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SPECIAL EDITION

Controversies in Surgery for Thoracic Aorta

Why I choose to repair and not to replace the aortic valve?

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Abstract
Aortic valve replacement whether surgical or transcutaneous remains an option for the treatment of severe aortic valve disease; however, current prosthetic devices are associated with complications including, but no limited to, valve thrombosis and thromboembolic events, bleeding events associated with anticoagulation use, prosthetic valve endocarditis and structural valve deterioration. In this effect, aortic valve repair (AVr) has become an attractive alternative in circumventing these potential complications by preservation of the native aortic valve apparatus. In this article, we attempt to present the progress made for AVr over the last two decades. We also wish to highlight the critical steps for successful AVr and the outcome data that demonstrate that can be first-choice treatment in selected patients and finally to emphasize on the key steps for further future development.

Keywords Aortic valve · Aortic valve repair

Abbreviations

AV	Aortic valve
AVr	Aortic valve repair
AI	Aortic insufficiency
COR	Class of recommendation
LOE	Level of evidence
LVEF	Left ventricular ejection fraction
LVESD	Left ventricular end systolic dimension
LVEDD	Left ventricular end diastolic dimension
AVJ	Aortoventricular junction
STJ	Sinotubular junction
MV	Mitral valve
FAA	Functional aortic annulus
CVG	Composite valve graft
TAVI	Transcatheter aortic valve implantation
SCA	Subcommissural annuloplasty

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Introduction

Aortic valve replacement (AVR) with a biological or mechanical prosthesis has traditionally been the treatment of choice for patients with aortic valve insufficiency (AI) with or without aortic root pathology. However, the disposition of prosthetic valves is far from an ideal solution as it is associated with numerous complications. Mechanical valves require life-long anticoagulation placing the patient at risk of haemorrhage. On the contrary, biological valves undergo structural valve degeneration inherit the eventuality of needing to be replaced. Furthermore, all implanted valves put the patient at risk for prosthesis-related complications including endocarditis, thromboembolism, and reoperation [1]. Unfortunately, as the ideal prosthetic valve does not yet exist, the native valve disease is typically replaced by the "prosthetic valve disease" [2]. Like in the case of the mitral valve (MV), these concerns became the impetus for the development of the aortic valve repair (AVr). The AVr provides longer durability than the biological valves as utilization of the native tissue is performed, additionally it also does not introduce the patients to the lifelong risks associated with anticoagulation as in the case of mechanical valves, providing as the first choice of treatment, especially for young patients with AI. Nevertheless, the chances of patient prosthesis mismatch are minimal since no prosthesis in implanted but rather the native tissue has been repaired.

A historical overview

The journey of AVr presents a significant resemblance to that of MV. By analogy, with MV repair, we include in the term AVr not solely the repair of the cusp but also the valve-sparing root replacement including functional aortic annulus stabilization. The preservation of the normally functioning aortic valve in the context of aortic root pathology was perhaps the first important milestone in AVr. The valve-sparing techniques of re-implantation and remodelling pioneered by David and Feindel [3] and Yacoub et al. [4] were the first annuloplasties of aortic valve compelling surgeons to better understand the anatomic and functional relationships of the aortic annulus and cusps [5]. Following these, a variety of leaflet repair techniques were developed, including free margin plication, free margin resuspension, triangular resection and pericardial patch augmentation [6, 7]. In the most recent years, we had the emergence of a classification system for AI, similar to the one that Carpentier introduced for the mitral valve insufficiency, and an increased number of published studies which report outcome data for longer follow-up, beyond 10 years, and reveal good repair durability and a low rate of valve-related complications with AVr [5, 8, 9].

Anatomical understanding of the aortic valve

Prescribing the normal aortic valve (AV), the AV leaflets insert into the aortic annulus proximally at the aortoventricular junction (AVJ) and distally at the sinotubular junction (STJ). Hence, as a functional entity, the AV consists of the STJ and AVJ, which together form the functional aortic annulus (FAA) and the valve cusps. The integrity of both functional components (the cusps and the FAA) is the basis for good valvular function and thus a fundamental principle in AVr is that both lesions of the cusps and lesions of the FAA should be addressed at the time of AVr. In a normal AV, also, although cusp coaptation relatively constantly reaches the midlevel between the AVJ and the STJ, a certain degree of individual variation exists in the length of coaptation, ranging from 2 to 6 mm. Although a coaptation of 2 mm is enough to ensure valve competence in a FAA of normal size, longer coaptation may represent some sort of coaptation reverse in the event of FAA dilatation. This anatomic feature, in combination with the individual compliance of the cusp tissues, explains the multiple clinical presentations with regard to the correspondence between the degree of FAA dilatation and the severity of AI [10].

Unlike MV disease, which is associated with a relatively high proportion of repair, AVr is only performed in 2–8% of all AV surgeries [11, 12]. This difference is largely due to the commonly seen pathology of the AV, i.e. calcific aortic stenosis, which is not amenable to repair. Furthermore, surgical and technical aspects make AVr rather challenging than the MV repair. Relatively stating and in contrast to the MV, surgeon's view of the AV is from its outflow side, making it virtually impossible for surgeons to visually access and test the valve in its pressurized state. Echocardiographic and anatomic assessment of the AV is, therefore, critical for successful AVr. Second to none, the FAA, which is amongst the two basic structures that are imperative in the case of AVr, is not a single entity but as it was mentioned above, it consists from the AVJ and the STJ, both of which play an important role in the normal valve function. Thus, annuloplasty of the AV requires attention to those components [5]. Yet an important limitation to the universal application of AVr techniques is the lack of surgical training, expertise and experience in this field resulting in the patients who are candidates to be referred mainly to specific centres and specific surgeons. However, this is changing rapidly with increasing interest in AVr.

Surgical indications

Carpentier said that 'surgeons are not basically concerned with lesions, we care more about function'. Therefore, one may define the aim of a valve reconstruction as restoring normal function rather than normal valve anatomy [13]. Surgical indications for AVr are similar to those for AVR (Table 1). Therefore, AVr is indicated for symptomatic patients with severe AI regardless of left ventricular (LV) systolic function (Stage D, COR: I, LOE: B), asymptomatic patients with chronic severe AI and LV systolic dysfunction (LVEF < 50%) (Stage C2, COR: I, LOE: B), as well as for patients with severe AI (stage C or D) while undergoing cardiac surgery for other indications (COR: I, LOE: C). Also, AVr is reasonable for asymptomatic patients with severe AI with normal LV systolic function (LVEF · 50%) but with severe LV dilatation (LVESD > 50 mm, stage C2, COR: IIa, LOE: B), in patients with moderate AI (stage B) who undergo other cardiac surgery (COR: IIa, LOE: C) and finally may be considered for asymptomatic patients with severe AI and normal LV systolic function (LVEF · 50%, stage C1) but with progressive severe LV dilatation (LVEDD > 65 mm) if surgical risk is low ([12], COR: IIb, LOE: C) [14]. Another group of patients who undergo aortic valve 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

Table 1 Indications of aortic valve repair as similar to aortic valve replacement

Recommendations	COR	LOE
AVr is indicated for symptomatic patients with severe AR regardless of LV systolic function (stage D)	I	B
AVr is indicated for asymptomatic patients with chronic severe AI and LV systolic dysfunction (LVEF < 50%) (stage C2)	I	B
AVr is indicated for patients with severe AR (stage C or D) while undergoing cardiac surgery for other indications	I	C
AVr is reasonable for asymptomatic patients with severe AI with normal LV systolic function (LVEF 50%) but with severe LV dilation (LVESD > 50 mm, stage C2)	IIa	B
AVr is reasonable in patients with moderate AI (stage B) who are undergoing other cardiac surgery	IIa	C
AVr may be considered for asymptomatic patients with severe AI and normal LV systolic function (LVEF·50%, stage C1) but with progressive severe LV dilation (LVEDD > 65 mm) if surgical risk is low	IIb	C

LV left ventricular, *LVEDD* left ventricular end diastolic dimension, *LVEF* left ventricular ejection fraction, *LVESD* left ventricular end systolic dimension, *AI* aortic insufficiency, *AVR* aortic valve replacement, *COR* class of recommendation, *LOE* level of evidence

disease. In these patients, the primary indication for intervention is driven by aortic size [15].

The assessment of tissue quality is the next crucial step on the approach of the abnormal valve, giving useful information regarding the type of the repair that is going to be chosen but defining also the extent of the procedure. For example, pure AI could be revealed under conditions like aortic aneurysm, bicuspid aortic valve, degenerative leaflet prolapse, endocarditis, autograft failure, acute aortic dissection and commissural disruption, requiring different management in each one of them.

Decision-making for surgical intervention on AV disease 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. In a nutshell, the understanding of the functional anatomy and pathophysiology is very important on the assessment of the diseased AV, providing useful data for the underlying mechanism of dysfunction and, furthermore, for the surgical treatment which needs to be chosen.

Present and future of aortic valve repair

It is true that the lack of randomized trials and non-randomized studies comparing AVr with AVR makes it difficult to define the role of repair in the management of AV disease. While there is a wealth of data that exist on outcomes following AVR, data on outcomes following AVr are limited to selected centres and surgeons. Combining data from observational studies [1, 16, 17] and evaluating the progress of the AVr over the last few years, important messages are delivered. First of all, the patient population and the surgical techniques of the AVr are continuously evolving. Second, the most recent studies [5, 8, 9, 18–21] provide long-term data. Third, the mid- to long-term outcome following AVr appears to be acceptable. 5 and 10 years of rates of freedom, in most of the studies are above 90% and around 75–80%, respectively. This compares favourably to bioprosthetic valve, which in the same population, counting a rate of degeneration 3.7%/pt-year for age < 50 and 2%/pt-year for age 50–60 [21], carries a durability of 81–90 and 63–80% at 5 and 10 years, respectively. On the other hand, the risk of reoperation seems to be higher with AVr versus mechanical AV replacement where the freedom from reoperation is typically over 90% at 10 years. Fourth, the linearized risk of thromboembolic complications in case of AVr is lower than following mechanical or biological AVR (0.5%/pt-year vs 1–2/pt-year). It is reported to be even higher following composite replacement of the AV and root with a mechanical prosthesis, being as high as 10%/pt-year [16]. Finally, it deserves to be mentioned that the aortic valve-sparing operations, as many studies demonstrate [18–23], are associated with better haemodynamic performance, reduced cardiac mortality and valve-related complications when compared with composite valve graft (CVG) procedures, with either a bioprosthesis or mechanical valve, and at the same might represent a valuable option for patients with Marfan syndrome with aortic aneurysm.

There are two important limitations regarding the above conclusions which need to be reported. The first is that AVr is still performed in selected patients, at certain specialized centres and within those centres, only by a handful of surgeons. Second, the relatively young age of the patients undergoing AVr results also in low mortality and morbidity. An interesting addition to this section is that repaired AV has the potential for growth, which is important in the paediatric population.

As the preservation and repair of AV matures as a discipline, there are several important challenges and opportunities that lie ahead. First, there is a need to expand the repertoire of surgical techniques available for AVr. For example, techniques and materials to address AVJ dilatation in the setting of a non-dilated root, often seen in patients with bicuspid AV, require further refinement. On the same direction, the development of materials for cusp augmentation and reconstruction which will endure the haemodynamic stress of the AV without degeneration or calcification, will not tagger an immunoresponse, be available off the shelf, have excellent intraoperative handling properties, and will improve further the outcomes of AVr and mainly the need for re-intervention. The second important frontier in the advancement of AVr is the careful conduct of long-term outcome studies. Furthermore, as more data accrue, outcomes of AVr need to be compared with those of AVR with mechanical valve, bioprosthetic valve and pulmonary autograft. At the same time, there is an emerging increasing need the AVr also to be compared with the transcatheter aortic valve implantation (TAVI), together with the valve-in-valve technique which seems to gain more and more on the treatment of the aortic valve disease. The training of the new surgeons is the last step. Malas et al. reported that AVr is reproducible and appears to have a learning curve of approximately 40–60 cases [24]. Adjunctive tools to facilitate education should be considered, including the use of animal or cadaveric models and computer simulation. Surgical techniques could be implemented within finite element models of the AVs, which will be created based on real patient data from echocardiograms, predicting the outcome of certain anatomic manipulations [5].

Assessment of the repairable aortic valve

To replace or repair the aortic valve is a commensal of every decision we are faced with when it comes to AV surgery. From the technical perspective, all patients with primary AI are potentially candidates for repair. However, before embarking on any decision, we ought to recognise the importance of the valve pathology and functional anatomy. It is also of added value to address the pathophysiology, tissue quality and the application of reproducible surgical techniques which attain durable outcome and are the critical steps for a successful repair.

The management of the regurgitant bicuspid AV remains a challenge from the technical aspect of view. As bicuspid AV disease is associated with a connective tissue with dilatation of the aortic root, El Khoury [1] reported that it is more beneficial to choose a reimplantation aortic valve-sparing root replacement technique that implants the entire FAA within a prosthesis, precluding future dilatation. Another point contributing excellent results in the repair of bicuspid AV is the choice of an aggressive approach regarding the leaflet reconstruction. Phenotypically, bicuspid leaflets often have excess tissue and exhibit some degree of prolapse. It is recommended to liberally correct leaflet prolapse to achieve coaptation at the mid-height of the sinuses of Valsalva and with a good coaptation length [1].

It has been demonstrated that the three most important parameters for a successful and durable repair are the absence of any more than mild residual AI, a coaptation length greater than 4 mm and coaptation starting well above the plane of the aortic annulus [25]. The success of the repair can be estimated immediately after the removal of the aortic clamp, as the pressure applied by the cardiopulmonary bypass flow through the arterial cannula into the aortic root will cause regurgitation into the left ventricle if the repaired cusps do not coapt adequately. The TEE also will disclose any residual defect of coaptation. The most common causes for immediate unsatisfactory repair could be summarized into low coaptation, residual prolapse, inadequate annular size reduction, some degree of restriction in valve opening causing high gradient, cusp perforation, missed fenestration, patch dehiscence, perforation of the base of the anterior mitral leaflet, disruption of subcommissural annuloplasty (SCA), tear or fistula if the aortic wall tissue is abnormally fragile (mainly in SCA cases) and pseudoaneurysm of the ascending aorta [26].

Although every patient, especially young, with structural AI could be considered candidate for AVr, the following conditions could be listed as contraindications for AVr: severe calcification and/or fibrosis of the cusps and/or aortic root, valves with an active infection, extremely reduced cusp mobility and lack of surgical experience. In most of the studies the candidates are younger than 70 years, but Urbanski et al., recently reported reconstruction of the AV in the elderly, demonstrating that AVr in this patient population offers low cardiac and valve-related mortality and morbidity, leading to life expectancy applicable to patients' ages [27, 28].

Conclusion

Over the past two decades, important milestones in the development of AVr have matured from a discipline practiced by a few pioneering surgeons, to an increasingly accepted alternative to valve replacement in selected patients with AV disease. The current data reveal that AVr is a safe and feasible choice for the treatment of patients with AI, free from the risks that are correlated with the anticoagulation treatment and provide durable outcomes in the midterm. Further long-term studies, comparing the outcome of repair with replacement will better define the role of repair in this population. Despite this limitation, there is an increasing agreement that AVr should be the recommended method of correction of AI and should be considered in all cases in which surgery is contemplated and the valve is considered to be repairable.

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