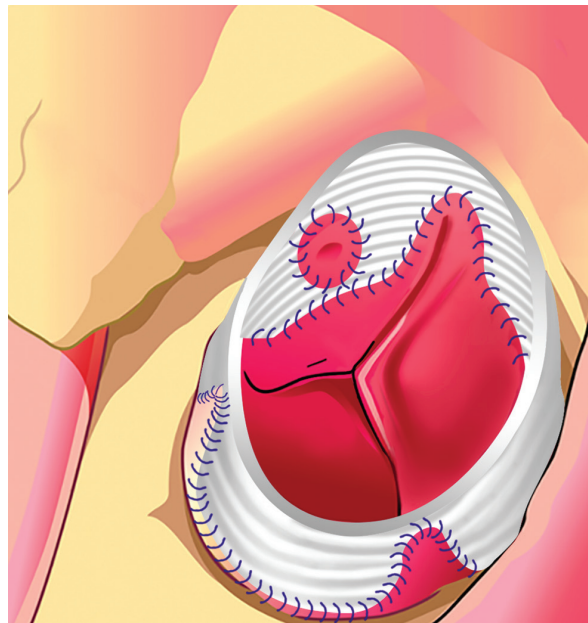
Both aortoventricular and sinotubular junctions are dilated in aortic root aneurysms, while aortic cusps may still be normal or minimally stretched in many patients, rendering them potential candidates for reconstructive surgery of the aortic valve. Two 'valve-sparing' options exist. Remodelling the aortic root (Yacoub technique) (Figure 3) involves excision of all three dilated sinuses of Valsalva, and suturing the scalloped ends of a suitable tubular Dacron graft directly to the remnant strip of aortic wall surrounding the native valve cusps (Yacoub et al, 1998).

**Figure 2. Isolated dilatation of the sinotubular junction (type Ia lesion) as a result of supracoronary aneurysmal dilatation of the ascending aorta.**

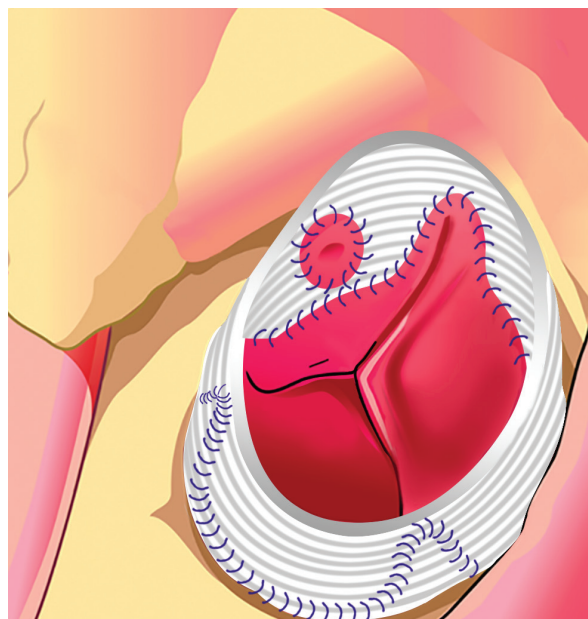


In reimplantation of the aortic valve (David technique) (Figure 4), native valve cusps are resuspended and secured within the tubular Dacron graft, which extends onto the base of the aortic annulus to prevent its future dilatation (David et al, 1999). In either technique, the coronary arteries are reimplanted into their respective sinuses, and the graft is anastomosed to the distal ascending aorta or aortic arch depending on the extent of the aneurysm. Reimplantation of the aortic valve is advocated in patients

**Figure 3. Remodelling of the aortic root (Yacoub technique). The dilated sinuses of Valsalva are replaced with a tubular Dacron graft.**



**Figure 4. Reimplantation of the aortic valve (David technique). The native valve cusps are resuspended within the tubular Dacron graft that also supports the base of the aortic annulus from the outside.**



“ Isolated dilatation of the aortoventricular junction can cause aortic regurgitation through the loss of central cusp coaptation. ”

with Marfan syndrome because it corrects and prevents future annular dilation, whereas remodelling of the aortic root may be more suitable for patients with normal aortoventricular junctions (David et al, 2015).

**Dilatation of the aortoventricular junction (type Ic lesions)**

Isolated dilatation of the aortoventricular junction can cause aortic regurgitation through the loss of central cusp coaptation. Notably, other aetiologies of aortic regurgitation are frequently accompanied by dilatation of the aortoventricular junction, so a reduction annuloplasty is often needed to increase the coaptation surface area between aortic cusps. This is commonly addressed by plicating the subcommissural triangles using horizontal mattress sutures with Teflon felt pledgets on either side of each commissure, so-called ‘subcommissural annuloplasty’ (de Kerchove et al, 2016) (Figures 5 and 6).

**Correction of aortic cusp anomalies**

**Cusp perforation (type Id lesions)**

Defects are usually closed using a simple patch of fresh or glutaraldehyde-fixed autologous pericardium that is secured on the aortic side of the cusp (Mosala Nezhad et al, 2014) (Figure 7).

**Cusp prolapse (type II lesions)**

Elongation of cusp free margin can be corrected by resecting a triangular segment from the central region

Figure 5. Subcommissural annuloplasty for correction of aortoventricular junction dilatation.

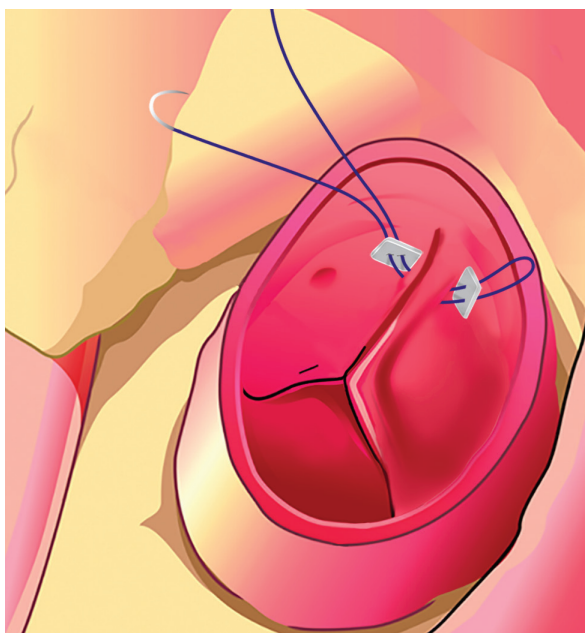
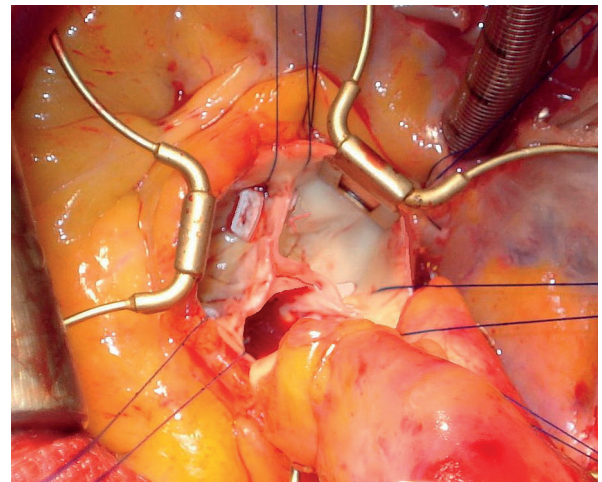


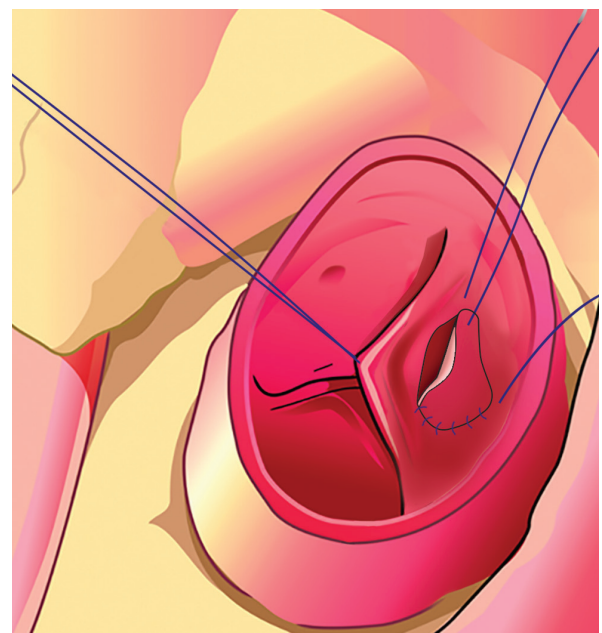
Figure 6. Operative view of subcommissural annuloplasty. Excellent central coaptation between aortic valve cusps has been restored.



of the nodule of Arantius, plicating the free margin, or weaving a 5-0 polytetrafluoroethylene suture along the free margin and anchoring it to the commissure (Price et al, 2011) (Figure 8). The extent of shortening is determined by comparison to adjacent non-prolapsed cusps or using dedicated instruments (Schäfers et al, 2006; Izzat, 2012). When correcting a bicuspid aortic valve prolapse, sutures are used to shorten and elevate the free margin of the redundant conjoint cusp so that the free margins of both cusps coapt at the same level.

Commissural detachment in a patient with an aortic dissection is managed by commissural resuspension. The dissected aortic wall layers are sealed with sutures or glue, and the ascending aorta is replaced with an interposition graft.

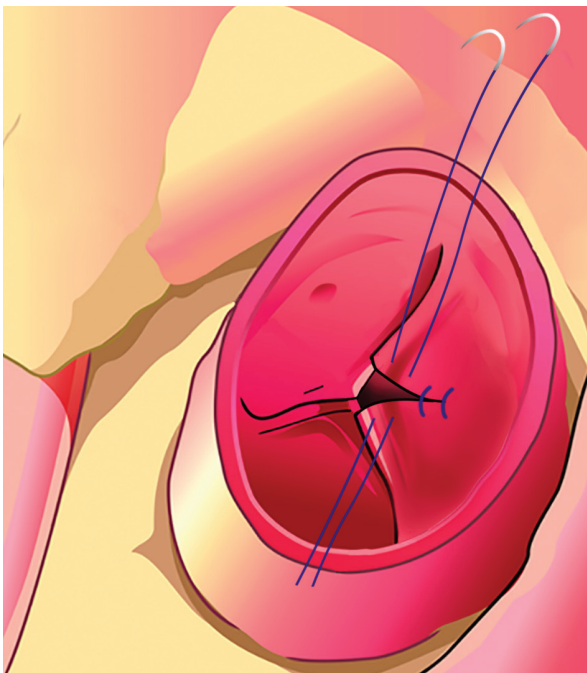
Figure 7. Cusp perforation closure with a simple pericardial patch.



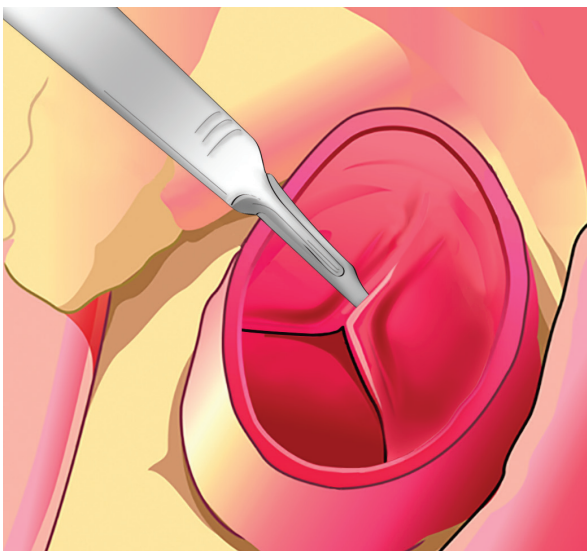
### Cusp restriction (type III lesions)

The main objective is to increase cusp mobility. Commissural fusion can be managed by performing sharp commissurotomy (Figure 9) and shaving isolated calcific nodules from both cusps. Cusp free margins may be bent towards the sinuses, hence reducing the height of the cusps, and unfolding of the free margin is possible through careful incisions parallel to the margin. Very thick and retracted valve cusps may need to be extended using glutaraldehyde-fixed bovine or autologous pericardium in order to recover the normal coaptation area between aortic cusps (Mosala Nezhad et al, 2014), although this requires the cusp base to remain thin and pliable.

**Figure 8.** Free margin shortening by resecting a triangular segment from the central region of the nodule of Arantius.



**Figure 9.** Sharp commissurotomy of commissural and free margin fusion.



“ Compared to long-term results following aortic valve replacement with either bioprosthetic or mechanical valves, patients undergoing reconstructive surgery of the aortic valve have a significantly better overall and cardiovascular long-term survival. ”

### Surgical results

#### Early operative outcome

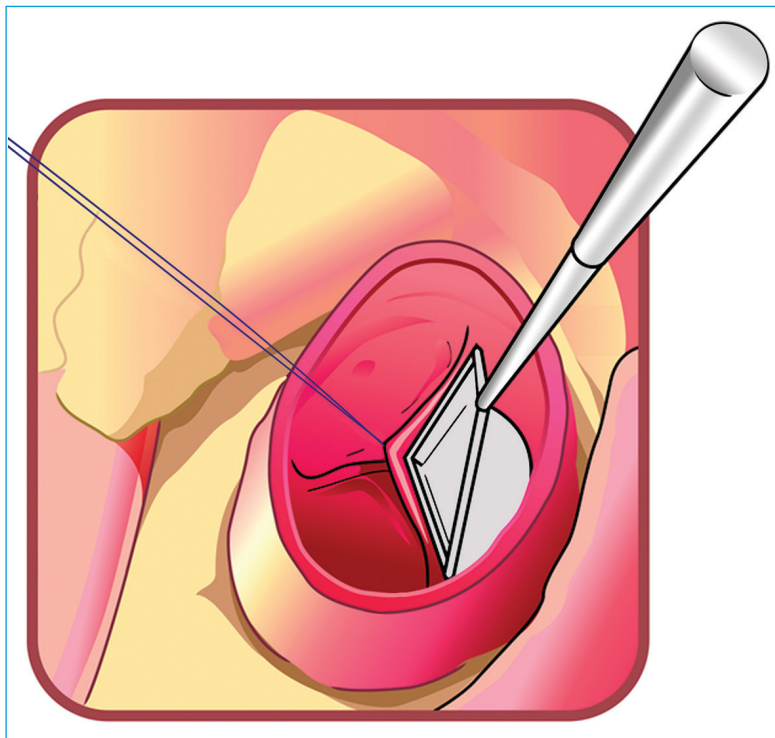
First time, elective reconstructive surgery of the aortic valve is associated with very low operative risk (1–2%) (Saczkowski et al, 2013). On the other hand, surgery in patients who require urgent or emergency intervention because of acute type A aortic dissection or advanced New York Heart Association functional class is associated with increased operative risk. Operative mortality and morbidity rates also increase when additional procedures are needed, such as myocardial revascularization and mitral valve surgery.

Immediate technical success in reconstructing the aortic valve largely depends on careful selection of suitable patients and meticulous application of appropriate surgical techniques. The best functional results are usually achieved in patients undergoing aortic valve reconstruction by experienced surgeons in specialized centres (Malas et al, 2015).

#### Long-term results

Reconstructive surgery of the aortic valve is associated with a satisfactory long-term durability. The overall freedom from mild aortic regurgitation at 10 years exceeds 86%, and the overall freedom from the need for aortic reoperations at 10 years is around 89% (Saczkowski et al, 2013). Key factors that may predict the need for late aortic reoperations are the presence of >2+ residual aortic regurgitation at the end of the surgical procedure, and the rheumatic or degenerative aetiology of aortic valve dysfunction (le Polain de Waroux et al, 2007; Bashir et al, 2014). Best long-term durability can usually be achieved in pathologies of the functional aortic annulus (type I lesion) managed by replacing the ascending aorta or by an aortic valve reimplantation procedure, followed by prolapse of thin valve cusps (type II lesion) corrected by plicating their free margins (Price et al, 2011; David et al, 2013). The long-term durability of cusp extension using glutaraldehyde-treated autologous pericardium in rheumatic or degenerative lesions (type III lesion) is still unknown (Mosala Nezhad et al, 2014), hence these techniques are usually reserved for older patients and for young subjects in whom anticoagulation may be a problem.

When compared to long-term results following aortic valve replacement with either bioprosthetic or mechanical valves, patients undergoing reconstructive surgery of the aortic valve have a significantly better overall and cardiovascular long-term survival (Price et al,



**Figure 10.** A recently developed aortic cusp sizer in use. The spoon-shaped device evaluates the inner surface area and free margin length of the cusp.

2013). Notably, long-term freedom from delayed aortic re-intervention is better with aortic valve reconstruction than that expected with bioprosthetic valve replacements. A reconstructed aortic valve that is functioning well at 10 years is expected to do so ad infinitum, while bioprosthetic valves continue the exponential increased risk of valve deterioration 10 years after implantation (Chan et al, 2011). Mechanical valve replacements are associated with slightly higher, albeit not statistically significant, rates of long-term freedom from the need for aortic reoperation (over 90% at 10 years) compared to aortic valve reconstruction (de Meester et al, 2014). However, mechanical valve prostheses are associated with the anticoagulation-related lifelong burden of thromboembolic and bleeding complications, estimated at 1–2%/patient-year, which is substantially higher than the 0.5%/patient-year risk in patients undergoing aortic valve reconstruction (Aicher et al, 2010).

### Recent advances and future trends

#### Advances in surgical instrumentations

Recognizing the exact alterations responsible for aortic regurgitation is required to restore the natural correlation between various valve components. New dedicated surgical instruments were designed for measuring critical cusp and annular dimensions (*Figure 10*), and evidence indicates that these instruments can guide selection of the appropriate surgical technique, and are likely to lead to high reproducibility of aortic valve reconstruction methods (Schäfers et al, 2006; Izzat et al, 2015).

#### Novel annuloplasty rings

Implantable aortic annuloplasty rings – both internal and external – have been developed to correct and prevent future dilatation of the aortoventricular junction, which may predict late recurrence of aortic regurgitation (le Polain de Waroux et al, 2007), and are undergoing clinical evaluation (Lansac et al, 2006; Mazzitelli et al, 2013). These devices can also facilitate aortic valve annuloplasty in patients with borderline aortic root dilatations in whom a valve-sparing root replacement may seem excessive.

#### Tissue engineering

Several patch materials have been used for extending retracted valve cusps, including patients' autologous pericardium (fresh or glutaraldehyde-treated), bovine pericardium, and polytetrafluoroethylene. All these materials are subject to delayed structural degeneration and calcification which has been associated with limited long-term durability compared to using native cusp tissue alone (El Khoury and Vohra, 2012). Tissue engineering may address this limitation through fabrication of de novo living tissue that has the potential for biological adaptation and remodelling (Butcher et al, 2011), and which may also be used in young patients who require future valve growth.

### Conclusions

Reconstructive surgery of the aortic valve was developed to avoid the risks associated with implantation of aortic valve prostheses. Bioprosthetic aortic valves are subject to structural valve deterioration and have a median time to explant of 8–10 years. Mechanical valve prostheses, on the other hand, require lifelong anticoagulation, which is also associated with the risks of thromboembolic and bleeding events.

Deeper understanding of the functional anatomy of the aortic valve and of the pathophysiological mechanisms of aortic regurgitation have facilitated the refinement of surgical techniques that can restore natural cusp coaptation and aortic valve competence. Current data confirm that reconstructive surgery of the aortic valve is a safe and feasible new alternative to aortic valve replacement in many patients with aortic regurgitation. While it is associated with the limited risk of recurrent aortic regurgitation that may require late reoperation, reconstructive surgery of the aortic valve is associated with improved survival and high rates of freedom from valve-related and anticoagulation-related events, which makes it particularly attractive for young patients who want to avoid long-term anticoagulation.

While recent advances in materials and devices to facilitate aortic valve reconstruction are expected to further improve its long-term durability, broader adoption of these techniques is still limited by the difficulty in disseminating the necessary complex skills. Growing interest in reconstructive surgery of the aortic

valve, coupled with innovative approaches such as three-dimensional modelling and virtual surgery, may help to resolve this limitation. **BJHM**

*Conflict of interest: none.*

Aicher D, Fries R, Rodionycheva S, Schmidt K, Langer F, Schäfers HJ (2010) Aortic valve repair leads to a low incidence of valve-related complications. *Eur J Cardiothorac Surg* **37**(1):127–132. <https://doi.org/10.1016/j.ejcts.2009.06.021>

Bashir M, Oo A, De Paulis R, Borger MA, El Khoury G, Bavaria J, Elefteraides JA (2014) Can the results of aortic valve repair equal the results of a biologic aortic valve replacement? *Aorta* **2**(1): 1–9. <https://doi.org/10.12945/j.aorta.2014.14-005>

Boodhwani M, de Kerchove L, Glineur D et al (2009) Repair-oriented classification of aortic insufficiency: impact on surgical techniques and clinical outcomes. *J Thorac Cardiovasc Surg* **137**(2): 286–294. <https://doi.org/10.1016/j.jtcvs.2008.08.054>

Boodhwani M, El Khoury G (2014) Aortic valve repair: indications and outcomes. *Curr Cardiol Rep* **16**(6): 490. <https://doi.org/10.1007/s11886-014-0490-7>

Butcher JT, Mahler GJ, Hockaday LA (2011) Aortic valve disease and treatment: the need for naturally engineered solutions. *Adv Drug Deliv Rev* **63**(4–5): 242–268. <https://doi.org/10.1016/j.addr.2011.01.008>

Chan V, Malas T, Lapierre H et al (2011) Reoperation of left heart valve bioprostheses according to age at implantation. *Circulation* **124**(11\_suppl\_1) Suppl: S75–S80. <https://doi.org/10.1161/CIRCULATIONAHA.110.011973>

Craver JM (1990) Aortic valve debridement by ultrasonic surgical aspirator: A word of caution. *Ann Thorac Surg* **49**(5): 746–753, discussion 752–753. [https://doi.org/10.1016/0003-4975\(90\)90014-W](https://doi.org/10.1016/0003-4975(90)90014-W)

David TE, Armstrong S, Ivanov J, Webb GD (1999) Aortic valve sparing operations: an update. *Ann Thorac Surg* **67**(6): 1840–1842, discussion 1853–1856. [https://doi.org/10.1016/S0003-4975\(99\)00420-8](https://doi.org/10.1016/S0003-4975(99)00420-8)

David TE, Feindel CM, Armstrong S, Maganti M (2007) Replacement of the ascending aorta with reduction of the diameter of the sinotubular junction to treat aortic insufficiency in patients with ascending aortic aneurysm. *J Thorac Cardiovasc Surg* **133**(2): 414–418. <https://doi.org/10.1016/j.jtcvs.2006.09.049>

David TE, Armstrong S, Manlhiot C, McCrindle BW, Feindel CM (2013) Long-term results of aortic root repair using the reimplantation technique. *J Thorac Cardiovasc Surg* **145**(3) Suppl:S22–S25. <https://doi.org/10.1016/j.jtcvs.2012.11.075>

David TE, Coselli JS, Khoury GE, Miller DC, Svensson LG (2015) Aortic valve repair. *Semin Thorac Cardiovasc Surg* **27**(3): 271–287. <https://doi.org/10.1053/j.semthor.2015.10.010>

de Kerchove L, Jashari R, Boodhwani M (2015) Surgical anatomy of the aortic root: implication for valve-sparing reimplantation and aortic valve annuloplasty. *J Thorac Cardiovasc Surg* **149**(2): 425–433. <https://doi.org/10.1016/j.jtcvs.2014.09.042>

de Kerchove L, Mastrobuoni S, Boodhwani M et al (2016) The role of annular dimension and annuloplasty in tricuspid aortic valve repair. *Eur J Cardiothorac Surg* **49**(2): 428–438, discussion 437–438. <https://doi.org/10.1093/ejcts/ezv050>

de Meester C, Pasquet A, Gerber BL, Vancraeynest D, Noirhomme P, El Khoury G, Vanoverschelde JLJ (2014) Valve repair improves the outcome of surgery for chronic aortic regurgitation: A propensity score analysis. *J Thorac Cardiovasc Surg* **148**(5): 1913–1920. <https://doi.org/10.1016/j.jtcvs.2014.02.010>

El Khoury G, Vohra HA (2012) Polytetrafluoroethylene leaflet extensions for aortic valve repair. *Eur J Cardiothorac Surg* **41**(6): 1258–1259. <https://doi.org/10.1093/ejcts/ezs030>

Izzat MB (2012) Calibrated cusp sizers to facilitate aortic valve repair: development and clinical application. *Interact Cardiovasc Thorac Surg* **14**(2): 133–137. <https://doi.org/10.1093/icvts/iv082>

Izzat MB, Hamzeh K, Mahmoud F, Bakour MM (2015) Aortic cusp sizers to establish the functional classification of aortic insufficiency: algorithm and midterm outcome of operative repair. *Interact Cardiovasc Thorac Surg* **21**(1): 77–80. <https://doi.org/10.1093/icvts/ivv081>

## KEY POINTS

- Most patients with aortic valve insufficiency or aortic root aneurysms are potential candidates for reconstructive surgery of the aortic valve.
- The most important determinant of the possibility of aortic valve reconstruction in any patient is the morphology of aortic valve cusps.
- The functional classification of lesions leading to aortic regurgitation can guide selection of the most appropriate surgical techniques to restore normal valve physiology.
- Intraoperative transoesophageal echocardiography permits precise analysis of the mechanisms of aortic regurgitation and provides the necessary appraisal following completion of the surgical procedure.
- Reconstructive surgery of the aortic valve is associated with a satisfactory long-term durability and high rates of freedom from valve-related and anticoagulation-related events.
- Compared to aortic valve replacement with bioprosthetic or mechanical valves, the overall and cardiovascular long-term survival are significantly better following aortic valve reconstruction.

Lansac E, Di Centa I, Bonnet N, LePrince P, Rama A, Acar C, Pavie A, Gandjbakhch I (2006) Aortic prosthetic ring annuloplasty: a useful adjunct to a standardized aortic valve-sparing procedure? *Eur J Cardiothorac Surg* **29**(4): 537–544. <https://doi.org/10.1016/j.ejcts.2005.12.055>

le Polain de Waroux JB, Pouleur AC, Goffinet C et al (2007) Functional anatomy of aortic regurgitation: accuracy, prediction of surgical reparability, and outcome implications of transesophageal echocardiography. *Circulation* **116**(11) Suppl: I264–I269. <https://doi.org/10.1161/CIRCULATIONAHA.106.680074>

Malas T, Saczkowski R, Sohmer B et al (2015) Is aortic valve repair reproducible? Analysis of the learning curve for aortic valve repair. *Can J Cardiol* **31**(12): 1497.e15–1497.e22. <https://doi.org/10.1016/j.cjca.2015.05.016>

Mazzitelli D, Nöbauer C, Rankin JS et al (2013) Early results after implantation of a new geometric annuloplasty ring for aortic valve repair. *Ann Thorac Surg* **95**(1): 94–97. <https://doi.org/10.1016/j.athoracsur.2012.08.034>

Mosala Nezhad Z, de Kerchove L, Hechadi J et al (2014) Aortic valve repair with patch in non-rheumatic disease: indication, techniques and durability. *Eur J Cardiothorac Surg* **46**(6): 997–1005, discussion 1005. <https://doi.org/10.1093/ejcts/ezu058>

Price J, De Kerchove L, El Khoury G (2011) Aortic valve repair for leaflet prolapse. *Semin Thorac Cardiovasc Surg* **23**(2): 149–151. <https://doi.org/10.1053/j.semthor.2011.08.010>

Price J, De Kerchove L, Glineur D, Vanoverschelde JL, Noirhomme P, El Khoury G (2013) Risk of valve-related events after aortic valve repair. *Ann Thorac Surg* **95**(2): 606–613, discussion 613. <https://doi.org/10.1016/j.athoracsur.2012.07.016>

Saczkowski R, Malas T, de Kerchove L, El Khoury G, Boodhwani M (2013) Systematic review of aortic valve preservation and repair. *Ann Cardiothorac Surg* **2**(1): 3–9. <https://doi.org/10.3978/j.issn.2225-319X.2013.01.07>

Schäfers HJ, Bierbach B, Aicher D (2006) A new approach to the assessment of aortic cusp geometry. *J Thorac Cardiovasc Surg* **132**(2): 436–438. <https://doi.org/10.1016/j.jtcvs.2006.04.032>

Sutton JP 3rd, Ho SY, Anderson RH (1995) The forgotten interleaflet triangles: A review of the surgical anatomy of the aortic valve. *Ann Thorac Surg* **59**(2): 419–427. [https://doi.org/10.1016/0003-4975\(94\)00893-C](https://doi.org/10.1016/0003-4975(94)00893-C)

Van Dyck MJ, Watremez C, Boodhwani M, Vanoverschelde JL, El Khoury G (2010) Transesophageal echocardiographic evaluation during aortic valve repair surgery. *Anesth Analg* **111**(1): 59–70. <https://doi.org/10.1213/ANE.0b013e3181dd2579>

Yacoub MH, Gehle P, Chandrasekaran V, Birks EJ, Child A, Radley-Smith R (1998) Late results of a valve-preserving operation in patients with aneurysms of the ascending aorta and root. *J Thorac Cardiovasc Surg* **115**(5): 1080–1090. [https://doi.org/10.1016/S0022-5223\(98\)70408-8](https://doi.org/10.1016/S0022-5223(98)70408-8)