Curr Cardiol Rep (2014) 16:490
DOI 10.1007/s11886-014-0490-7

VALVULAR HEART DISEASE (VT NKOMO, SECTION EDITOR)

Aortic Valve Repair: Indications and Outcomes

Munir Boodhwani · Gebrine El Khoury

Published online: 18 April 2014

Abstract Aortic valve replacement has traditionally been the treatment of choice for patients with aortic valve insufficiency with or without aortic root pathology. Aortic valve repair is emerging as an attractive treatment alternative that avoids the long-term risks associated with prosthetic valve implantation including thromboembolism, endocarditis, prosthetic valve deterioration, and anticoagulation related hemorrhage. Important achievements in this discipline have occurred over the past decade including development and refinement of valve preserving aortic root replacement techniques, development of a classification system for aortic insufficiency, surgical approaches to cusp disease with varying cusp anatomy. As surgical techniques for aortic valve repair continue to evolve, clinical outcomes up to and beyond the first decade are promising with excellent survival and low risk of valve related events.

Keywords Aortic valve · Aortic insufficiency · Valve repair · Thoracic aorta aneurysm · Survival · Thromboembolism · Endocarditis · Aortic valve repair

This article is part of the Topical Collection on *Valvular Heart Disease*

M. Boodhwani (✉)
Division of Cardiac Surgery, University of Ottawa Heart Institute, 40 Ruskin Street, H3405, Ottawa, ON K1Y 4W7, Canada
e-mail: mboodhwani@ottawaheart.ca

G. El Khoury
Department of Cardiovascular and Thoracic Surgery Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, Brussels 1200, Belgium
e-mail: elkhoury@uclouvain.be

e-mail: gebrine.elkhoury@uclouvain.be

Introduction

Patients presenting with aortic valve insufficiency, with or without aortic root aneurysms have traditionally been treated with isolated aortic valve replacement or composite valve and root replacement (Bentall procedure). While the early outcomes following these procedures are excellent, patients incur the cumulative long-term risk of prosthetic valve related complications which include thromboembolism, prosthetic valve endocarditis, structural and non-structural dysfunction requiring reoperation, and in the case of mechanical valves, the inconvenience and risks of anticoagulation related hemorrhage. Frequently, these procedures are performed in young patients in their third, fourth, or fifth decades of life and therefore, the cumulative risks accrued over several decades can be substantial. Some studies have also demonstrated increased risk of late mortality in patients treated with mechanical aortic valves.

Preservation and repair of the aortic valve promises to substantially reduce or eliminate these risks. In addition, repaired aortic valves have the potential for growth, which is important in the pediatric population, and are also more likely to preserve normal hemodynamics and function of the aortic valve and root complex. These advantages are expected to reduce long-term morbidity and mortality and may also improve quality of life for these patients.

Aortic Valve Anatomy and Function

Normal function of the aortic valve requires a complex interaction between the aortic valve cusps and the annulus [1]. The functional aortic annulus (FAA) is not a single structure but is made up of three distinct components. These include the sinotubular junction, the ventriculo-aortic junction, and the anatomic crown-shaped annulus which serves as the insertion point of the aortic valve leaflets termed the function aortic annulus (FAA) [2]. In a normal AV, the cusps coapt at the centre of the AV orifice with a coaptation height that is approximately at the mid-level between the AVJ and the STJ. A fundamental principle in AV repair is that lesions of the cusps *and* the FAA should both be addressed at the time of valve repair.

Indications for Aortic Valve Preservation and Repair

Decision making for surgical intervention for aortic valve surgery needs to incorporate the natural history of medically managed disease, the risks associated with surgical intervention, and longer term risks that may accrue related to prosthetic valve implantation. Indications for aortic valve repair for aortic insufficiency currently are similar to those for aortic valve replacement. Patients with severe AI and symptoms, or asymptomatic patients with left ventricular dysfunction or significant left ventricular dilatation (LV end diastolic diameter>70 mm or LV end systolic diameter>50 mm) are considered for surgical intervention [3]. However, aortic valve repair carries a similar, if not lower, risk of perioperative complication with a low risk of valve related events over time. Similar to mitral valve repair for mitral regurgitation[4], there is some suggestions that aortic valve intervention should be considered earlier in patients in whom AV repair is likely [5].

Another broad category of patients who undergo AV preservation and repair are those with primary aortic pathology, involving the aortic root and/or the ascending aorta, and varying degrees of associated aortic valvular disease. In these patients, the primary indication for intervention is driven by aortic size [6, 7•].

From a technical perspective, all patients with primary aortic insufficiency are potentially candidates for repair. However, the success of AV repair is determined largely by the quality of cusp tissue available. Thus, patients with significant leaflet calcification, destruction due to active endocarditis, or rheumatic involvement are least likely to undergo successful and durable AV repair [8]. In contrast, repair has been shown to have good results in patients with bicuspid [9, 10] (and in smaller series, unicuspid [11] and quadricuspid [12]) aortic valves, despite the abnormalities in cusp anatomy.

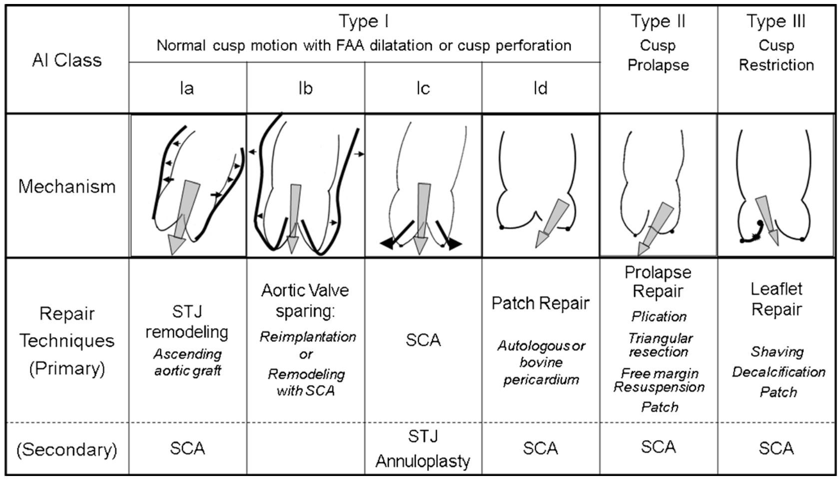
An important limitation to the universal application of AV repair techniques is the lack of surgical expertise and experience in this field. However, this is changing rapidly with increasing interest in AV repair. Patients who are candidates for repair should be referred to centres with appropriate expertise.

Key Developments in Aortic Valve Repair

Over the past two decades, there have been important developments that have been crucial to progress in AV repair. The preservation of the normally functioning aortic valve in the context of aortic root pathology was perhaps, the first important milestone in aortic valve repair. The valve sparing techniques of reimplantation and remodelling pioneered by David [13] and Yacoub [14] were aimed at treating aortic root pathology but were also the first annuloplasties of the aortic valve, compelling surgeons to better understand the anatomic and functional relationships of the aortic valve annulus and cusps. In the last decade, we have seen the emergence of a variety of leaflet repair techniques including free margin plication, free margin resuspension, triangular leaflet resection, and pericardial patch augmentation [15, 16]. In recent years, we have also seen the emergence of a classification system for aortic insufficiency [8] that provides us with the vocabulary with which to converse about aortic valve repair, much like the Carpentier classification did for mitral valve repair [17]. Outcome data beyond the first decade is starting to emerge. Published studies have already reported good repair durability and a low rate of valve related complications with aortic valve repair [18, 19•].

Classification of Aortic Insufficiency

Choice and application of the appropriate surgical techniques requires an understanding of the mechanism of aortic insufficiency. The classification of aortic insufficiency [8] (Fig. 1) provides a framework to help understand these mechanisms and to choose the appropriate technique. This classification centres around the idea that the aortic valve, much like the mitral valve consists of two major components, namely the aortic annulus and the valve leaflets. Contrary to the mitral valve, however, the annulus of the aortic valve is not a single anatomic structure. The functional aortic annulus, rather, consists of two separate components, namely the ventriculo-aortic junction and the sino-tubular junction. As in Carpentier's classification of mitral valve disease [17], regurgitation associated with normal leaflet motion is designated as type I. This is largely due to lesions of the functional aortic annulus with type 1a AI due to sino-tubular junction enlargement and dilatation of the ascending aorta, type Ib due to dilatation of the sinuses of Valsalva and the sino-tubular junction, type Ic due to dilatation of the ventriculo-aortic junction, and lastly type 1d due to cusp perforation without a primary functional aortic annulus lesion. Type II AI is due to leaflet prolapse secondary to excessive cusp tissue or due to commissural disruption. Type III AI is due to leaflet restriction which may be found in bicuspid, degenerative, or rheumatic valvular



AI Class	Type I Normal cusp motion with FAA dilatation or cusp perforation				Type II Cusp Prolapse	Type III Cusp Restriction
	Ia	Ib	Ic	Id		
Mechanism						
Repair Techniques (Primary)	STJ remodeling *Ascending aortic graft*	Aortic Valve sparing: *Reimplantation or Remodeling with SCA*	SCA	Patch Repair *Autologous or bovine pericardium*	Prolapse Repair *Plication* *Triangular resection* *Free margin Resuspension* *Patch*	Leaflet Repair *Shaving* *Decalcification* *Patch*
(Secondary)	SCA		STJ Annuloplasty	SCA	SCA	SCA

Fig. 1 Mechanism-based and repair-oriented classification of aortic insufficiency. STJ – sinotubular junction; SCA – sub-commissural annuloplasty; FAA – functional aortic annulus; AI – aortic insufficiency. (With permission from: Boodhwani M, de Kerchove L, Glineur D, Poncelet A, Rubay J, Astarci P, Verhelst R, Noirhomme P, El Khoury G. Repair-oriented classification of aortic insufficiency: impact on surgical techniques and clinical outcomes. J Thorac Cardiovasc Surg 2009;137:286-294) [8]

disease due to calcification, thickening, and fibrosis of the aortic valve leaflets.

Patients can present with either single or multiple lesions contributing to their aortic insufficiency. For example, patients with isolated type Ib AI (due to dilatation of the sinuses of Valsalva) are expected to have a central regurgitant jet. Thus, the presence of a sinus of Valsalva aneurysm with an eccentric AI jet suggests concomitant leaflet prolapse (type II) or restriction (type III). Further assessment of leaflet anatomy can help to better delineate the different mechanisms contributing to AI.

Surgical Techniques

An exhaustive review of surgical techniques is beyond the scope of this manuscript and the readers are referred to published reviews on the subject [20]. Generally speaking, surgical techniques for AV repair can be divided into two categories, namely, techniques for the aortic root and annular remodelling, and cusp repair techniques.

Aortic Root and Annular Techniques

Aortic insufficiency resulting from the dilatation of any of the components of the functional aortic annulus is classified as type 1 lesions. These lesions can occur in isolation or in conjunction with cusp disease. Type 1a aortic insufficiency occurs due to a supracoronary ascending aortic aneurysm which leads to dilatation of the STJ. This type of aortic insufficiency is typically associated with a central jet of AI. Repair involves replacing the ascending aorta and reducing the size of the STJ using an appropriately sized Dacron graft sutured at the level of the STJ [21]. In the presence of significant associated AI, sub-commissural annuloplasty is added to improve cusp coaptation [22]. Aortic root aneurysms (type 1b) are frequently associated with dilatation of both the distal (STJ) and proximal (VAJ) components of the functional aortic annulus. These are also associated with a central regurgitant jet and repair typically involves valve-sparing aortic root replacement. The reimplantation technique is preferred as it provides better stabilization and permits greater remodelling of the VAJ. The details of this procedure have been previously described [23]. Valve sparing root replacement procedures have been performed in trileaflet and bicuspid aortic valves, with or without pre-existing aortic insufficiency with good results [24]. In cases of bicuspid aortic valves, where the sinotubular junction and aortic root are normal, and only the VAJ is dilated, a subcommissural annuloplasty may be performed but has been associated with late repair failure [25]. In these patients, in whom a valve-sparing root replacement is not indicated and may seem excessive, other annuloplasty techniques and devices, both internal and external, are currently in development and early clinical evaluation [26-28].

Cusp Repair Techniques

Cusp prolapse is the most frequent cusp pathology encountered and is caused by excess free margin length. Correction of cusp prolapse can be performed using either central free margin plication [29] or free margin resuspension [16] with a PTFE suture. When a single cusp is prolapsing, the two non-prolapsing cusps can be used as the reference to determine the amount of reduction required in the free margin. When two cusps appear to be prolapsing, the third non-prolapsing cusp serves as a reference. If all the cusps are prolapsing, the aim is to achieve a cusp coaptation height at the mid-level of the sinuses of Valsalva. Alternative techniques for adjusting cusp height using calliper based references have been advocated by some.

Free margin plication is performed using a small caliber Prolene suture placed in the centre of the free margin to plicate, shorten and reduce its length thus raising its height. Free margin resuspension accomplishes the same objective by passing a PTFE suture over and over the free margin, anchored at the commissures. Pulling on this suture has the effect of performing multiple plications along the free margin, thus shortening and raising it.

Bicuspid aortic valve (BAV) disease not only affects the valve cusps, but also various components of the functional aortic annulus. The STJ, sinuses of Valsalva and the VAJ may be dilated in these patients, in isolation or all together. According to a classification proposed by Sievers and adapted to AV repair, bicuspid AV can be divided into two general types [10, 30]. The more infrequently encountered type 0 bicuspid AV (10–20 % of repaired BAVs) does not contain a median raphe, has two symmetric aortic sinuses, two commissures, and a symmetric base of leaflet implantation of the two cusps. AI in these valves is usually due to cusp prolapse.

Type 1 bicuspid AVs are significantly more prevalent (over 80 % of repaired BAVs) and have a median raphe on the conjoint cusp and an asymmetric distribution of the aortic sinuses, which can be quite variable. Most commonly, the conjoint cusp is a fusion of the left and right coronary cusps. The raphe attaches to the cusp base as a ‘pseudo-commissure’, and has a height lower than that of the true commissures. The quality of the raphe is an important determinant of the type of repair. The raphe may be restrictive, calcified and have reduced mobility or may simply be fibrous and be associated with excess cusp tissue and prolapse. In addition, the base of leaflet implantation is typically larger (i.e. occupying a greater proportion of valve circumference) and higher on the conjoint cusp compared to the non-conjoint cusp. AI in type 1 BAVs may be due to cusp restriction, typically seen with a rigid and calcified raphe or due to prolapse of the conjoint cusp in the setting of a short raphe and well developed cusps. Bicuspid valve anatomy can lie anywhere along a spectrum between type 0 and type 1.

While the techniques of free margin plication and resuspension can be applied to bicuspid aortic valves, management of the raphe and the pseudo-commissure is an important step in BAVs. Techniques for managing the raphe include shaving and preservation, when it is fibrous, resection with primary reapproximation, or resection and cusp restoration with patch material. Patch material has also been used to facilitate tricuspidization of BAVs and for the repair of more complex cusp anatomy as observed in unicuspid and quadricuspid aortic valves. The use of extrinsic material for cusp augmentation is associated with increased late repair failure compared to repair using native cusp tissue alone [10]. This may represent inherent limitations of patch materials available or may be a marker for more severe disease. Innovations in the materials available for cusp repair may result in improved valve repair durability.

Outcomes

The driving force behind aortic valve repair is the absence of an ideal prosthetic aortic valve. An ideal prosthetic valve would be easy to implant, be readily available, have excellent hemodynamics, no risk of thromboembolism or endocarditis, not require anticoagulation, and be durable in the long-term. Unfortunately, currently available aortic valve substitutes have limitations in all these areas. In the typically younger aortic valve repair population, bioprosthetic valves have limited durability and a median time to explants of less than 8 to 10 years [31]. Mechanical valves carry a risk of thromboembolism and require the inconvenience, burden and annual risk of 1–2 % of serious hemorrhage due to lifelong anticoagulation. Furthermore, mechanical valves do not guarantee lifelong durability and the cumulative risks of valve related events (up to 4–5 %/patient-year) over time can be substantial for the young patient. Lastly, prosthetic valve endocarditis is a devastating disease with high morbidity and mortality.

In contrast, aortic valve repair has been shown in multiple studies to have a lower risk of valve-related events. In a cohort of 475 consecutive patients, AV repair was associated with a risk of thromboembolism, bleeding and endocarditis of 1.1 %, 0.23 % and 0.19 % respectively [19•]. Another large cohort study of 640 patients demonstrated a low incidence of thromboembolism (0.2 %/year) and endocarditis (0.16 %/year) with a 10 year freedom from all valve-related complications of 88 % [18]. In a consecutive cohort of bicuspid AV repair patients, the 8-year freedom from bleeding, thromboembolism and endocarditis was 96 % [10]. In all the above studies, early mortality for elective aortic valve repair procedures was<1 %. These findings have validated the potential for AV repair to provide patients with a life free of potentially disabling complications and from lifelong oral anticoagulation. Given this profile of low risk of valve-related events, it is interesting to examine whether this intervention should be offered to patients early, i.e. prior to the development of significant LV dilatation and dysfunction. To date, there are no comparative studies of early versus late AV repair and its impact on outcome and this is likely to be an important focus for future investigations.

Despite the low risk of valve related events, durability of the repaired valve remains both an important limitation and also an opportunity for improvement in patients undergoing aortic valve repair. Overall, freedom from reoperation at 10 years is typically in the range of 80–90 %. However, this number does not tell the complete story. Several studies have highlighted important predictors of repair failure. The earliest AV repairs consisted of valve sparing aortic root replacement in patients with largely normal quality leaflets and the long-term data in these patients has shown a 77 % survival and

89 % freedom from significant aortic insufficiency at 15 years [32•].

With increasing experience, aortic valve preservation and repair techniques have been extended to patients presenting with significant cusp pathology. According to the classification of AI, type III disease, due to cusp restriction, is a risk factor for recurrent AI and reduced repair durability. Patients with cusp restriction have a 5-year reoperation risk of 15 %, compared to ~5 % in patients with type I and II disease [8].

Important insights have also been obtained in patients with bicuspid aortic valve disease undergoing repair. It has become increasingly apparent that the reduction and stabilization of the functional aortic annulus is an important component of valve repair. BAV patients presenting with AI have significantly larger aortic annuli compared to patients with aortic stenosis and successful repair requires a 4–5 mm reduction in annular diameter. As such, patients who are left with a dilated aortic annulus post-repair have increased risk of failure [33]. Furthermore, the use of more robust annuloplasty techniques (e.g. valve-sparing aortic root replacement with the reimplantation technique) are associated with improved repair durability [25]. Development of devices that facilitate AV annuloplasty may further improve outcomes. BAV patients are also more likely to require cusp repair. Cusp and commissural configuration post-repair has also been found to be an important predictor of repair failure and in patients undergoing primarily root remodelling, commissural angle<160° is associated with repair failure [9]. Lastly, the use of patch material for cusp restoration or augmentation is associated with late repair failure. Improvements in biomaterials available for cusp reconstruction may address this limitation.

Conclusions and Future Directions

Over the past two decades, aortic valve repair has matured from a discipline practiced by a few pioneering surgeons to an increasingly accepted alternative to valve replacement in selected patients with AV disease. Much like mitral valve repair, improvements in the understanding of the mechanisms of disease, advances in surgical techniques and longitudinal follow-up studies have all helped to improve outcomes. Improvements in devices and materials currently being evaluated to facilitate AV repair is expected to further improve repair durability. Perhaps the most important challenge in its more widespread use is the dissemination of the tacit and sometimes complex skills required. Innovative approaches using advanced, patient-specific, modelling of valve anatomy using 3-dimensional echocardiography and virtual surgery to correct valve defects within these models prior to operative intervention may facilitate dissemination of AV repair techniques to a broader population.

Compliance with Ethics Guidelines

Conflict of Interest Munir Boodhwani and Gebrine El Khoury declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. Anderson RH. Clinical anatomy of the aortic root. Heart. 2000;84: 670–3.
2. Underwood MJ, El Khoury G, Deronck D, Glineur D, Dion R. The aortic root: structure, function, and surgical reconstruction. Heart. 2000;83:376–80.
3. Bonow RO, Carabello BA, Kanu C, de Leon Jr AC, Faxon DP, Freed MD, et al. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease): developed in collaboration with the Society of Cardiovascular Anesthesiologists: endorsed by the Society for Cardiovascular Angiography and Interventions and the Society of Thoracic Surgeons. Circulation. 2006;114:e84–231.
4. Gillinov AM, Mihaljevic T, Blackstone EH, George K, Svensson LG, Nowicki ER, Sabik JF, 3rd, Houghtaling PL, Griffin B. Should patients with severe degenerative mitral regurgitation delay surgery until symptoms develop? Ann Thorac Surg. 2010;90:481–488.
5. Sharma V, Suri RM, Dearani JA, Burkhart HM, Park SJ, Joyce LD, Li Z, Schaff HV. Expanding relevance of aortic valve repair-is earlier operation indicated? J Thorac Cardiovasc Surg. 2014;147(1):100–7.
6. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey Jr DE, et al. ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with Thoracic Aortic Disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. Circulation. 2010;121:e266–369.
7.• Svensson LG, Adams DH, Bonow RO, Kouchoukos NT, Miller DC, O'Gara PT, et al. Aortic valve and ascending aorta guidelines for management and quality measures: executive summary. Ann Thorac Surg. 2013;95:1491–505. *This Society of Thoracic Surgeons Guideline document provides an up to date summary of indications for ascending aortic intervention.*
8. Boodhwani M, de Kerchove L, Glineur D, Poncelet A, Rubay J, Astarci P, et al. Repair-oriented classification of aortic insufficiency: impact on surgical techniques and clinical outcomes. J Thorac Cardiovasc Surg. 2009;137:286–94.
9. Aicher D, Kunihara T, Abou Issa O, Brittner B, Graber S, Schafers HJ. Valve configuration determines long-term results after repair of the bicuspid aortic valve. Circulation. 2011;123:178–185.

10. Boodhwani M, de Kerchove L, Glineur D, Rubay J, Vanoverschelde JL, Noirhomme P, et al. Repair of regurgitant bicuspid aortic valves: A systematic approach. J Thorac Cardiovasc Surg. 2010;140:276–84.
11. Schafers HJ, Aicher D, Riodionycheva S, Lindinger A, Radle-Hurst T, Langer F, et al. Bicuspidization of the unicuspid aortic valve: a new reconstructive approach. Ann Thorac Surg. 2008;85:2012–8.
12. Jeanmart H, de Kerchove L, El Bitar F, Glineur D, Vandyck M, Noirhomme P, et al. Tricuspidation of quadricuspid aortic valve: case reports. J Heart Valve Dis. 2007;16:148–50.
13. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg. 1992;103:617–21. *discussion 622*.
14. Yacoub MH, Gehle P, Chandrasekaran V, Birks EJ, Child A, Radley-Smith R. Late results of a valve-preserving operation in patients with aneurysms of the ascending aorta and root. J Thorac Cardiovasc Surg. 1998;115:1080–90.
15. Aicher D, Langer F, Adam O, Tscholl D, Lausberg H, Schafers HJ. Cusp repair in aortic valve reconstruction: does the technique affect stability? J Thorac Cardiovasc Surg. 2007;134:1533–8. *discussion 1538-1539*.
16. de Kerchove L, Boodhwani M, Glineur D, Poncelet A, Rubay J, Watremez C, et al. Cusp prolapse repair in trileaflet aortic valves: free margin plication and free margin resuspension techniques. Ann Thorac Surg. 2009;88:455–61. *discussion 461*.
17. Carpentier A. Cardiac valve surgery–the "French correction". J Thorac Cardiovasc Surg. 1983;86:323–37.
18. Aicher D, Fries R, Rodionycheva S, Schmidt K, Langer F, Schafers HJ. Aortic valve repair leads to a low incidence of valve-related complications. Eur J Cardiothorac Surg. 2010;37:127–32.
19.• Price J, De Kerchove L, Glineur D, Vanoverschelde JL, Noirhomme P, El Khoury G. Risk of valve-related events after aortic valve repair. Ann Thorac Surg. 2013;95:606–12. *One of the largest series of consecutive patients reporting outcomes on valve-related events following AV repair*.
20. Boodhwani M, El Khoury G. Aortic Valve Repair. Oper Tech Thorac Cardiovasc Surg. 2009;14:266–80.
21. David TE, Feindel CM, Armstrong S, Maganti M. 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. 2007;133:414–8.
22. Boodhwani M, de Kerchove L, Glineur D, Rubay J, Vanoverschelde JL, Van Dyck M, Noirhomme P, El Khoury G. Aortic valve repair with ascending aortic aneurysms: associated lesions and adjunctive techniques. Eur J Cardiothorac Surg. 2011;40:424–428.
23. Boodhwani M, de Kerchove L, El Khoury G. Aortic root replacement using the reimplantation technique: tips and tricks. Interact Cardiovasc Thorac Surg. 2009;8:584–6.
24. de Kerchove L, Boodhwani M, Glineur D, Poncelet A, Verhelst R, Astarci P, et al. Effects of preoperative aortic insufficiency on outcome after aortic valve-sparing surgery. Circulation. 2009;120: S120–6.
25. Navarra E, El Khoury G, Glineur D, Boodhwani M, Van Dyck M, Vanoverschelde JL, Noirhomme P, de Kerchove L. Effect of annulus dimension and annuloplasty on bicuspid aortic valve repair. Eur J Cardiothorac Surg. 2013;44:316–322; discussion 322–313.
26. de Kerchove L, Vismara R, Mangini A, Fiore GB, Price J, Noirhomme P, Antona C, El Khoury G. In vitro comparison of three techniques for ventriculo-aortic junction annuloplasty. Eur J Cardiothorac Surg. 2012;41:1117–1123; discussion 1123–1114.
27. Lansac E, Di Centa I, Bonnet N, Leprince P, Rama A, Acar C, et al. Aortic prosthetic ring annuloplasty: a useful adjunct to a standardized aortic valve-sparing procedure? Eur J Cardiothorac Surg. 2006;29:537–44.
28. Mazzitelli D, Nobauer C, Rankin JS, Badiu CC, Krane M, Crooke PS, Cohn WE, Opitz A, Schreiber C, Lange R. Early results after implantation of a new geometric annuloplasty ring for aortic valve repair. Ann Thorac Surg. 2013;95:94–97.
29. Boodhwani M, de Kerchove L, Glineur D, El Khoury G. A simple method for the quantification and correction of aortic cusp prolapse by means of free margin plication. J Thorac Cardiovasc Surg. 2010;139:1075–7.
30. Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg. 2007;133:1226–33.
31. Chan V, Malas T, Lapierre H, Boodhwani M, Lam BK, Rubens FD, Hendry PJ, Masters RG, Goldstein W, Mesana TG, Ruel M. Reoperation of left heart valve bioprostheses according to age at implantation. Circulation. 2011;124:S75–80.
32.• David TE, Armstrong S, Manlhiot C, McCrindle BW, Feindel CM. Long-term results of aortic root repair using the reimplantation technique. J Thorac Cardiovasc Surg. 2013;145: S22–25. *This paper provides the long-term follow-up of one of the largest series of patients undergoing valve sparing aortic replacement*.
33. de Waroux JB, Pouleur AC, Goffinet C, Vancraeynest D, Van Dyck M, Robert A, et al. Functional anatomy of aortic regurgitation: accuracy, prediction of surgical repairability, and outcome implications of transesophageal echocardiography. Circulation. 2007;116: I264–9.