EXPERT REVIEW

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Section Editor

Advances in Aortic Valve Repair: Focus on Functional Approach, Clinical Outcomes, and Central Role of Echocardiography

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The surgical classification of aortic regurgitation (AR) is based on cusp mobility. Based on this classification, there are 3 classes of AR: type I is defined as normal cusp mobility, type II is defined as excessive cusp mobility, and type III is defined as restricted cusp mobility. Patients often have multiple coexisting mechanisms. Because aortic valve (AV) repair is safe, effective, and durable, it likely will become a mainstream surgical option for the management of significant AR, even in the setting of a bicuspid valve. Intraoperative transesophageal echocardiography has a central role at all stages in AV repair. Before cardiopulmonary bypass, it can accurately diagnose the mechanism of AR to guide operative strategy for successful repair. After separation from cardiopulmonary bypass, it can comprehensively evaluate the AV repair, including the likelihood that the repair will be durable in the long-term. Important echocardiographic predictors of a durable AV repair include the absence of AR, cusp coaptation above the annular plane, a coaptation length >4 mm, and an effective cusp height >8 mm. The clinical applicability of AV repair continues to expand and likely will evolve into a mainstream surgical therapy for AR, including minimally invasive techniques.

KEY WORDS: aortic valve repair, bicuspid aortic valve, tricuspid aortic valve, transesophageal echocardiography, aortic stenosis, aortic regurgitation, cusp mobility, aortic annulus, sinus of Valsalva, sinotubular junction, functional aortic annulus, cusp height, coaptation length

AORTIC VALVE (AV) replacement classically has been the gold standard for the surgical management of AV disease. The clinical applicability of AV repair, however, has gained momentum. Resuspension of the AV already has become a durable strategy in the contemporary surgical management of acute type-A aortic dissection.[1-3] Furthermore, the development and dissemination of valve-sparing aortic root replacement techniques have further enhanced the functional understanding of the aortic root because these procedures entail aortic root replacement with preservation of the native AV.[4,5] An even better understanding of the aortic root has facilitated the rapid evolution of AV cusp repair even in the absence of aortic root disease.[6,7] The clinical imperatives driving the push for AV repair are primarily to avoid the risk of prosthetic valve complications such as thromboembolism, endocarditis, bleeding, and structural deterioration.[8,9] This article reviews the latest progress in AV repair, with particular emphasis on the considerations relevant to perioperative practice, including transesophageal echocardiography (TEE).

WHAT IS THE CONTEMPORARY FUNCTIONAL CLASSIFICATION OF AORTIC REGURGITATION?

Contemporary mitral valve repair is based on a classification of mitral regurgitation based on leaflet mobility. This functional classification was popularized by Carpentier[10] and was a major advance in the development and dissemination of mitral valve repair techniques. In an analogous fashion, aortic cusp mobility has evolved to be the basis of a functional classification of aortic regurgitation (AR).

In 1997, Haydar et al[11] classified AR into 3 types as the basis for AV repair in a predominantly pediatric cohort (N = 44, 1989-1995). Type-I AR was characterized by normal cusp mobility in the setting of a dilated aortic annulus. Type-II AR was characterized by excessive cusp motion, most typically cusp prolapse with an excess of cusp tissue. Type-III AR was characterized by restricted cusp mobility, often with deficient leaflet tissue. This classification of surgical AR was limited in that it did not address aortic root pathology and aortic cusp perforation in the pathogenesis of pathologic AR. Nevertheless, it was an important milestone in the development of a robust surgical classification of AR that guided surgical technique.

In 2005, El Khoury et al[12] extended and refined this classification of AR (Table 1). In the revised classification, the functional aortic annulus was defined as the aortic root bounded by the ventriculoaortic junction (VAJ: aortic annulus as typically measured by TEE) and the sinotubular junction (STJ),

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Table 1. Functional Classification of AR

Type of AR	Mechanism of AR
Type IA	Dilated sinotubular junction (normal cusp mobility)
Type 1B	Dilated sinuses of Valsalva (normal cusp mobility)
Type 1C	Dilated ventriculoaortic junction (normal cusp mobility)
Type 1D	Aortic cusp perforation (normal cusp mobility)
Type II	Aortic cusp prolapse (excessive cusp mobility)
Type III	Restricted cusp mobility (thickening, fibrosis, calcification)

defined as the point where the sinus segments of the aortic root join the tubular ascending aorta.[13]

Furthermore, El Khoury et al[12] defined 4 subgroups of type-I AR to account for dilatation at different levels in the functional aortic annulus. Type-IA AR is secondary to dilatation of the STJ and the ascending aorta. Type-IB AR is secondary to dilatation of the sinuses of Valsalva. Type-IC AR is secondary to dilatation of the VAJ. Type-ID AR is secondary to cusp perforation without dilatation of the functional aortic annulus. Type-II AR was defined as cusp prolapse caused by excessive cusp or commissural disruption. Type-III AR was defined as restricted cusp mobility because of thickening, fibrosis, and calcification, which is most typically associated with bicuspid, degenerative, and rheumatic AV disease.

The utility of this revised surgical classification of AR by El Khoury et al is that it guides the choice of surgical technique for repair, just as the Carpentier classification of mitral regurgitation guides mitral valve repair (Table 2). In type-IA lesions, the dilated STJ is remodeled to normalize aortic cusp coaptation. This frequently is achieved in conjunction with a carefully sized ascending aortic graft.[13,14] This serves as a distal annuloplasty of the functional aortic annulus. As a secondary procedure, proximal stabilization of the proximal annulus at the VAJ is achieved with subcommissural annuloplasty. This dual annuloplasty technique stabilizes the functional aortic annulus.

In type-IB lesions, the dilated sinuses of Valsalva are excised, and a valve-sparing root replacement is performed either with the reimplantation or the remodeling technique.[13,14] This type of aortic root replacement includes both proximal (VAJ level) and distal (STJ level) annuloplasty for full stabilization of the functional aortic annulus. This aortic root technique has to be adjusted slightly in the setting of a displaced coronary artery that is too close to the valve commissure to allow reattachment as a coronary button. In this special case, the displaced coronary artery is left attached and is included as is into a modified Dacron graft.[13-15]

In type-IC lesions, the dilated basal aortic annulus at the VAJ level is normalized with subcommissural annuloplasty to restore AV competency.[13,16] As a secondary procedure, STJ annuloplasty often is indicated to stabilize the distal aspect of the functional aortic annulus. In type-ID lesions, cusp perforations are repaired with autologous or bovine pericardium as a primary procedure. Basal annular reinforcement is typical by means of subcommmissural annuloplasty. Aortic cusp fenestrations may be associated with sinus of Valsalva dilatation.[17] These cusp perforations occur because the aortic cusps remain fixed at the commissural attachments, but the cusp tissue below is torn as the sinus segment dilates. These fenestrations may not be apparent during TEE and may make native valve preservation impossible. Furthermore, this scenario shows that a patient with surgical AR may have multiple mechanisms; in this case, type-IB (sinus of Valsalva dilation) and type ID (cusp perforation). In fact, more than 30% of patients with surgical AR may have multiple mechanisms.[13,16]

In type-II lesions, the aortic cusp prolapse is corrected, and the basal annulus at the VAJ level is reinforced with interrupted subcommissural annuloplasty plication sutures. Although El Khoury et al[11] did not subcategorize the type of prolapse, it is helpful to consider aortic cusp prolapse as either focal or generalized. In the case of focal cusp prolapse, the prolapsing cusp segment can be managed surgically with placation or triangular resection (with or without pericardial patch repair). In the case of total cusp prolapse, the free margin of the cusp is resuspended to restore both aortic cusp coaptation and AV competency.[13-16] In type-III lesions, the restricted aortic cusps typically are shaved and decalcified with or without patching.[12,13,16] Subcommissural annuloplasty typically is recommended as a secondary procedure to reinforce the basal annulus of the functional aortic annulus complex.[13]

WHAT ARE THE CURRENT CLINICAL OUTCOMES AFTER AORTIC VALVE REPAIR?

Although AV replacement is the gold standard for AV disease, the cumulative risk of a prosthetic valve–related complication is about 50% by 10 years.[18,19] Consequently, although AV repair has matured with a systematic classification and standardized array of surgical techniques, the associated clinical outcomes in the mid- to long-term will determine its future. A recent large series (N = 640, 1995-2007) from Germany evaluated this important clinical question.[20] According to the El Khoury classification, the major AR mechanisms were as follows: type I (n = 323), type II (n= 469), and type III (n = 20). Patients often had more than 1 mechanism, an observation already established by this group of investigators almost 10 years ago.[21] The AV morphology was as follows: tricuspid (64.2%), bicuspid (32.0%), unicuspid (3.3%), and quadricuspid (0.5%). Surgical management comprised root repair (n = 323), cusp repair (n = 529), or both (n = 208). Patient follow-up was

Table 2. AV Repair Based on the Type of Valve Lesion

Type of Lesion	Type of AV Repair
Type IA	Sinotubular junction remodeling (subcommissural annuloplasty)
Type 1B	Valve-sparing aortic root replacement
Type 1C	Subcommissural annuloplasty (sinotubular junction annuloplasty)
Type 1D	Aortic cusp repair (autologous or bovine pericardium)
Type II	Cusp prolapse repair with subcommissural annuloplasty (focal prolapse: plication, triangular resection) (generalized prolapse: free margin resuspension)
Type III	Cusp repair with subcommissural annuloplasty (shaving, decalcification, patch)