Principles of aortic valve repair

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During the past 15 years, important advances in the field of aortic valve (AV) repair have transformed it from an infrequent and anecdotal exercise to a feasible and attractive alternative to valve replacement in selected patients with pure aortic insufficiency (AI). These advances include a deeper understanding of the functional anatomy of the AV and pathophysiologic mechanisms of AI; the development of surgical techniques to restore normal geometry to the aortic root while sparing the AV; and the development of a common language that can be used by all clinicians to describe the lesions, discuss repair techniques, and compare immediate and long-term outcomes after AV repair. This article attempts to describe the important principles of AV repair by focusing on functional anatomy, surgical techniques for cusp repair, and outcome.

ANATOMY OF THE AORTIC VALVE AND THE FUNCTIONAL AORTIC ANNULUS

The AV leaflets insert into the aortic annulus proximally at the aorto-ventricular junction (AVJ) and distally at the sinotubular junction (STJ). In a normal AV, the cusps coapt at the center of the AV orifice with a coaptation height approximately at the mid-level between the AVJ and the STJ. The height of the sinuses of Valsalva (from the AVJ to the STJ) corresponds to the diameter of the STJ, which can be useful to size prostheses for aortic root replacement and to assess cusp geometry after AV repair.

As a functional entity, the AV consists of the STJ and the AVJ, which together form the functional aortic annulus (FAA), and the valve cusps. The integrity of these 2 functional components (ie, the cusps and FAA) is the basis for good valvular function, and alteration in one of these components is frequently associated with alteration in the other. Thus, a fundamental principle in AV repair is that lesions of the cusps and the FAA should be addressed at the time of valve repair.

FUNCTIONAL CLASSIFICATION OF AORTIC INSUFFICIENCY

A functional classification of AI should ideally identify all the contributing lesions of the cusps and the FAA, enable

a reconstructive approach to the AV, and help to identify patients in whom a durable repair is achievable. We previously described such a classification of AI¹ that encompasses all the different causes of AI; provides a common language to be used by surgeons, cardiologists, and echocardiographers; helps the surgeon in choosing the repair techniques; and predicts the immediate success and long-term durability of the repair procedure. Analogous to the mitral valve, in this classification, type 1 disease is caused by lesions of the FAA in the setting of normal cusp motion, type 2 disease is caused by excessive cusp motion due to cusp prolapse, and type 3 disease is caused by restrictive cusp disease.

In this context, 2 important concepts deserve mention. The first notion is that multiple lesions can simultaneously contribute to AI, for example, dilatation of the aortic root or ascending aorta may be associated with alterations in cusp geometry and cusp prolapse. Thus, correction of all contributing lesions is critical for successful repair. The second notion is that as in the mitral valve, severe chronic valve insufficiency can lead to dilatation of the annulus. Thus, any correction of cusp pathology in the setting of chronic, severe AI should be accompanied by annuloplasty of the FAA, which has 2 components, the proximal (AVJ) and the distal (STJ).

GENERAL PRINCIPLES OF AORTIC VALVE REPAIR

The goal of AV repair is to restore a normal surface of coaptation by restoring normal geometry to the leaflets and FAA, while preserving normal mobility of the AV cusps. The mobility of the valve cusps can be viewed as a ratio between the free margin length and the length of the base of cusp implantation, such that:

$$\text{Cusp Mobility} \approx \frac{\text{Free Margin Length}}{\text{Length of Cusp Insertion}}$$

An increase in this ratio leads to greater cusp mobility and may occur because of the presence of excess free margin length or over-reduction of length of cusp insertion by annuloplasty (or the choice of a small prosthesis for a valve-sparing root replacement procedure). Similarly, a reduction in this ratio leads to reduced cusp mobility or cusp restriction. This is frequently observed in bicuspid AVs, which have a large base of cusp insertion compared with the free margin length, as well as in cases of over-correction of cusp prolapse by reduction of the free margin length. This concept also explains the idea that an annuloplasty of the AVJ (ie, reduction of the length of cusp insertion) can improve cusp mobility, reduce the AV gradient, and increase cusp coaptation.

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CUSP REPAIR IN TRICUSPID AORTIC VALVES

Cusp prolapse, by definition, occurs as the result of an increase in the free margin length compared with the length of the base of cusp insertion. This leads to a decrease in the height of the prolapsing cusp compared with the normal cusp(s). Prolapse correction therefore requires a reduction in the free margin length. The critical question thus is how much reduction in the free margin is required to restore cusp height to normal? This reference height can be taken from the non-prolapsing cusp(s), because it is rare to have all 3 cusps prolapsing in a native AV (although it occasionally can be induced after a valve-sparing procedure). An alternative is to use the mid-height of the commissures as a reference height or use an instrument to measure effective cusp height, as previously described by Schafers and colleagues.² The techniques described for cusp prolapse correction include free margin plication³ and free margin resuspension,⁴ which can be used alone or in combination.

CUSP REPAIR IN BICUSPID AORTIC VALVES

Regurgitant bicuspid AVs frequently present with dilatation of the aortic annulus, aortic root, or ascending aorta, and as such almost always have multiple lesions responsible for the AI. Cusp morphology in bicuspid AV can be heterogeneous, and the classification system by Sievers and Schmidtke⁵ provides a useful framework to divide the valves into 2 general types. Type 0 bicuspid AVs are less common, do not contain a median raphe and have 2 symmetric aortic sinuses, 2 commissures, and a symmetric base of leaflet implantation of the 2 cusps. The mechanism of AI in this setting is usually cusp prolapse of 1 or both cusps.

The more prevalent type 1 bicuspid AVs have a median raphe on the conjoint cusp and an asymmetric distribution of the aortic sinuses, with a large aortic sinus accompanying a large non-conjoint cusp and 2 smaller cusps fused together with a median raphe. The raphe often attaches to the cusp base in the form of a "pseudo-commissure," which has a height lower than that of the true commissures. AI in type 1 valves can be due to a rigid and restrictive raphe associated with small fused cusps, resulting in a triangular coaptation defect. Alternatively, the raphe may be short and nonrestrictive, with well-developed cusps and associated prolapse of the conjoint cusp. Bicuspid AVs can exist anywhere along a spectrum between type 0 and type 1.⁶

In type 0 valves, cusp prolapse correction is performed as for tricuspid AVs, using either a non-prolapsing cusp as the reference or restoring the height of coaptation to the mid-point of the sinuses of Valsalva. Cusp prolapse is repaired using free margin plication or resuspension, and the often thickened and fibrotic central aspect of the leaflet is resected. In type 1 valves, the median raphe is addressed first. If the raphe is relatively mobile and only mildly thickened and fibrosed, it is preserved and shaved.

If the raphe is restrictive or calcified, a parsimonious triangular resection of this tissue is performed. Next, the quantity of remaining cusp tissue is assessed by putting the 2 arms of a 6-0 polypropylene suture on the free margin of the conjoint cusp, on either side of the resected raphe. At this point, lack of cusp restriction and good valve opening are signs of the presence of adequate cusp tissue. The leaflet edges are reapproximated primarily when adequate cusp tissue is present; in the absence of adequate tissue, a triangular autologous treated or bovine pericardial patch is used for cusp restoration. Next, the free margins of both cusps are compared for the presence of any prolapse, which is corrected using free margin plication or resuspension with polytetrafluoroethylene.

OUTCOME

Data on the durability of AV repair techniques are currently limited to single-center series that are small to moderate in size, with a follow-up time of 5 to 10 years. Patients undergoing cusp repair in tricuspid AVs (mean age 56 years; 92% are male; 55% have associated aortic disease) have an 8-year freedom from AV reoperation of 96% and freedom from recurrent AI greater than 2+ of 90%. These results are independent of the cusp repair technique, which is a finding consistent across other studies.^{7,8} Bicuspid AV repair, performed in a slightly younger cohort (mean age 44 years, 92% are male, 57% have associated aortic dilatation), leads to an excellent survival of 97% at 8 years, freedom from late AV reoperation of 98% and 87% at 5 and 8 years, respectively, and freedom from recurrent AI greater than 2+ of 94% at 5 years. In our experience, valve-sparing root replacement for root and annular stabilization leads to a more durable outcome compared with subcommissural annuloplasty alone.⁶ The results for bicuspid AV repair are less consistent across other series, likely because of differences in surgical techniques and operative indications.^{9,10} A consistent finding across all major series of AV repair is the low risk of valve-related morbidity: thromboembolism, bleeding, and endocarditis (<0.5%/patient year).^{6,11}

CONCLUSIONS

AV repair is a safe and feasible alternative to AV replacement in selected patients with AI with or without aortic dilatation. The results are durable in the mid-term, but longer-term studies that compare outcome of repair with replacement will better define the role of repair in this population. The low incidence of valve-related morbidity makes valve repair particularly attractive for young patients who want to avoid long-term anticoagulation.

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