Aortic Root Replacement: Can the Aortic Valve Be Spared?
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Objectives
The objectives of this session are to understand (1) aortic root anatomy and function, (2) classification of aortic root pathology, (3) aortic valve sparing surgical techniques and (4) pre and post CPB TEE evaluation for aortic valve sparing procedures.

Aortic Root Anatomy and Function
It is important to understand the term “aortic root” which is frequently used when describing diseases of the aorta. The aortic root begins at the aortic annulus and ends at the upper level of the aortic valve commissures, the sino-tubular junction (STJ). It includes the aortic valve (AV), the sinuses of Valsalva and the origins of the main coronary arteries. The aortic annulus is a complex structure that is comprised of several parts. It is coronet shaped and while “aortoventricular junction” might be a more accurate descriptive, the term “aortic annulus” is used universally. Normal aortic cusps are soft and pliable. Aortic valve competence depends on sufficient overlap of the adjacent cusp’s free margins when closed. The cusps are unequal in size with the non-coronary cusp typically larger than the other two cusps. Variations in the number of cusps also exist, the most common configuration being a bicuspid aortic valve that has two cusps. The sinuses of Valsalva play an important role in the local hydrodynamic forces that influence AV cusp motion as well as coronary blood flow into the coronary ostia.

The attachments of the cusps form the hemodynamic junction between the LV and aorta. Structures attached proximal to the cusps are subjected to ventricular pressure, distally attached structures to aortic pressures. The anatomic separation between LV and aorta occurs where ventricular structures change to the fibro-elastic wall of the aorta. The aortic root is a dynamic structure. Its upper portion exposed to aortic pressures expands during systole (cross-section increases 16%) facilitating AV opening. The basal portion exposed to ventricular pressures expands during diastole and contracts during systole.

Classification of Aortic Root Pathology
Analogous to the Carpentier classification of mitral valve disease, El Khoury et al has described a simple classification of aortic root pathology. The classification is based primarily on cusp function and secondly on root anatomy (see Table 1). The functional aortic annulus (FAA) is defined as the region between the sino-tubular junction (STJ) and the aorta-ventricular junction (AVJ). Three classes of abnormalities are described. Type I includes pathologies with structurally and functionally normal AV cusps, but enlargement of an area supporting the cusps. Clinical conditions that lead to type I lesions include those related to atherosclerosis, connective tissue aortopathies, trauma or infection. Type II lesions involve prolapse of one or more cusps below the level of normal coaptation. Examples of type II lesions may occur as a result of degenerative cusp changes, acute aortic dissection, subaortic VSD or from previous cardiac surgery. Type III lesions describe restricted cusp mobility with inadequate coaptation and are usually a result of calcific degenerative changes or rheumatic disease.

Since AV competence depends on the presence of normal anatomic relationships in the aortic root, it is not difficult to appreciate how diseases of the ascending aorta and/or the aortic root may lead to AV incompetence, even in the presence of normal AV cusps. Surgical intervention for abnormal aortic root or cusp pathology may be indicated in the absence of aortic insufficiency (AI).

<table>
<thead>
<tr>
<th>Type</th>
<th>Clinical Examples</th>
<th>Corrective Surgery</th>
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<tbody>
<tr>
<td>I: Normal cusp, FAA dilation</td>
<td></td>
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<tr>
<td>Ia: distal asc Ao/STJ dilation</td>
<td>atherosclerosis</td>
<td>STJ ‘plasty’ (RAA)</td>
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<td>Ib: proximal (sinuses Valsalva) ± STJ</td>
<td>Marfan’s, BAV</td>
<td>AV sparing procedure</td>
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<td>Ic: isolated FAA dilation</td>
<td></td>
<td>annuloplasty</td>
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<tr>
<td>Id: cusp perforation + FAA dilation</td>
<td>endocarditis, trauma</td>
<td>Cusp repair</td>
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Surgery in Aortic Root Pathology

Isolated ascending aortic aneurysm involving the STJ may result in AI from distraction of the commissures. If the aortic root is normal, simply replacing the aneurysmal portion of the ascending aorta with a graft and carefully ensuring the proper positioning the valve commissures at the proximal suture line will usually correct the valve incompetence. This is a relatively easy and reproducible operation.

In some cases only one sinus of Valsalva is dilated while the other sinuses and STJ may be normal. A synthetic tube graft with a tongue that is tailored to replace the isolated diseased sinus may be all that is necessary to and will correct any associated AI. Occasionally the valve cusp associated with the sinus of Valsalva aneurysm is prolapsed and may require a primary repair if the valve is to be saved. This can be corrected by plicating the free margin of the cusp.

Two basic types of valve sparing operations have been designed for those patients who have an aortic root aneurysm with a normal or near normal AV. These are the reimplantation operation and the remodeling operation. Drs David and Feindel first described the re-implantation technique in 1992. In this technique the entire AV along with its annulus is secured inside an appropriately sized synthetic tube graft. The graft is first secured to the aortic annulus just below the level of the valve cusps. Then the preserved AV is “implanted” inside the graft by sewing the 2-3 mm rim of remaining aortic wall to the graft. Finally the coronary buttons are sewn to the tube graft, which in turn is sewn to the ongoing ascending aorta. An important feature of this operation is that the aortic annulus is secured by the graft and thus prevented from future annular dilatation. The remodeling technique was first described by Yacoub in 1983 and published in 1993. In this technique each of the valve commissures is sewn to a synthetic graft that is cut longitudinally to form three separate neo sinuses. These three tongues are then sewn directly to the rim of aortic tissue. This is followed by connecting the coronary buttons to the neo sinuses and then the operation is completed by sewing the distal end of the graft to the ongoing ascending aorta. This operation does not secure the aortic annulus and will not prevent further annular dilatation unless additional measures are taken, such as reinforcing the fibrous portion of the annulus in the region of the non-coronary sinus.

While both the implantation and the remodeling techniques allow the surgeon to spare the AV, there is ongoing controversy about the advantages and disadvantages of the two procedures. There are two key issues central to the debate: the failure of the remodeling technique to secure the aortic annulus and prevent further dilatation and the failure of the reimplantation technique to provide neo sinuses of Valsalva. Although a number of modifications have been proposed for both techniques, the favored procedure currently appears to be the reimplantation technique.

Contraindications for Aortic Valve Sparing Operations

There are situations in which the AV cusps are obviously not normal and therefore should not be considered for valve sparing surgery. Calcified valves, rheumatic valves, valves with large fenestrations or severely over stretched cusps should not be spared. While repair of an isolated single cusp is possible, preserving a valve with more than one prolapsed cusp is probably not appropriate, as these repairs are difficult even in the hands of experienced surgeons. The discovery of a pliable and well functioning bicuspid valve may be amenable to a valve sparing operation although the surgeon should be wary of the natural history of bicuspid valves. AT TGH, we have reserved valve sparing operations for bicuspid valves only in young patients in whom the need for anticoagulation was considered problematic.

Finally there are circumstances in which a valve sparing procedure would be unwise even if the valve appears salvageable. Valve-sparing operations require prolonged aortic cross clamp times and therefore should be avoided in patients with poor ventricular function or when other concomitant complex procedures are necessary.

TEE and Aortic Root Pathology

Standard TEE views used to image the AV and aortic root include the mid-esophageal (ME) AV short axis (30-60°) and the ME AV long-axis (LAX) view (120-160°). The AV SAX view is the only TEE view that shows all 3 AV cusps simultaneously. From the ME AV LAX view the diameter of the LVOT, AV annulus, sinuses of Valsalva, STJ and the ascending aorta can be measured. Color Doppler in the ME views quantifies the location and amount of AI. Two transgastric (TG) views are used to assess the
hemodynamic flow through the AV, the TG LAX view at (120°) and the deep TG view (0°). These views are especially useful to measure transvalvular gradients.

The geometric relations of the aortic root are consistent over a wide range of body sizes. Measurements are made during systole at the basal valvular attachments (annulus), widest portion of the sinuses and STJ. The diameter of the STJ is 10-15% smaller than the annulus. The STJ dilates with age. The aortic root height is the distance from the AV annulus to STJ and should be <22mm. The ratio of the aortic root height to STJ changes from the normal <0.8, to >1.0 if the STJ dilates as in Marfan’s and is preserved <1.0 in hypertensive aortopathy. An aortic annulus >28mm frequently requires an aortic annuloplasty to reduce its size.

Individual cusps and corresponding sinuses of Valsalva are of slightly different sizes with the largest being the non > right > left. The bases of individual cusps are 1.5 times longer than the cusps free margin lengths and the height of cusps range from 12-18mm.

**Annuloaortic Ectasia**
Annuloaortic ectasia is a term that describes annular, STJ and ascending aorta dilatation and is frequently associated with connective tissue disorders such as Marfan’s. These disorders involve the fibrous skeleton of the heart frequently resulting in stretching of the aortic annulus especially in the region of the non-coronary sinus which distorts the non-coronary cusp. TEE examination shows a prominent aortic root, central cusp malcoaptation with central AI. The ME AV LAX view identifies a small AV opening compared to the dilated sinus. The sinuses may be the same size as the STJ making it difficult to establish the exact location of the STJ.

**Sinus of Valsalva Aneurysm**
Sinus of Valsalva aneurysm may be congenital (rare) or acquired defects associated with trauma, endocarditis, Marfan’s or syphilis. A ruptured aneurysm is complex with fistula formation into an adjacent structure. An unruptured aneurysm may cause RVOT obstruction, arrhythmias, or myocardial ischemia. There may be an associated VSD or AR related to cusp pathology. Symmetric sinus dilatation may result in central AI. Cusp prolapse results in eccentric AI. Repair is recommended if the sinuses are > 50% (isolated sinus) or > 40mm (multiple).

**Ascending Aorta Aneurysms**
Ascending aorta aneurysms have a dilated STJ and ascending aorta, though they may involve the sinuses but not the annulus. AI results from outward displacement of the commissures due dilatation of the STJ. TEE examination reveals a normal sized aortic root with ascending aorta dilatation beginning after the STJ. Central AI of varying severity is present. There is frequent association of a bicuspid aortic valve which should be carefully examined for as it complicates AV sparing procedures.

**Aortic Dissection**
Patients with Type A dissection may or may not also have aortic root dilatation. In the presence of a normal appearing AV the reimplantation AV sparing procedure can be used. If there is involvement of one or more commissures with significant AI the patient will require resuspension of the commissures and replacement of the ascending aorta.

**TEE and Valve Sparing Surgery**
Surgery for aortic root pathology involves either sparing or replacing the aortic valve in combination with repairing the aortic root. The decision to preserve the AV during aortic root surgery is aided by perioperative TEE.

Pre cardiopulmonary bypass (CPB) TEE findings document the presence of uni/bi/tri or quadricuspid AV. The absence of calcification and significant cusp prolapse improve the chance of repair. The presence of thinned, fenestrated or curled cusp edges makes valve-sparing procedures less successful. The severity and jet direction of AI is assessed. Eccentric AI jets frequently imply additional cusp pathology complicating valve sparing procedures. Root dimensions are measured. A long root height (20mm) or root height/annulus ratio of >1 complicates valve sparing. A dilated aortic annulus (> 28mm) may require an additional aortic annuloplasty. The single most important criterion in selecting patients for AV sparing root procedures is the morphological appearance of the aortic cusps. Cusps may become thinned, with curled edges and fenestrations making them unsuitable for repair.
In the post CPB period, TEE is used to assess the adequacy of aortic cusp morphology and function. Ideally the cusps should coapt above the aortic annular plane in the sinuses of Valsalva, without evidence of residual cusp prolapse. The length of coaptation should be at least 5mm. There should be trace to mild AR with color Doppler the presence of more AR will compromise the durability of the repair. Adequacy of ventricular function is assessed to exclude regional wall motion abnormalities which may signify inadequate coronary perfusion from problematic coronary reimplantation.

PreCPB TEE for AV sparing surgery includes:

1. Measurements (ME AV LAX)
   - Annulus (<28mm)
   - Sinuses (<40mm)
   - STJ (<30mm)
   - Asc Aorta (<35mm)
2. Cusps
   - Number (ME AV SAX): uni/bi/tri/quad
   - Thinned, fenestrated, curled edges
   - Calcified
   - Prolapsed
   - Coaptation point
3. Direction and quantity AI
   - Central (malcoaptation) vs eccentric (prolapse)
   - Mild, moderate, severe
4. Aortic calcification, atheroma

Post CPB TEE for AV sparing surgery includes:

1. Evaluation of cusp coaptation
2. Residual AI (severity, jet direction), Trace to mild AI is acceptable. Moderate or eccentric AI is more likely to require early surgical intervention
3. Root dimensions
4. LV function

Discussion
Aortic valve sparing surgery requires considerable judgment and skill especially when it comes to making the decision about whether or not an AV should be spared. Patients who appear to be good candidates for valve sparing surgery should be referred to specialized centers where surgeons are skilled in these procedures and where careful follow up is assured. Intraoperative TEE facilitates management of these patients.

Selected readings