Remodeling the Aortic Root and Preservation of the Native Aortic Valve

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The aortic root is the segment of the cardiovascular system that contains the aortic valve. It starts at the aortoventricular junction and ends at the sinotubular junction. Although a detailed anatomic description of the aortic root is beyond the scope of the this article, certain features will be reviewed because they are needed to understand the principles of remodeling of the aortic root with preservation of the native aortic valve.

The term aortic annulus is used to describe the aortoventricular junction albeit the aortic root has no fibrous annulus. The aortic root is attached directly to the left ventricle; approximately 45% of its circumference is attached to ventricular muscle and 55% to fibrous tissue. This fibrous tissue is the membranous interventricular septum and the fibrous body that connects the anterior leaflet of the mitral valve to the aortic root. Figure 1 illustrates the aortoventricular junction and its anatomic relationships. The aortoventricular junction is scalloped and corresponds to the insertion of the three aortic valve leaflets. It is important to recognize that most of the annulus of the right and left leaflets is attached to the interventricular septum. Thus, the tissue underneath the commissure between the right and left leaflets is also the interventricular septum. Another anatomic feature of the aortic leaflet is that the length of its base in which it is inserted in the aortic root is approximately one and a half times longer than the length of its free margin, as illustrated in Figure 2. The length of the free margin ranges from 28 to 34 mm (average of 32 mm) in adults. The height of the aortic leaflets is slightly less than one half of the length of its free margin, and it ranges from 13 to 16 mm in adults. The noncoronary leaflet is larger than the right and left leaflets in humans. The right leaflet is often slightly larger than the left. The size of the leaflet and the size of the aortic sinus maintain a certain relationship. Thus, the noncoronary sinus of Valsalva is larger than the right and left sinuses. The right sinus of Valsalva is often slightly larger than the left sinus. The upper limit of the aortic sinuses is marked by the sinotubular junction. The ascending aorta begins at that point. The diameters of the aortic annulus and of the sinotubular junction are a function of the size of the aortic leaflets. The aortic annulus is slightly larger (10% to 15%) than the sinotubular junction, as shown in Figure 3.

Annuloaortic ectasia is a term used to describe dilatation of the aortoventricular junction, which normally should not exceed 25 to 28 mm in adults. This dilatation occurs almost entirely along the fibrous component of the aortic root, that is, the membranous septum and the base of the anterior leaflet of the mitral valve. Patients with annuloaortic ectasia frequently have dilated aortic sinuses and sinotubular junction. As the aortic root enlarges, aortic insufficiency develops because the leaflets cannot seal the aortic orifice. Aortic insufficiency is caused by dilatation of the aortic annulus and of the sinotubular junction. Most cases of aortic root dilatation are idiopathic. However, dilatation may be associated with Marfan syndrome, aortic dissection, aortitis, and other disorders that cause weakness of the aortic wall, such as Ehlers-Danlos syndrome, osteogenesis imperfecta, and pseudoxanthoma elasticum. The idiopathic cases may represent a forme fruste of Marfan syndrome. Although it has been shown that the fibrillin in the aortic and mitral leaflets is abnormal in patients with Marfan syndrome, experience with mitral valve repair, and more recently, with reconstruction of the aortic root and preservation of the native aortic valve suggests that these are durable operative procedures, and that they may be preferable to valve replacement in selected patients.

We believe that the single most important criterion in selecting patients with annuloaortic ectasia for remodeling of the aortic root with preservation of the native aortic valve is the morphological appearance of the aortic valve leaflets. As the aortic root dilates, the leaflets are subjected to increased tension and they will stretch. Although the whole leaflet thins, the commissural areas are more affected and often display large fenestrations and tears. The length of their free margins approximates that of their base. These leaflets should not be preserved, and therefore, the best operative procedure in these patients is a composite replacement of the aortic valve and of the ascending aorta with a valved conduit. However, it has been our experience that, in approximately one third of all patients with annuloaortic ectasia and dilatation of the aortic root who require surgery, the aortic leaflets are minimally

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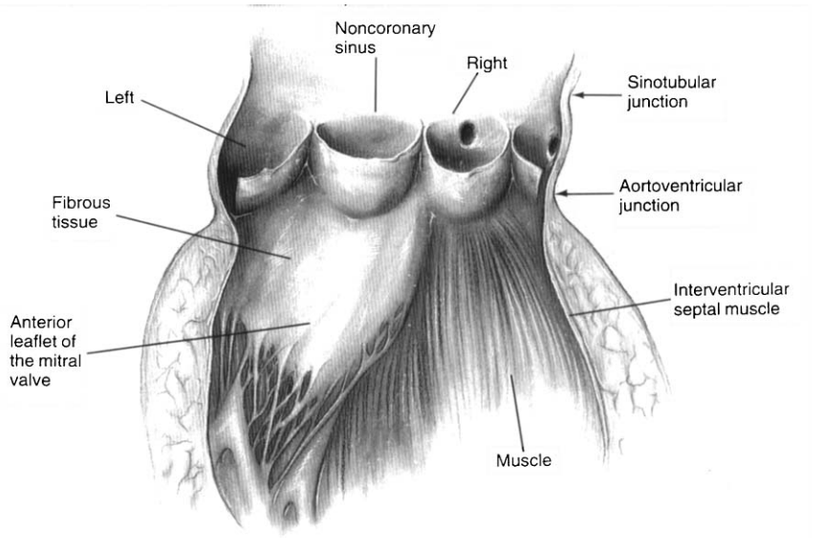
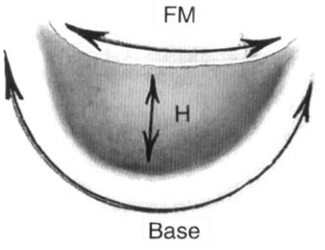


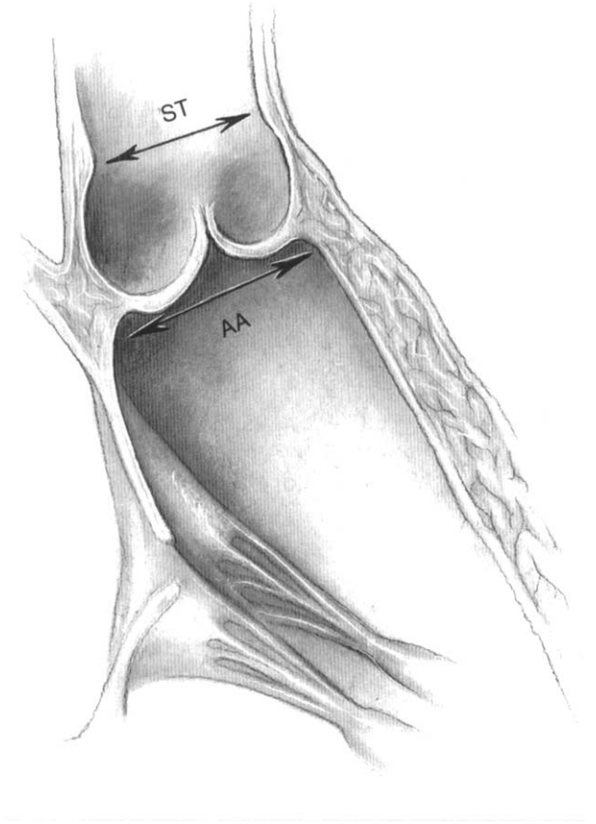
1 The aortoventricular junction and its relationships. Note that approximately 45% of the circumference of the aortic root is attached to left ventricular muscle and 55% to fibrous tissue.



2 The aortic leaflet. The length of its base is 1.5 times longer than the length of its free margin.

stretched and the length of their free margins is still significantly shorter than the length of their bases. This morphological feature is important because it indicates that the leaflets will not prolapse after remodeling of the aortic root. Transthoracic and transesophageal multiplane Doppler echocardiography gives a great deal of information regarding the aortic leaflets, although the decision whether or not to repair can only be made intraoperatively.

Many patients with dilated ascending aorta develop aortic insufficiency because of dilatation of the sinotubular junction. These patients do not have annuloaortic ectasia but, depending on the pathological process in the aorta, the sinuses of Valsalva become dilated and the coronary arteries are displaced cephalad, as in the case of patients with aortic root aneurysm and annuloaortic ectasia. However, the aortic annulus remains normal. The aortic insufficiency is largely caused by outward displacement of the commissures of the valve because of dilatation of the sinotubular junction. Remodeling of the aortic root in these patients is simpler and all that is required is to correct the sinotubular junction and replace the aortic sinuses if they are aneurysmal.

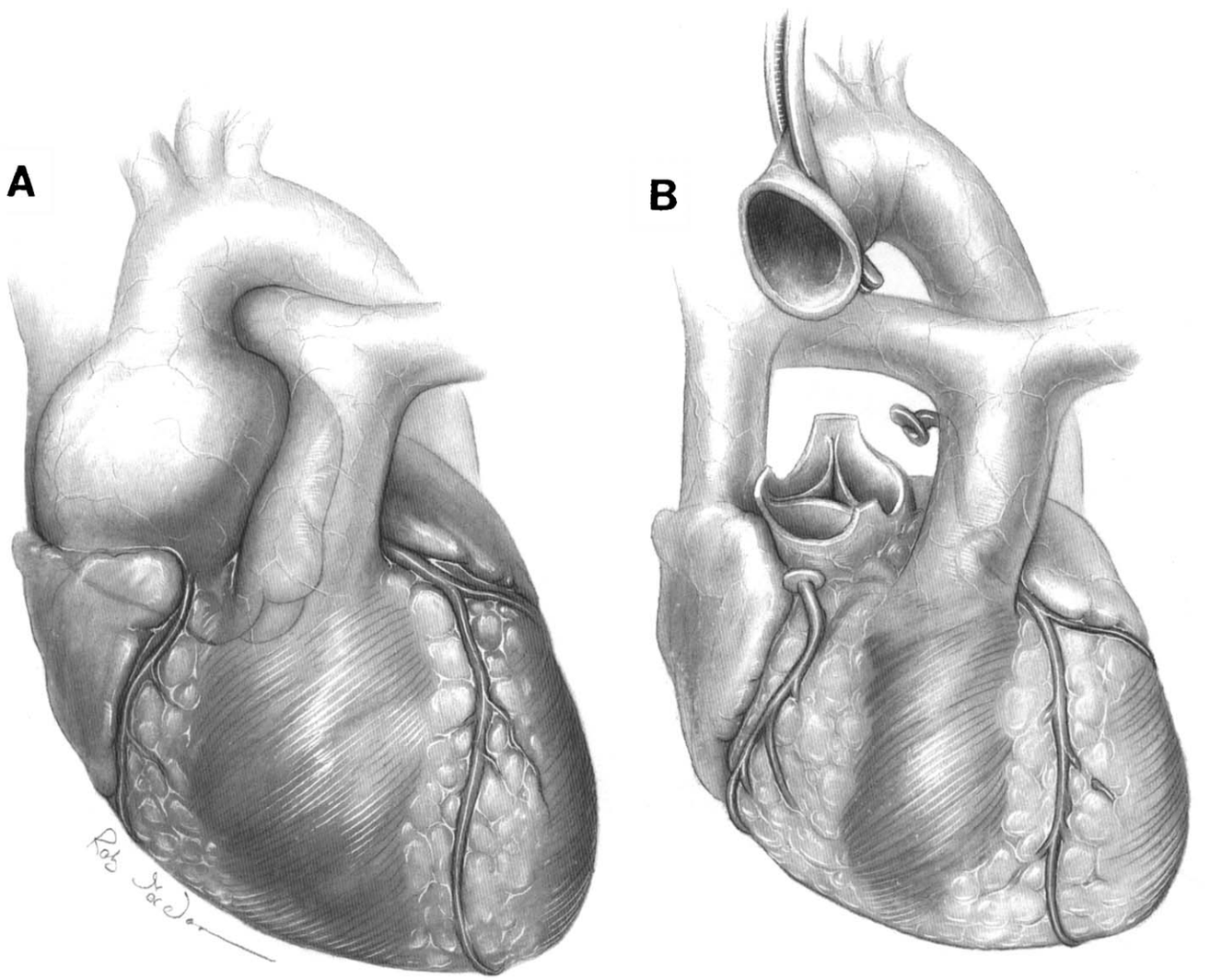


3 The aortic root. The diameter of the aortic annulus is approximately 10% to 15% larger than the diameter of the sinotubular junction.

SURGICAL TECHNIQUE

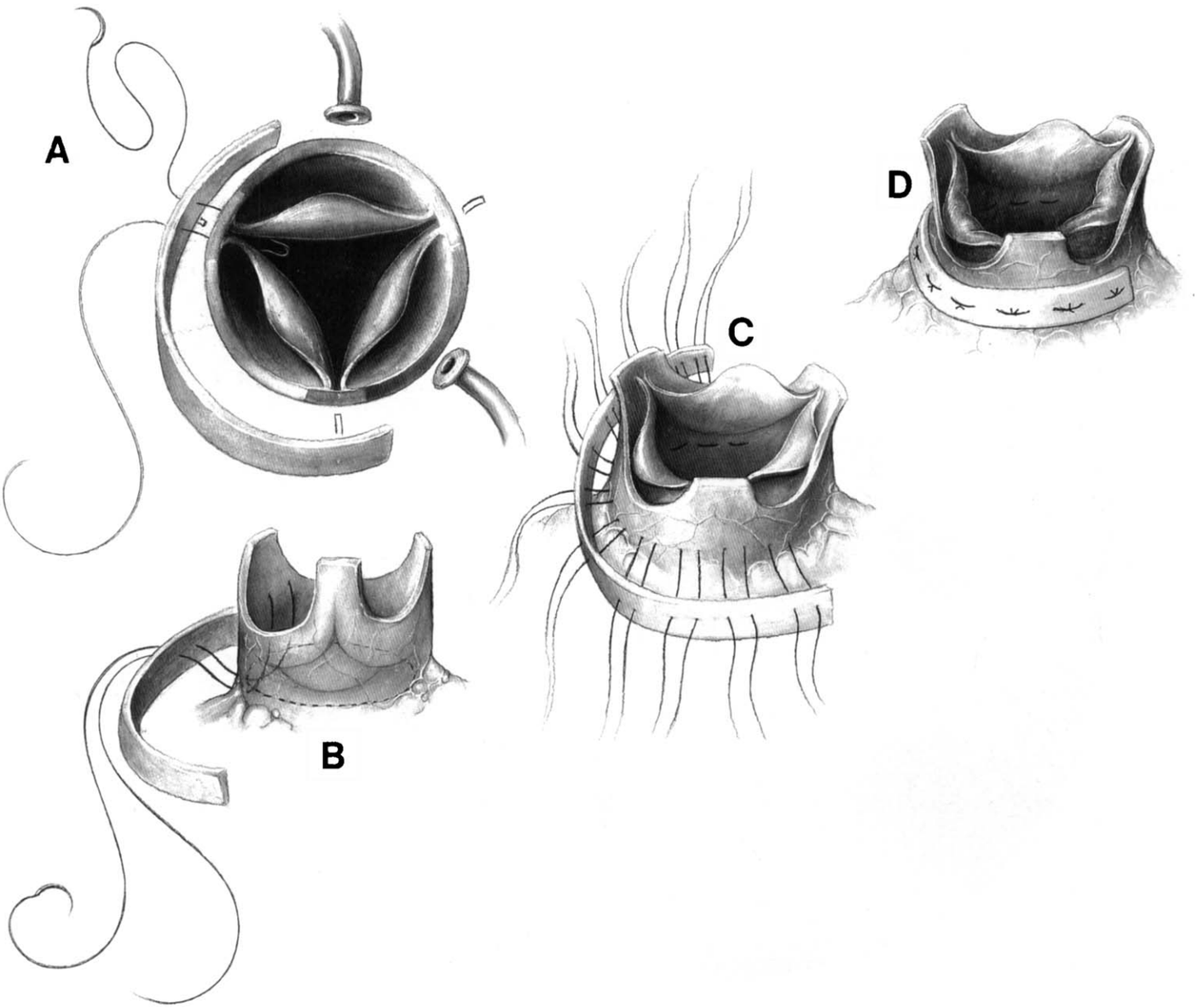
The chest is entered through a midline sternotomy and the pericardium is opened longitudinally and along its junction with the diaphragm anteriorly. The margins of the pericardium are sutured to the fascia of the pectoralis major muscle to create a cradle and bring the heart and great vessels closer to the sternum. Cardiopulmonary bypass is established by cannulating the distal ascending aorta, transverse aortic arch, or femoral artery, depending on the extensiveness of the aneurysm. We avoid femoral artery cannulation and retrograde arterial perfusion in older patients because of the risk of cerebral embolization from atherosclerotic ulcerated plaques in the abdominal and thoracic aorta. The right atrium is also cannulated to drain the venous blood. Unless circulatory arrest is being contemplated, we do no use systemic hypothermia during cardiopulmonary bypass. The ascending aorta is cross-clamped just below the origin of the innominate artery and the aortic root aneurysm is opened. Both coronary arteries are cannulated with balloon-tipped cannulas, and continuous blood cardioplegia at 20°C is administered at the rate of 100 to 250 mL/min, depending on the left ventricular mass. A ventricular vent is inserted through the right superior pulmonary vein and placed on continuous suction to obtain a dry operative field.

Patients With Annuloaortic Ectasia

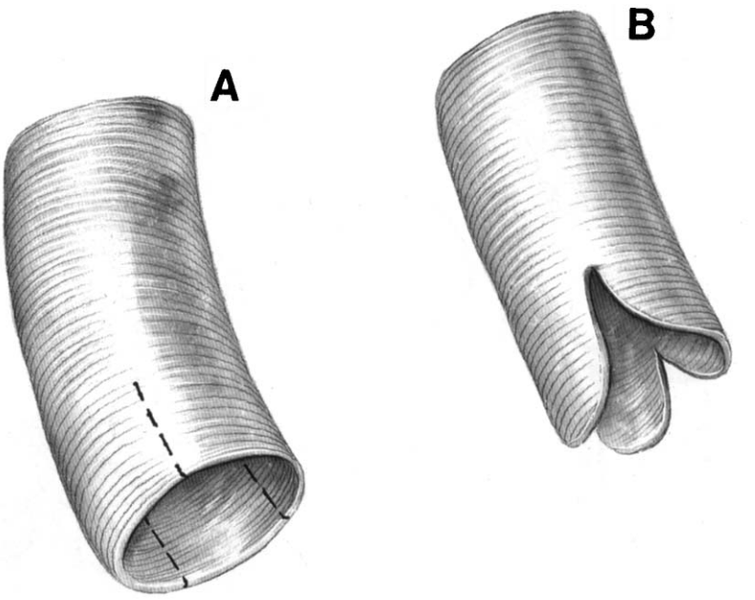


4 The ascending aorta is transected 1 cm above the commissures of the aortic valve (A). The aortic leaflets are then carefully inspected. One needs not to measure the length of the free margin and the length of the base of each leaflet to determine if it they are overstretched or not. This assessment can be performed simply by holding the arterial walls immediately above the commissures of a leaflet at an appropriate distance from each other and observing the leaflet. If it does not prolapse, it is an indication that its free margin is shorter than its base. If all three leaflets are fairly normal or only minimally stretched, remodeling of the aortic root with preservation of the aortic valve is feasible.

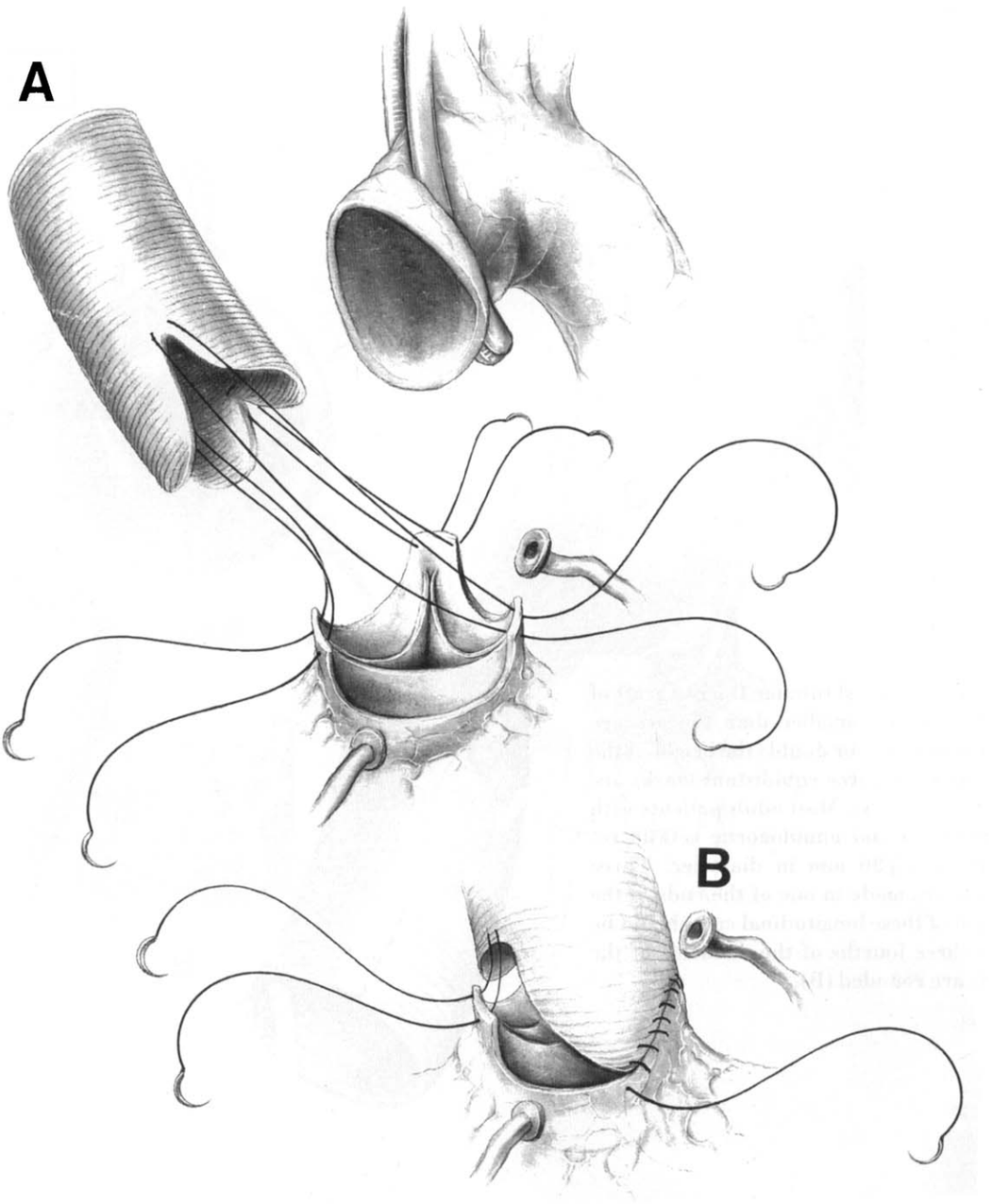
The aortic root is circumferentially dissected down to the level of the aortoventricular junction. The aortic root has to be freed from the pulmonary artery, the right ventricle, and the roof of the left atrium. Next, all three aortic sinuses are excised, leaving only 4 to 6 mm of arterial wall attached to the aortic annulus and around each coronary artery orifice. Both coronary arteries should be mobilized for a length of 1.5 to 2 cm to facilitate reimplantation later on (B).



5 The length of the free margin and the height of each leaflet are measured and averaged. The diameter of the aortic annulus should not exceed the length of the free margin of the leaflets or twice the height of the leaflets. Because these patients have annuloaortic ectasia, a reduction in the diameter of the aortic annulus is often necessary. It is important to remember that the dilatation of the aortic annulus occurs only along its fibrous components. Thus, reduction of the aortic annulus is performed along its fibrous portion. This is accomplished by an aortic annuloplasty. Multiple horizontal mattress sutures of 4-0 or 3-0 multifilament polyester are passed from the inside to the outside of the fibrous portion of the left ventricular outflow tract immediately below the lowest level of the aortic annulus through a single horizontal plane (A, B). These sutures are then passed through a strip of Dacron fabric to reduce the diameter of the aortic annulus, especially underneath the commissures of the noncoronary leaflet (C). All sutures are tied outside of the aortic root (D). The aortic annuloplasty is completed.

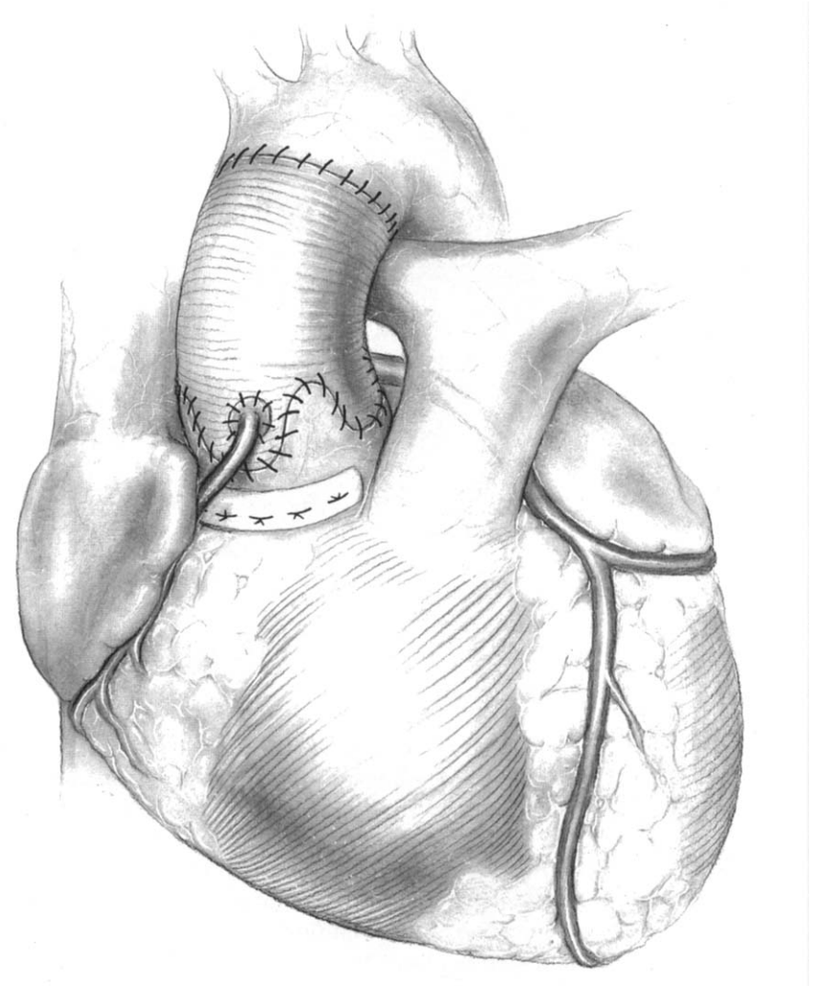


6 A collagen impregnated tubular Dacron graft of a diameter 10% to 15% smaller than the average length of the free margins (or double the height of the leaflets) is selected and three equidistant marks are made in one of its ends (A). Most adult patients with aortic root aneurysm and annuloaortic ectasia require grafts of 26 to 30 mm in diameter. Three longitudinal cuts are made in one of the ends of the graft. The length of these longitudinal cuts should be approximately three fourths of the diameter of the graft. The ends are rounded (B).

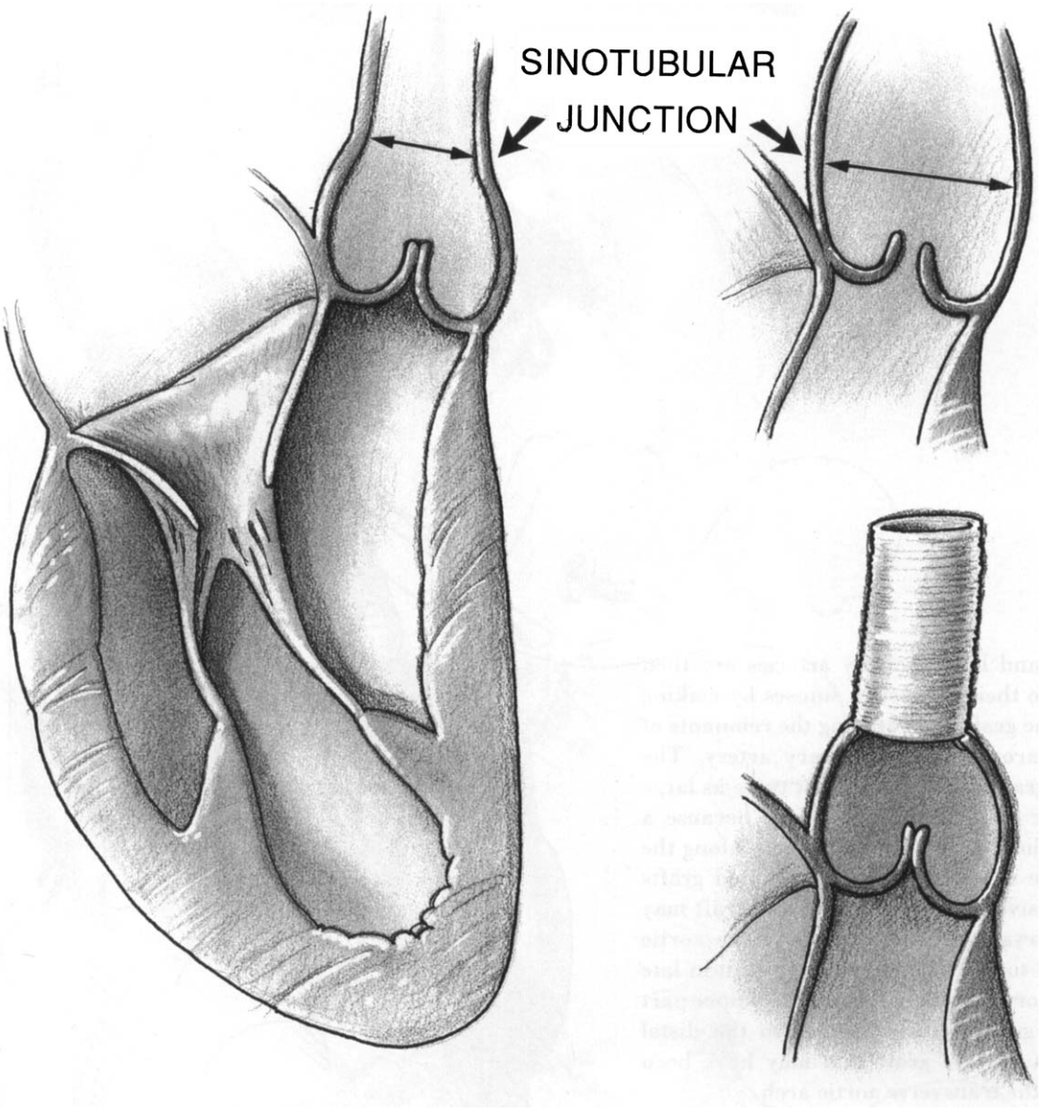


7 Both arms of a 4-0 polypropylene suture are passed from the inside to the outside of the graft immediately above the end of the longitudinal cuts, and then from the inside to the outside of the remnants of the aortic sinus above one of the commissures. The two needles are passed through a Teflon pledget (C.R. Bard, Bard Vascular, Haverhill, MA) and the arms of the suture are tied together. The same procedure is performed in each commissure. The Dacron graft is then sutured to the remnants of the aortic sinuses along the aortic annulus. It is safer to start at the commissural level and to sew toward the central portion of the sinus to prevent maldistribution of the tailored graft along the aortic annulus. The graft should lie inside the remnants of the aortic sinuses. Once all three sinuses have been reconstructed, the aortic valve is tested for competence by injecting saline into the graft and observing how the three leaflets coapt. If the leaflets do not touch each other in the center, the graft may be too large; this can be corrected by reducing the diameter of the sinotubular junction. If the leaflets coapt excessively, they may prolapse under pressure. Obviously, the best method to assess the function of the leaflets is by Doppler echocardiography after discontinuation of cardiopulmonary bypass.

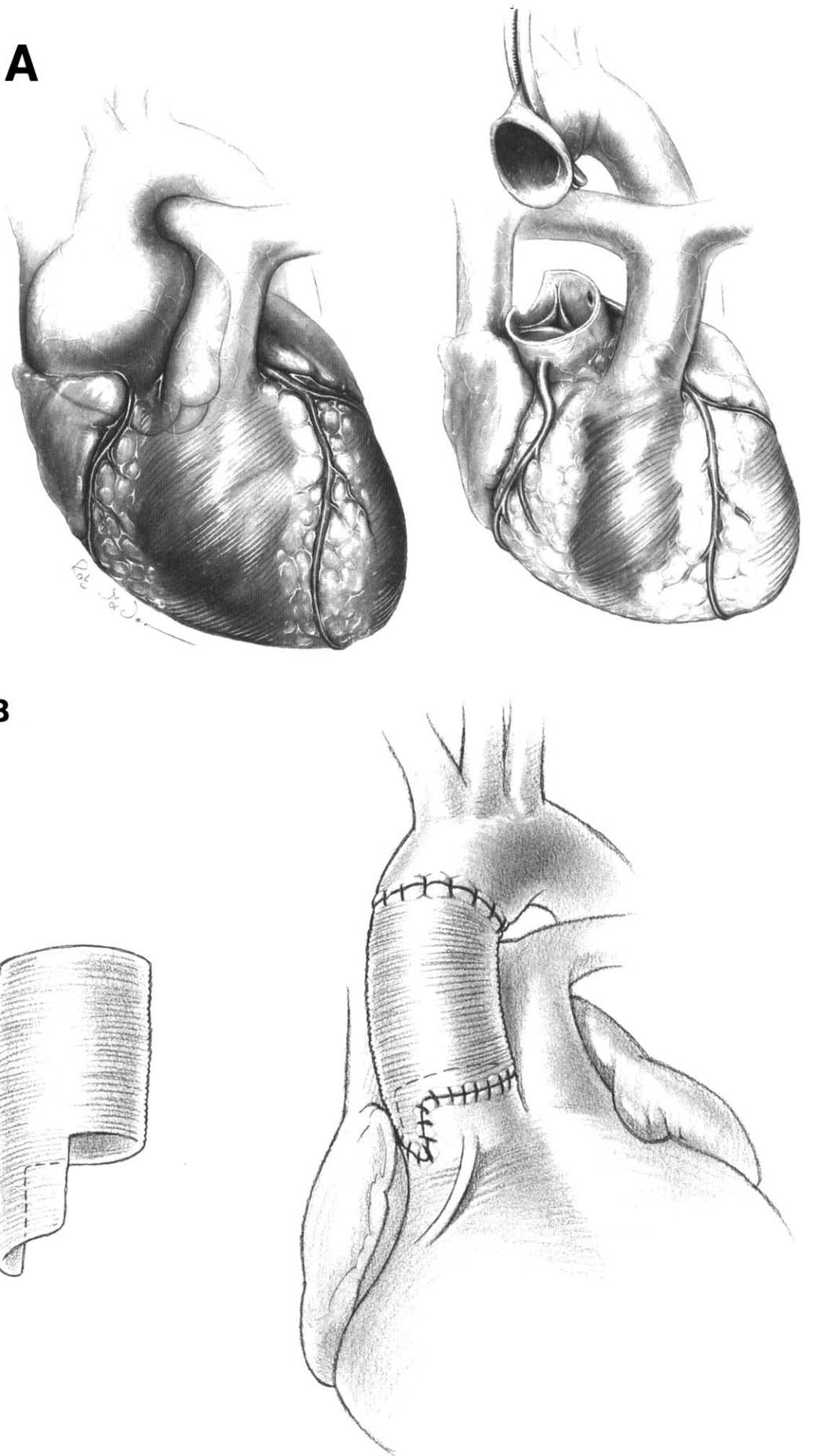
8 The right and left coronary arteries are then reimplanted into their respective sinuses by making an opening in the graft and suturing the remnants of the sinus wall around each coronary artery. The opening in the graft should be at least twice as large as the diameter of the coronary artery because a thick pseudointima (up to 3 mm) develops along the anastomotic line when collagen impregnated grafts are used. Excessively large orifices in the graft may cause late aneurysm of the remnants of the aortic sinus tissue and too small orifices may result in late stenoses of the coronary artery ostia. The upper part of the Dacron graft is then sutured to the distal ascending aorta or to a graft that may have been used to replace the transverse aortic arch.



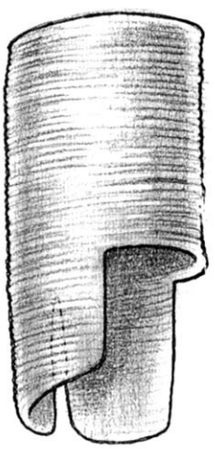
Patients With a Normal Aortic Annulus

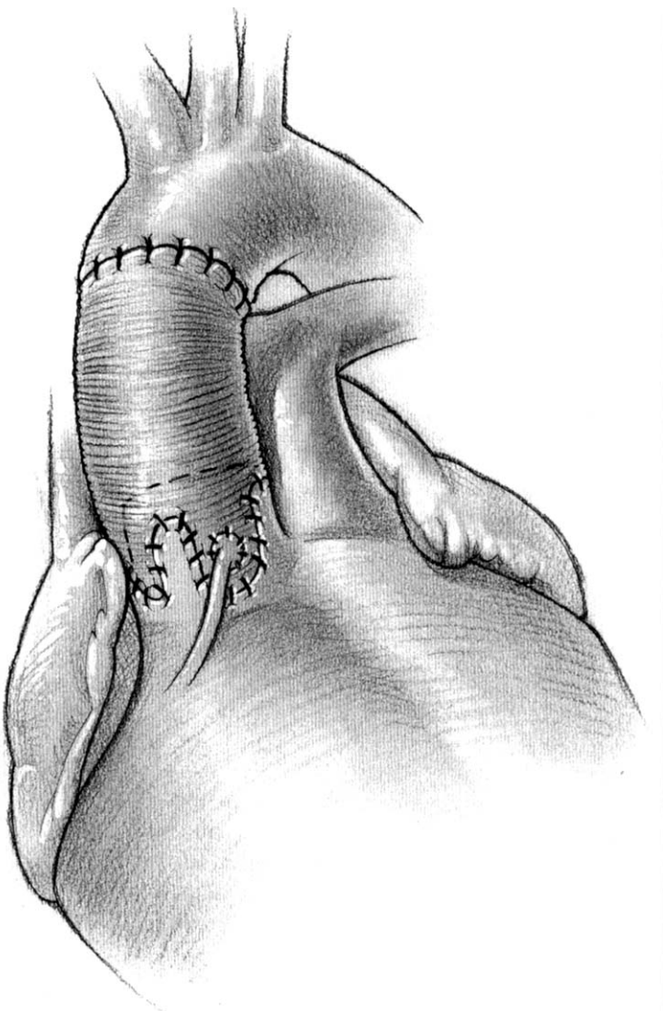


9 The ascending aorta is transected 1 cm above the commissures of the aortic valve and the leaflets are carefully inspected, as previously described. If they are fairly normal, remodeling of the aortic root with preservation of the native aortic valve is feasible. Next, the sinuses of Valsalva are carefully inspected. If they are not dilated, it is possible to restore normal valve function by creating a normal sinotubular junction. If an ascending aortic aneurysm is present, restoration of the sinotubular junction can be achieved by suturing a tubular Dacron graft a few millimetres above the commissure of the aortic valve where the dilated sinotubular junction used to be. The diameter of this graft should be 10% to 15% less than the length of the free margin of the aortic leaflets (or approximately twice the height of the leaflets). The end of the graft that is sutured to the aortic root at the level of the sinotubular junction should be divided in three equal thirds and each third should be sutured to each aortic sinus at the level of the sinotubular junction. Because the noncoronary leaflet is slightly larger than the left and right leaflets, the third corresponding to the noncoronary sinus could be slightly longer than the other two. (Reprinted with permission from David, et al: Repair of the aortic valve in patients with aortic insufficiency and aortic root aneurysm. *Journal of Thoracic and Cardiovascular Surgery*, Vol. 109, 1995, pp. 345-352.)

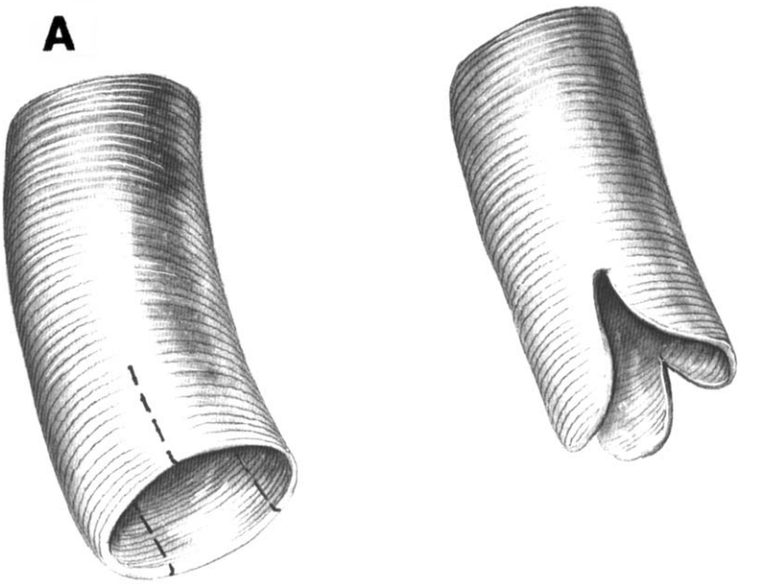


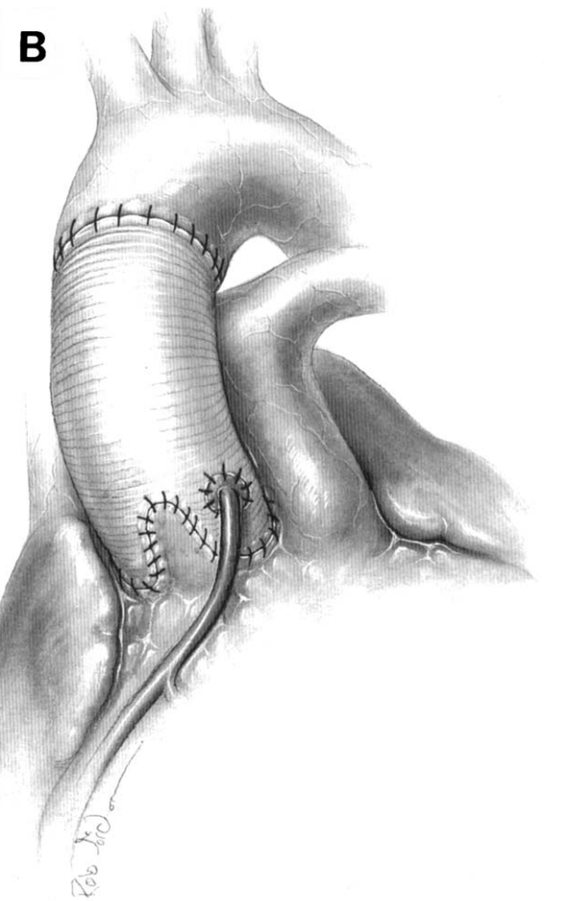
10 The noncoronary aortic sinus is the first one to dilate in patients with ascending aorta aneurysm. Thus, some patients with ascending aortic aneurysm and aortic insufficiency have fairly normal left and right aortic sinuses, but the noncoronary aortic sinus is dilated. Remodeling can be accomplished by excising the noncoronary aortic sinus and suturing a tailored Dacron graft to the sinotubular junction along the left and right aortic sinuses and to the remnants of the noncoronary sinus at the level of the aortic annulus. The size of the graft is determined by measuring the lengths of the free margins and the heights of the leaflets; the diameter of the graft should be approximately 10% to 15% smaller than the length of the free margins (or double the height of the leaflets). Three equidistant marks are made in one of the ends of the graft and longitudinal cuts are made along these marks for a length of approximately three fourths of the diameter of the graft. Two of the three ends created are excised and the third one is rounded. This end of the graft is used to remodel the aortic root. (Figure 10B reprinted with permission from David, et al: Repair of the aortic valve in patients with aortic insufficiency and aortic root aneurysm. *Journal of Thoracic and Cardiovascular Surgery*, Vol. 109, 1995, pp. 345-352.)





11 The right coronary aortic sinus is the second most commonly involved sinus by aneurysmal dilatation in patients with ascending aorta aneurysm. In some patients, remodeling is accomplished by replacing two sinuses, using the technique previously described to prepare the Dacron graft. (Reprinted with permission from David, et al: Repair of the aortic valve in patients with aortic insufficiency and aortic root aneurysm. *Journal of Thoracic and Cardiovascular Surgery*, Vol. 109, 1995, pp. 345-352.)





12 If all three aortic sinuses are involved, but the aortic annulus is not dilated, remodeling of the root is performed by replacing all three aortic sinuses and reimplanting the coronary arteries. No annuloplasty is needed because the aortic annulus is not dilated. The Dacron graft is selected and prepared as previously described (A, B).

COMMENTS

Remodeling procedures of the aortic root are technically demanding operations and extreme care must be exercised during the dissection, resection, and suturing of the Dacron graft to the remnants of the aortic sinuses and to the coronary arteries. Bleeding has not been a problem in our patients, even in those who presented with acute type A aortic dissection. Actually, this type of reconstruction of the aortic root is particularly useful in acute dissections because most of the tissues involved by the dissection are excised from the aortic root, and the graft is largely sutured to fibrous structures close to the aortic annulus.

One of the most difficult aspects of these operations is to determine the size of the Dacron graft that should be used for reconstruction of the aortic root. We have found that both the length of the free margin and the height of the leaflets give a fairly accurate estimation of the diameter of the sinotubular junction. If one is to err in selecting the size of the graft, it is safer to use a larger one because, if the leaflets do not coapt after suturing the graft in, it is possible to reduce the diameter of the sinotubular junction by plicating the graft immediately above the level of the commissures. This maneuver brings the free margins of the leaflets toward the center of the aorta. These operations should be performed with intraoperative Doppler echocardiography to assess the function of the aortic valve after completion of the procedure.

We began to perform these operative procedures in 1987. By the end of 1995, we had operated on 82 patients with only one operative death, one operative failure, and one late failure. The operative death was caused by a myocardial infarction in a patient who presented with acute type A aortic dissection and who had diffuse nonbypassable three-vessel coronary artery disease. The operative failure occurred early in our experience when we were still developing these techniques. In fact, the first few patients had a quite different operative procedure whereby the skeletonized aortic valve was reimplanted inside of a tubular Dacron graft similar to what is performed during implantation of an aortic homograft using the free-hand technique.[1-3] The late failure occurred in a young patient with Marfan syndrome who had a perfectly competent aortic valve after repair, but it became dysfunctional after 2 years, likely because of excessive growth of the valve inside the conduit. All other patients are asymptomatic. No patient is taking oral anticoagulant or antiplatelet agents. There have been no valve-related complications, and the repair remains stable in all patients. Only two patients have moderate aortic insufficiency, but it has been stable without evidence of progression over the years. The remaining patients have mild or no aortic insufficiency by Doppler echocardiography. In this group of patients, approximately one third of them have Marfan syndrome.

It is possible to remodel the aortic root and preserve the native aortic valve in carefully selected patients with aortic root/ascending aorta aneurysms and aortic insufficiency. Patients with annuloaortic ectasia should also have an aortic annuloplasty. The clinical results during the first 8 years of our experience with these procedures have been excellent. We do believe that patients with Marfan syndrome are candidates for this type of conservative operation as long as the aortic valve leaflets are normal or minimally stretched.

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