Aortic valve (AV) replacement has been until recently the standard surgical procedure for the treatment of AV diseases. However, this trend is progressively changing towards surgical repair in selected cases. Initial attempts at AV repair, performed during the 1960s and 1970s, consisted of commissurotomy, leaflet shaving, pericardial patches, and leaflet extension in rheumatic valves. A greater understanding of the relationship between the AV and root in the 1980s contributed to the development of valve-sparing aortic root replacement techniques that allow for preservation of a normal native valve when a diseased aortic root is replaced. More recently, understanding of the functional interactions among the aortic cusps, aortic annulus, subcommissural triangles, and the sinotubular junction (STJ) has led to the concept of tailored surgical repair of aortic insufficiency (AI) with or without aortic root disease. In contrast, even in the best series, repair of calcified and/or rheumatic AVs is limited because of the high rate of recurrent cusp restriction, restenosis, or patch dehiscence. There is an increasing interest in the use of AV sparing and valve repair for the treatment of AI with the advantages of eliminating the need for long-term anticoagulation and reducing the risk of the prosthesis-related complications of thromboembolism, endocarditis, bleeding, and structural valve deterioration. Repair also has a comparatively low operative mortality and a good midterm durability and, in children, has the additional advantage of allowing for growth, delaying for several years the need for AV replacement.

Multiple imaging modalities, e.g., magnetic resonance and computed tomography, are useful for the preoperative assessment of AI. However, intraoperative transesophageal echocardiography (TEE) is uniquely suited to identify those AI lesions that are suitable for repair based on valve anatomy and an analysis of the mechanisms of incompetence. Furthermore, an immediate postrepair evaluation provides important information about the quality of the surgical repair and mechanisms of any residual AI.

In this article, we review a mechanistic classification of AI accompanied by the typical echocardiographic appearance of each pathophysiologic mechanism, and describe the surgical repair techniques along with their echocardiographic appearance. Lastly, we discuss the key echocardiographic features that constitute an optimal postoperative result.

ANATOMY OF THE AV AND ROOT
The aortic root acts as a native stent, surrounding and supporting the 3 aortic cusps. It extends from the basal attachments of the cusps within the left ventricle (the “basal ring” or “ventriculoaortic junction” [VAJ], that refers to the aortic annulus measured with echo) to their distal attachment at the STJ. Because of the crown-like semilunar attachment of the leaflets within the sinuses of Valsalva, 3 interleaflet triangles separate each cusp (Fig. 1).

Detailed anatomy of the valve has been reviewed, but it is important to understand that, functionally, the leaflets, the annulus, and the STJ are integral parts of the valve mechanism. Therefore, all of these elements need to be considered in determining the mechanism of AI and for tailored surgical correction.

PREREPAIR ECHOCARDIOGRAPHIC ANALYSIS OF THE AV AND ROOT
When dealing with intraoperative pre– cardiopulmonary bypass (CPB) evaluation of reparability of a regurgitant AV, quantification of the insufficiency is less important than the analysis of its mechanism performed in the presence of the surgeon. These patients have frequently been evaluated with numerous cardiac imaging modalities that have led to the decision for surgical intervention. Prerepair TEE should thus focus on a careful analysis of the aortic cusps, analysis of the direction of the AI jet, and measurements of the aortic root diameter (Fig. 2). The general assessment of the AV anatomy and
POSTREPAIR TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ANALYSIS

As with any valve repair procedure, one of the primary roles of TEE is the immediate evaluation of the quality of the repair. The expected postoperative result is a flexible valve that opens well and is competent without residual insufficiency.

Before aortic cross-clamp release, the effectiveness of the repair can be estimated by administering a terminal dose of blood cardioplegia into either the aortic root or tube graft. The root pressurization will oppose the cusps against each other. This technique has been described in pediatric cases of AV repair but is sometimes difficult because the empty nonbeating cardiac structures are not always easily identified at that time.

After the aorta has been unclamped, the pressure caused by the CPB through the aortic cannula into the aortic root will unmask any defect of coaptation. Any significant residual AI at that time indicates an unsatisfactory repair.

Based on a retrospective analysis of the intraoperative echocardiographic data in 186 patients who underwent AV repair, le Polain de Waroux et al. established the following stepwise algorithm incorporating functional and morphological features measured immediately after weaning from CPB. First, the level of cusp coaptation should be above the aortic annulus. This means that the lower level of the coaptation should be higher than the VAJ and its highest level should approach the midheight of the sinuses of Valsalva. The second step consists of evaluating the presence and the direction of any residual AI. Finally, in patients who have a level of coaptation above the aortic annulus and who do not have any significant AI, the third step consists of measuring the coaptation length. In this study, a postrepair coaptation length strongly associated with an increased risk of subsequent recurrent AI.

These observations are in agreement with other studies that also confirmed the importance of postrepair cusp coaptation. Pethig et al. showed that after valve-sparing procedures, the lowest part of the coaptation should be higher than the aortic annular graft implantation; otherwise, it could lead to a recurrent AI necessitating reoperation. Schäfers et al. have designed a special caliper that allows measuring the “effective cusp height,” i.e., the height difference between the highest coaptation point of the cusps and their aortic insertion. Based on their observation that patients who subsequently needed reoperation for AI with recurrence of cusp prolapse had an abnormally low (4–6 mm) height difference compared with the other patients (8–11 mm), they consistently aim at achieving an effective height of 9 to 10 mm.

In case of any residual AI after AV repair surgery, the echocardiographer should quantify it according to the guidelines of the American Society of Echocardiography (Table 1 and see Web supplement) and attempt to identify its mechanism.
Whether or not they are reimplanted, because the surgeon places sutures within the aortic root, the coronary arteries can be damaged. The echocardiographer should be aware of such possible injury and look for regional wall motion abnormalities and, if possible, to visualize blood flow in the proximal segments of the coronary arteries.

Because valve repair can reduce the valve opening, mean and peak transvalvular gradients should be measured in the operating room to exclude significant stenosis. Mean and peak gradients in excess of 15 and 30 mm Hg, respectively, are considered unsatisfactory and could be associated with higher risk of developing severe aortic stenosis necessitating reoperation. Caution is necessary when measuring pressure gradients in the operating room because these gradients are highly flow dependent and thus under the influence of the patient’s hemodynamic status.

If the repair is judged unsatisfactory, a thorough echocardiographic analysis of the valve is absolutely critical and will guide the surgeon in an attempt to correct the causes of residual AI during reexploration. In addition to the postrepair appearance and function of the valve, the decision to reexplore the valve after repair depends on a number of valvular factors including the underlying mechanism of AI, the aggressiveness of attempted repairs, the quality of valve tissue, and a variety of patient factors including age, patient comorbidities, choice of prosthesis (if replaced), and left ventricular function.

In cases in which repair is judged to be no longer feasible, the decision may be made to replace the valve.

### Echocardiographic Description of Various Causes of AI

**Functional Classification of AI**

In 1997, Haydar et al. defined, in a largely pediatric population, type I AI in the presence of an aortic annular dilation, whereas type II AI was the result of redundant leaflet tissue and type III of restricted leaflet motion. El Khoury et al. further refined this classification by considering the aortic root as a functional entity with two borders (the VAJ and the STJ). They also further divided type I into subtypes based on which root component was dilated. This classification focuses on the mechanism of valve dysfunction and helps the surgeon choose the most appropriate repair technique to restore normal valve physiology (Fig. 3).

Preoperative assessment of the functional anatomy by TEE has proven to be an accurate and strong predictor of valve repairability and postoperative outcome. The following sections discuss the various mechanisms of AI along with the surgical techniques used and postrepair echocardiographic analysis.

**Type I: Dilation of the Functional Aortic Annulus**

**Type IA: STJ Dilation and Ascending Aortic Aneurysm**

Dilation of the ascending aorta distal to the aortic root will not cause AI unless there is associated dilation of the STJ (video clip 4, see Supplemental Digital Content 9, http://links.lww.com/AA/A133; see Appendix for video captions).

TEE. End diastolic measurements made in the midesophageal (ME) AV long-axis (LAX) view confirm that the aortic annulus and the sinuses are not dilated whereas the ascending aorta and the STJ are enlarged. Evaluation of the aortic arch and the descending aorta is also involved in the dilation.

Color flow Doppler shows central AI jet parallel to the left ventricular outflow tract (LVOT). In the short-axis (SAX) view of the valve, the origin of the jet is central. The surgical correction aims at restoring a normal STJ and replacing the aneurysmal portions of the thoracic aorta. Surgery will typically consist of a supracoronary ascending aortic replacement with a Dacron graft. A key surgical decision in these cases is the sizing of the prosthesis, because an undersized prosthesis may induce cusp prolapse resulting in AI. In the setting of significant preoperative AI, subcommisural anuloplasty sutures are sometimes added to stabilize the proximal portion of the functional aortic annulus and increase the leaflet coaptation surface.

**Type IB: Aneurysms of the Aortic Root**

In such cases, the VAJ and the sinuses of Valsalva are dilated and the STJ is effaced (video clip 5, see Supplemental Digital Content 10, http://links.lww.com/AA/A134; see Appendix for video captions.). The dilation of the aortic root causes an outward displacement of the valve commissures and thus a tethering of the leaflets, which do not coapt adequately during diastole. This appearance is typical of Marfan and Ehlers-Danlos disease and other diseases of the aortic media.

Patients with bicuspid AVs can also present with aortic wall abnormalities that can lead to such aortic root dilation. The AI caused by these aortic pathologies increases aortic stroke volume that, together with structural changes in the

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### Table 1. Doppler Methods for Aortic Insufficiency Evaluation

<table>
<thead>
<tr>
<th>Jet width/LVOT width (%)</th>
<th>Mild</th>
<th>Moderate to Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet width/LVOT width (%)</td>
<td>&lt;25</td>
<td>25–45</td>
</tr>
<tr>
<td>PHT (ms)</td>
<td>&gt;500</td>
<td>200–500</td>
</tr>
<tr>
<td>R (cm)</td>
<td>&lt;0.3</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>EROA (cm²)</td>
<td>&lt;0.10</td>
<td>0.1–0.2</td>
</tr>
<tr>
<td>Regurgitant volume (ML/beat)</td>
<td>&lt;0.3</td>
<td>0.3–0.6</td>
</tr>
</tbody>
</table>

EROA = effective regurgitant orifice area; LVOT = left ventricular outflow tract; PHT = pressure half time; R = radius.

Jet width relative to LVOT width and vena contracta width are to be measured at Nyquist limit of 50 to 60 cm/s.
aortic wall, contribute to further dilate all the components of the aortic root and aggravate the AI.45,46

**TEE.** The pathology also involves the ascending aorta, and the aortic leaflets can be normal. Transesophageal echocardiographic analysis in the ME AV SAX view shows a central defect in coaptation and the ME AV LAX view shows that the coaptation length is reduced.

Color flow Doppler will show the associated AI, which has a central origin in the SAX and a central direction, parallel to the LVOT, in the LAX.

Surgical treatment of aneurysms of the aortic root historically consisted of root replacement with replacement of the AV (Bentall procedure). However, a valve-sparing aortic root replacement is now becoming the preferred procedure to manage this pathology. Numerous techniques have been described, but the following 2 are used most often (Fig. 4).

The remodeling technique consists of replacing the sinuses of Valsalva and the ascending aorta with an appropriately sized graft fitting between the native commissures.7,13,26,47,48 Sizing of the graft is based on the diameter of the STJ. In the reimplantation procedure, the native aortic cusps and their commissures are reimplanted inside a tubular Dacron graft that replaces the diseased sinuses and the aneurysmal part of the ascending aorta.49,49 This technique is sometimes preferred because it provides more stable valve function and prevents further dilation of the VAJ.9,19 Certain benefits have been proposed for the creation of neo-aortic sinuses in the tube graft.50-52 This can be done by plication of the Dacron graft in the spaces between the commissures or by anastomosing 2 Dacron grafts of different sizes.9,19 Recently, a prosthesis with built-in sinuses (Gelweave Valsalva, Vascutek/Terumo, Inchinnan, Renfrewshire, Scotland) has been developed, which attempts to restore an almost normal anatomy and functional appearance of the aortic root.53-55 Sometimes, only 1 sinus is diseased, giving an asymmetrical appearance to the AV in both the SAX and LAX views. In such cases, only the diseased sinus can be replaced using a teardrop-shaped patch.56

**Postrepair TEE.** A tubular prosthesis looks like a cylinder that can be followed down to the aortic annulus. When a Valsalva prosthesis with built-in sinuses is used for aortic root replacement, its typical shape can be easily appreciated in either the ME AV LAX view or the transgastric LAX and deep transgastric LAX views.
The prosthetic “neo-sinuses” appear larger than either the aortic annulus or the ascending prosthesis.

**Type II: Cusp Prolapse**

One or more leaflets can prolapse into the LVOT because of either excessive tissue or commisural disruption (video clip 6, see Supplemental Digital Content 11, http://links.lww.com/AA/A135; see Appendix for video captions).

**Transesophageal Echocardiography**

Cusp prolapse is defined when the free edge of 1 or more aortic cusps overrides the plane of the aortic annulus. As in mitral valve prolapse, the resulting regurgitant jet is eccentric and directed in the opposite direction. A prolapse of the right coronary cusp (RCC) will give rise to a jet directed posteriorly, but a prolapse of any of the posterior cusps will cause an anteriorly directed jet\(^{32,33}\) (Fig. 5). Because the posterior cusp in the ME AV LAX view can be either the left coronary cusp (LCC) or the noncoronary cusp (NCC), only the SAX analysis of the AV (or the simultaneous display of orthogonal planes) will help to distinguish between a prolapse of either the LCC or the NCC.

Cusp prolapse can be further categorized into 3 subtypes\(^{16}\): partial cusp prolapse, whole cusp prolapse, and flail cusp (Fig. 6).

Partial cusp prolapse is the prolapse into the LVOT of the distal part of a cusp. This is often associated with a clear bending of the cusp body visible in both the LAX and SAX views and also intraoperatively by the surgeon (Fig. 7). This fold is typically fibrous and thickened, which could be attributable to the diastolic pressure exerted on a weaker redundant cusp.

Whole cusp prolapse is defined as the free edge of the cusp overriding the plane of the aortic annulus, with the entire body of the cusp billowing into the LVOT. This billowing can be appreciated as a circular structure in the SAX view of the LVOT, immediately below the valve.

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**Figure 5.** Aortic cusp prolapse, midesophageal aortic valve long-axis views. a, Eccentric aortic regurgitant jet directed posteriorly (toward the anterior mitral leaflet). Such an orientation suggests a prolapse of the right coronary cusp. b and c, Eccentric jet directed anteriorly, as seen in the case of a prolapse of the noncoronary cusp (b) or of the left coronary cusp (c). This latter patient also presented with an eccentric mitral regurgitation (MR) jet. In such cases of anteriorly directed jets, analysis of the cusps in the midesophageal aortic valve short-axis view or with 3-dimensional echocardiography can help in localizing the prolapsing cusp. LA = left atrium; Ao = ascending aorta.

**Figure 6.** Representative examples of the 3 subtypes of cusp prolapses in the midesophageal aortic valve long-axis view. a, Partial prolapse of the right coronary cusp with midcusp bending (arrow). b, Whole prolapse of the right coronary cusp. c, Eversion of the right coronary cusp (flail).
Cusp flail occurs when there is a complete eversion of the cusp into the LVOT in the LAX view. Sometimes, the AI jet is eccentric without evidence of cusp prolapse; careful inspection of the free edge of the affected cusp both in gray scale and color Doppler can disclose a small tear along the margin corresponding to a fenestration. Rupture of a fenestration can also present with similar findings as cusp prolapse with an eccentric jet.16

Surgical Correction
Various surgical techniques are used to repair a prolapsing aortic cusp.2,3,33,57–59 Central plication, triangular resection, or implantation of a pericardial patch may be used. Free margin resuspension, using a polytetrafluoroethylene suture can also be used to shorten and elevate the free margin and improve coaptation.59,60 When cusp prolapse occurs in conjunction with aortic root or ascending aortic dilation, the dilated portions of the aorta are replaced and this serves to stabilize the functional aortic annulus, preventing further dilation. In the setting of isolated cusp prolapse, cusp repair is typically accompanied by a subcommissural annuloplasty performed at the level of the interleaflet triangles, with the aim of stabilizing the annulus similar to the prosthetic annulus placed in mitral valve repair. This technique also serves to increase cusp coaptation surface.

Postrepair TEE
The resuspension suture performed at the free margin of the prolapsing cusp can be appreciated in both the SAX and LAX views as a striated, more echogenic aspect of the leaflet. Cusp plication will thicken the middle part of the free edge of the leaflet. The pledgets of a subcommissural annuloplasty are sometimes visible by TEE as dense structures at the level of the commissures, below the coaptation level (see all these aspects on video clips 4 [http://links.lww.com/AA/A133], 6 [http://links.lww.com/AA/A135], and 7 [http://links.lww.com/AA/A136]; see Appendix for video captions.). One should be aware that this could limit the valve opening and therefore it is useful to measure the systolic pressure gradient across the repaired valve.

Type III: Cusp Restriction
The aortic cusps can be affected by any rheumatic or degenerative disease that causes commissural fusion, fibrous thickening, and cuspal retraction, potentially causing some stenosis and incomplete valve closure causing AI. These lesions are different from calcifications that usually affect the cusp tissue itself. AI in these type III cases is usually central and, because the valve is stiffer, typically originates higher in the sinuses of Valsalva.32

Endocarditis can also be responsible for valve destruction and may present with perforation, vegetations, and other associated pathology. With adequate preoperative antimicrobial treatment, cusp perforations in this setting can sometimes be repaired, avoiding the use of an artificial prosthesis.

Transeosophageal Echocardiography
The valve is thickened, more echogenic, and sometimes contains calcifications. The commissures are fused and the valve opening is reduced (Fig. 8). Systolic leaflet doming can be present, i.e., the leaflets are concave toward the center of the aorta during systole, and any degree of aortic stenosis should be quantified by Doppler measurements in the transgastric views.

A precise echocardiographic analysis of the cusps helps to determine the repairability of the valve. Some authors have proposed a grading of aortic calcifications16,61 extending from grade 1 (no calcifications) to grade 4 (extensive calcifications of all cusps with restricted cusp motion). Aortic repair seems to be more often feasible when calcification severity is less than grade 3 and when calcifications are confined to the free margins instead of involving the body of the cusps. Such findings have also been described for bicuspid AVs.62

Surgical Correction
Type III valves are the most difficult to repair appropriately and more prone to late repair failure and recurrent AI.16

Figure 7. The typical fold (arrow = bending) of a prolapsing right coronary cusp (RCC) as seen echocardiographically in both the midesophageal aortic valve long-axis (a) and short-axis (b) views, and intraoperatively by the surgeon (c). LA = left atrium; NCC = noncoronary cusp; LCC = left coronary cusp.
Surgery is tailored to the pathology encountered and may consist of shaving the thickened margins of the cusps, enucleation of hypertrophied nodes of Arantius, decalcification, commissurotomy of fused commissures, or even cusp extension.3,18,63 Certain cusp defects can also be repaired by autologous or bovine pericardium.10,11 Good long-term results can be obtained by an individualized approach in selected patients.63

Postrepair TEE
The valve should be mobile, open widely, without any significant gradient and coapt without residual AI. The patches used for perforated cusp closure or cusp extension can sometimes be visualized as more mobile structures that are circular in the SAX view.

Multifactorial Causes of AI
Sometimes AI is caused by multiple mechanisms; a cusp prolapse can be associated with aortic root dilation or could appear after a valve-sparing procedure (video clips 7 [http://links.lww.com/AA/A136] and 8 [http://links.lww.com/AA/A137]; see Appendix for video captions.). Chronic aortic root dilation may alter the dimensions of the valve leaflets, necessitating correction of both the root dilation and the leaflet free-edge length to achieve a competent valve.64 A prolapsing cusp can also present with fenestrations. In such cases, all causative lesions should be corrected simultaneously to ensure a good result.8,65–67 It is therefore of paramount importance to examine both the valve and the ascending aorta as part of a complete and systematic transesophageal echocardiographic evaluation.

THE BICUSPID AV
Bicuspid AVs are often associated with other pathologies such as coarctation of the aorta, patent ductus arteriosus, ventricular septal defects, and anomalous origin of the coronary arteries43 (video clip 8 [http://links.lww.com/AA/A137]). This congenital pathology of the valve leaflet formation has a familial occurrence. In addition, it has been associated with abnormalities of matrix metalloproteinases within the aortic wall leading to loss of smooth muscle in the ascending aortic media, causing aortic root dilation, aneurysm formation, and dissection.44 In addition, calcification of a bicuspid valve is accelerated in comparison with a tricuspid AV,68,69 and the valve is more prone to insufficiency and endocarditis.

Transesophageal Echocardiography
The preoperative analysis of the valve should define the orientation of the coaptation line and the presence of a raphe. The most common bicuspid valve (type 1) is asymmetrical and presents with a median raphe and rudimentary commissure.70 Fusion of the LCC and RCC is most common, and a fusion of the RCC and the NCC is more often associated with moderate or severe aortic stenosis and/or AI.71 However, type 0 bicuspid valves are symmetrical and have neither raphe nor rudimentary commissure and tend to have more aberrant coronary anatomy. All aspects of the valve should be examined with TEE to help the surgeon determine its repairability.72 One study has shown that transesophageal echocardiographic factors associated with a higher chance of bicuspid valve repairability were the presence of an eccentric jet (type II, cusp prolapse) and the absence of cusp thickening, cusp calcification, or commissural thickening.62 All types of AI mechanisms can be observed when dealing with bicuspid AVs:
cusp prolapse (type II), aortic root dilation (type I), thickening and restriction of the cusps (type III), calcification of the raphe, commissural fusion, and even perforation due to endocarditis.

**Surgical Procedures**

Bicuspid valve anatomy appears to facilitate leaflet repair because only a single coaptation line has to be appreciated. However, the regurgitant bicuspid AV is the perfect example of why both the valve and all the components of the aortic root complex have to be addressed and repaired together. Valve repair will realign the height of the leaflets and usually consists of plication of the free margin or triangular resection of the raphe with or without placement of a pericardial patch and leaflet free-edge resuspension. Subcommissural annuloplasty and STJ remodeling are occasionally used to maintain an ideal relationship between the annulus and the STJ. Because of the increased rate of aortic root dilation, it is generally accepted that the ascending aorta should be replaced if its diameter exceeds 5 cm. In the setting of valve repair, however, an even more aggressive stance (4.5 cm) has been proposed to replace the aortic root because it serves to stabilize the cusp repair and prevent further dilation of the aortic annulus.

Both root remodeling and root reimplantation techniques can be used. Repair of diseased bicuspid AVs and preservation of functionally normal bicuspid valves during surgery for aortic aneurysm both have demonstrated acceptable midterm durability.

**Postrepair TEE**

The repaired leaflet can be somewhat stiffer, with a typical bicuspid appearance. It should present both a satisfactory opening without a significant gradient and an appropriate level of coaptation without residual AI.

**THE QUADRICUSPID VALVE**

The quadricuspid valve has a rare occurrence rate of <1% in patients presenting for AV surgery and leads to early valve stenosis and/or AI. Although most reported cases ended up having a valve replacement, some have successfully been repaired (video clip 9, see Supplemental Digital content 14, http://links.lww.com/AA/A138; see Appendix for video captions).

**Transesophageal Echocardiography**

The examination should focus on the relative dimensions and mobility of the 4 cusps, the presence of a rudimentary commissure, and on the analysis of the mechanism of AI (restriction versus prolapse).

**Surgical Procedures**

The valve can be rendered tricuspid by resection of the commissural fusion and suturing of the 2 smaller cusps into 1 larger cusp. A pericardial patch is sometimes used to augment the neocusp tissue.

**Postrepair TEE**

The valve is asymmetrical with a larger reconstructed cusp, its opening is almost normal, and little or no insufficiency should be seen in either the SAX or LAX view.

**CONCLUSION**

TEE is a mandatory diagnostic and monitoring tool during any AV repair or valve-sparing surgery. Careful preoperative anatomic assessment of the valve and the aortic root, along with analysis of the origin and the direction of the regurgitant jet, aids in understanding of the AI mechanism. The use of a functional AI classification predicts reparability and enables a systematic repair strategy, thereby helping the surgeon achieve a better and longer-lasting postoperative result. Intraoperative echocardiography can be used to evaluate the success of repair involving all of the emerging surgical techniques described, with the immediate postoperative goal of optimal height and length of cusp coaptation and little or no residual AI.

**APPENDIX: VIDEO CAPTIONS**

**Video Clip 1**, analysis of the aortic valve. A, ME AV SAX view. Left, Midesophageal aortic valve short-axis view of a normal aortic valve. The 3 cusps are identified. Right, Color flow Doppler shows no aortic insufficiency during diastole. B, ME AV LAX view. Left, Midesophageal aortic valve long-axis view of a normal aortic root. The shape of the root is normal and the sinotubular junction is well depicted. Right, Color flow Doppler shows no aortic regurgitation during diastole. C, Still frame, ME AV LAX view. Normal aortic root in the midesophageal aortic valve long-axis view at end diastole. Measurements are made at 4 levels: A, the aortic annulus; B, the widest cross-section at the sinuses of Valsalva; C, the sinotubular junction; and D, the ascending aorta 1 cm beyond the sinotubular junction. D, Still frame, ME AV LAX view. The cusp coaptation is depicted (blinking bar) and its highest part reaches the midportion of the sinuses of Valsalva (line B). Ao = ascending aorta; LA = left atrium; LV = left ventricle; LVOT = left ventricular outflow tract; NCC = noncoronary cusp; LCC = left coronary cusp; RCC = right coronary cusp; PV = pulmonary valve; RA = right atrium; RV = right ventricle.

**Video Clip 2**, aortic insufficiency (AI) analysis and quantification in the ME AV LAX view. All the following loops and still frames correspond to the same patient with aortic insufficiency. A, Still frame. Measurement of the vena contracta in the ME AV LAX view. The vena contracta is measured at the narrowest portion of the jet, which is usually at the level of the aortic valve, immediately below the flow convergence region, B, Still frame. Measurement of the AI jet/LVOT width ratio in the ME AV LAX view, color M-mode. This mode of assessment of AI severity is based on the ratio of the maximal proximal jet width to the left ventricular outflow tract diameter immediately below the aortic valve, within 1 cm of the valve. The measurements should be done at the same point of time and this method tends to underestimate the severity of the jet. C, Still frame. Vena contracta measurement in the ME AV SAX view. Video Clip 3, aortic insufficiency (AI) analysis and quantification in the transgastric (TG) views. Two TG views can help to analyze the aortic valve and to help in aortic insufficiency quantification. A, Deep TG LAX view. Left, Obtained at 0° by TG approach, this view, similar to the apical 4-chamber view obtained by transthoracic echo, permits vertical alignment of the left ventricular outflow tract, the aortic valve, and the aortic root. A detailed anatomic assessment of the valve is difficult but sometimes feasible allowing analysis of the cusp coaptation (see also video clip 6). Right, Good alignment with color flow Doppler allows for analysis of the flow across the aortic valve during both systole and diastole. However, the intensity of the regurgitant jet may be underestimated. B, TG LAX view. Obtained by rotation of the transducer from 0° to 160°, this view also permits calculation of the A2+AI jet. Gradient measurement: It is often feasible to align the continuous wave (CW) Doppler beam with the aortic outflow in 1 of the 2 TG views described above. This allows one to measure peak and mean velocities through the aortic valve and hence to calculate peak and mean gradients to calculate peak and mean gradients to calculate peak and mean gradients. C, Still frames: pressure half-time (PHT) measurement. PHT corresponds to the rate of deceleration of the diastolic regurgitant jet.
and reflects the rate of equalization of aortic and left ventricular pressures. In this case, PHT is measured at 498 milliseconds corresponding to a moderate aortic insufficiency. PISA measurement method. After a TG long-axis view the regurgitant volume is applied to the aortic valve and the Nyquist limit of the aliasing velocity is shifted toward the direction of flow (in this case at 39 cm/s). The radius of the hemispheric shell of the aliased velocity is then measured. F, Still frame. CW Doppler is applied to the regurgitant jet and an envelope is traced. Peak AI velocity and the velocity time integral (VTI) are so measured and allow calculation of both the effective regurgitant area (EROA) and total regurgitant volume. Ao = ascending aorta; AoV = aortic valve; EROA = effective regurgitant orifice area; LA = left atrium; LV = left ventricle; Mi = mitral valve; PISA = proximal isovelocity surface area; RV = right ventricle; VTI = time velocity integral.

**Video Clip 4**, type IA: ascending aorta dilatation starting from above the sinusotubular junction and extending to the aortic arch, surgically corrected by supracoronary tube graft replacement of the aorta and subcommissural annuloplasty. A, ME AV LAX view. Left, Midesophageal aortic valve long-axis view shows a dilatation of the ascending aorta. Right, Color Doppler interrogation shows a central eccentric aortic regurgitant jet directed to the left ventricle (LVOT). B, ME AV SAX view. Midesophageal aortic valve short-axis view shows the aortic regurgitant jet directed posteriorly toward the left ventricle (LVOT) and the anterior mitral leaflet (AML). C, Still frame: 1 ME AV SAX view. Measurements performed at the level of the sinuses of Valsalva (diameter 3.4 cm) and the sinotubular junction (STJ) (diameter 3.3 cm) are within normal range whereas the diameter of the ascending aorta just above the STJ is enlarged to 4.2 cm. This dilatation starts above the STJ. D, Still frame 2: midesophageal ascending aortic long-axis view. The aortic diameter at that level is 7.34 cm. In this patient, the dilatation extended to the origin of the left subclavian artery. E, Surgical repair. Surgery consisted of the replacement of the aorta by a tube graft extending from the sinotubular junction to the origin of the left subclavian artery. The graft was replaced and the great vessels were reimplanted under deep hypothermic circulatory arrest. Three subcommissural annuloplasty sutures were also performed to stabilize the aortic annulus and increase cusp coaptation. F, ME AV SAX view. In this midesophageal aortic valve short-axis zoom view, 2 of the 3 subcommissural annuloplasties are seen (arrows). G, ME AV LAX view. Left, Midesophageal aortic valve long-axis view shows that the native aortic sinuses have been preserved and that the ascending aorta has been replaced by a tube graft. The corrugated aspect of the graft is clearly seen (arrowheads). Right, Color Doppler interrogation shows no residual aortic insufficiency after surgery. Ao = ascending aorta; LA = left atrium; LV = left ventricle; LVOT = left ventricular outflow track; native Ao S = native aortic sinuses of Valsalva; NCC = noncoronary cusp; RCC = right coronary cusp; RA = right atrium; RV = right ventricle; STJ = sinotubular junction.

**Video Clip 5**, type IB: dilation of the entire aortic root, surgically corrected by an aortic valve-sparing root replacement (reimplantation technique) with a Valsalva® prosthesis. A, ME AV LAX view. Left, Midesophageal aortic valve long-axis view in a patient who presented with a symptomatic dilatation of the entire aortic root (arrowheads). There is also a small amount of pericardial effusion. Right, Color Doppler interrogation shows an eccentric aortic regurgitant jet directed toward the anterior mitral leaflet. B, ME AV LAX view. Left, Midesophageal aortic valve long-axis view shows a partial prolapse of the right coronary cusp with a thickened band (yellow arrow) and a resulting loss of coaptation. Right, Color Doppler interrogation shows an eccentric aortic regurgitant jet directed posteriorly toward the anterior mitral leaflet. C, Still frame: Midesophageal aortic valve short-axis view depicts the thickening of the right coronary cusp (yellow arrow). Right, Color Doppler interrogation shows that the regurgitant jet originates along the right coronary cusp and is directed posteriorly toward the commissure between the left and the noncoronary cusps. D, Still frame. The thickened band is shown (yellow arrow) in both the left view (midesophageal aortic valve long-axis) and right view (midesophageal aortic valve short-axis). E, Deep TG view. Left, Deep transgastric view shows the loss of coaptation of the aortic valve (blue arrow). Right, Color Doppler interrogation shows an eccentric regurgitant jet directed toward the mitral valve, F, Surgical repair. Surgery consisted of free margin plication of the right coronary cusp and 3 subcommissural annuloplasty sutures. G, Still frame: Deep TG view. Shows that the loss of free margin plication is shown here. This has been corrected by rotating the aortic cusps the same way as in the TEE ME AV SAX view. H, ME AV SAX view. Midesophageal aortic valve short-axis view shows the postoperative thickened aspect of both the cusp plication performed at the free margin of the right coronary cusp and of the subcommissural annuloplasty sutures and the remodeled intercommissural triangles. I, ME AV LAX view. Left, Midesophageal aortic valve long-axis view shows a good leaflet coaptation. Right, Color Doppler interrogation shows no residual aortic insufficiency. J, Deep TG view. Deep transgastric view confirms good leaflet coaptation and shows mild central residual aortic insufficiency. Ao = ascending aorta; LA = left atrium; LAA = left atrial appendage; LV = left ventricle; LVOT = left ventricular outflow tract; Mi = mitral valve; NCC = noncoronary cusp; RCC = right coronary cusp; PV = pulmonary valve; RA = right atrium; RV = right ventricle.

**Video Clip 7**, association of type IA (ascending aorta dilatation) and type II (cusp prolapse) as coexisting mechanisms of aortic insufficiency, corrected by subcommissural annuloplasty, free margin repositioning of the right coronary cusp, and replacement of the aorta by a supracoronary tube graft. A, ME AV LAX view. Midesophageal aortic valve long-axis view shows a partial prolapse of the right coronary cusp. The bending of the cusp and a thickened band are clearly seen. B, ME AV LAX view. Left, Midesophageal aortic valve long-axis view shows a partial prolapse of the right coronary cusp with a thickened band and a resulting loss of coaptation. Right, Color Doppler interrogation shows an eccentric eccentric aortic regurgitant jet directed posteriorly toward the anterior mitral leaflet. C, ME AV SAX view. In this midesophageal aortic valve short-axis view, the thickened aspect of the commissures after the repair is well depicted. D, ME AV SAX view. In this midesophageal aortic valve long-axis view, the thickened aspect of the aortic cusp after resuspension and the corrugated aspect of the prosthetic tube graft starting from the sinotubular junction. F, ME AV SAX view. In this postoperative midesophageal aortic valve short-axis view, the thickened aspect of the commissures after the repair is well depicted. G, ME AV SAX view. In this postoperative midesophageal aortic valve long-axis view, the thickened aspect of the aortic cusp after resuspension and the corrugated aspect of the prosthetic graft above the sinotubular junction (STJ) are visualized. A thin mobile structure connecting the RCC to the commissure corresponding to the RCS shows no residual insufficiency of the cusp to the commissure. H, Still frame. Midesophageal aortic valve long-axis view shows excellent cusp coaptation after repair (blinking yellow line). In this case, the length of coaptation is approximately 1 cm and extends from well above the plane of the aortic annulus up to an imaginary line drawn at the midlevel of the sinuses of Valsalva. Ao = ascending aorta; LA = left atrium; LV = left ventricle; PV = pulmonary valve; RA = right atrium; RV = right ventricle.
NC = noncoronary cusp; LCC = left coronary cusp; RCC = right coronary cusp; RA = right atrium; RV = right ventricle.

Video Clip 8, association of type IB (root dilation) and type II (cusp prolapse) causes of aortic insufficiency in a bicuspid aortic valve. A, ME AV SAX view. Left, Midesophageal aortic valve short-axis view of a bicuspid aortic valve. A raphe is clearly seen (arrowhead) along with a large oval structure corresponding to the short-axis cross-section of the prolapsing leaflet (arrow). Right, Color flow Doppler interrogation demonstrates a regurgitant jet along the whole commissural line. B, ME AV LAX view. Left, Midesophageal aortic valve long-axis view showing dilation of the aortic root and systolic doming of the valve opening. The sinotubular junction is effaced, the coaptation length appears short, and the anterior cusp is mildly prolapsing below the plane of the aortic annulus. Right, Color flow Doppler demonstrates an eccentric regurgitant jet directed posteriorly, toward the anterior mitral leaflet, confirming a prolapse of the anterior cusp. Ao = ascending aorta; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

Video Clip 9, quadricuspid aortic valve repair by rendering the valve tricuspid. A, ME AV SAX view. Left, Midesophageal aortic valve short-axis view shows a quadricuspid aortic valve presenting with a central defect of coaptation. Right, Color Doppler shows central insufficiency. B, ME AV LAX view. Midesophageal aortic valve long-axis view with Color Doppler shows a slightly eccentric regurgitant jet originating from the malcoapting cusps. C, Still image 1. Intraoperative aspect of the valve with 4 cusps as seen by the surgeon. D, Surgical repair. The valve has been rendered tricuspid by suturing the 2 smaller cusps (left coronary cusp [LCC] and fourth cusp). E, Still image 2. Intraoperative aspect of the valve as seen by the surgeon after the repair. The valve is now tricuspid with a reconstructed LCC. The suture line is visualized (arrow). F, ME AV SAX view. Midesophageal aortic valve short-axis view showing the post-repair appearance of the valve. The suture line in the middle portion of the LCC is seen (arrow). The presence of submucosal annuloplasty sutures explains the thickened aspect of 2 commissures. G, ME AV LAX view. Color Doppler imaging from the midesophageal aortic valve long-axis view after tricuspidization. Valve opening is good and only a trivial central aortic insufficiency is seen. Ao = ascending aorta; LA = left atrium; LV = left ventricle; NCC = noncoronary cusp; LCC = left coronary cusp; RCC = right coronary cusp; C = fourth cusp; PA = pulmonary artery; RA = right atrium; RV = right ventricle.

REFERENCES


