AORTIC ROOT RECONSTRUCTION WITH PRESERVATION OF NATIVE AORTIC VALVE AND SINUSES IN AORTIC ROOT DILATATION WITH AORTIC REGURGITATION

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Background: We assessed the results of a modified technique for aortic root reconstruction including preservation of the native aortic valve and sinuses. **Methods:** A modified technique for reconstruction of the aortic root was devised in which the native aortic sinuses are preserved and remodeled, the diameter of the sinotubular junction is reduced, the ventriculoaortic junction is reinforced with a Dacron prosthesis, and the coronary ostia are reimplanted. Since January 1995, this modified operative technique was performed in 13 patients with a mean age of 54 ± 21 years. The median grade of aortic regurgitation was 3; in 10 patients it was caused by dilatation of the sinotubular junction, and 3 had additional annuloaortic ectasia. **Results:** The aortic crossclamping time was 61 ± 18 minutes. In-hospital mortality was 2 of 13 (15.3%) patients, both deaths being related to complications of aortic dissection. In 1 patient aortic regurgitation increased to grade 3, necessitating aortic valve replacement. At a mean follow-up of 2.1 years, the remaining 10 patients had stable aortic valve function with a median grade of regurgitation of 1. The mean New York Heart Association functional class was 1.2. **Conclusions:** Aortic root reconstruction with preservation of the native aortic valve and sinuses allows symmetric reconstruction of the aortic sinuses and adaptation of the diameters of the sinotubular and ventriculoaortic junctions, thus optimizing aortic valve function. Moreover, it prevents contact of the aortic valve leaflets with the Dacron graft, which may enhance the durability of the repair. (J Thorac Cardiovasc Surg 1999;117:1151-6)

Dilatation of the aortic root resulting from long-standing aortic regurgitation (AR), often associated with overstretched aortic leaflets and a damaged fibrosa layer, usually necessitates composite replacement of the aortic valve and ascending aorta.¹⁻⁴ In a minority of patients, however, the aortic leaflets are remarkably normal despite long-standing AR. In such a situation, reconstruction of the aortic root with preservation of the aortic leaflets and resection of the sinuses of Valsalva, as reported by David and coworkers^{5,6} and Sarsam and Yacoub,⁷ seem to be attractive alternative options to avoid composite replacement of the aortic valve and

ascending aorta. However, one of the major concerns regarding these operations is related to the mechanism of closure of the aortic valve leaflets. In both operative techniques, although aortic valve leaflet abrasion has not been reported as yet, we have echocardiographically documented that in some cases the aortic valve leaflets during systole are in contact with the rough texture of the Dacron tubular graft. In an attempt to minimize the potential problem of leaflet damage, we have recently developed a modified technique of aortic root reconstruction in which the native sinuses of Valsalva are preserved and remodeled. This report describes our experience with this modified technique.

Patients and methods

The aortic root. The aortic root is a complex structure that is composed of 3 leaflets, 3 sinuses of Valsalva, and 3 inter-leaflet triangles. The leaflets are attached to the aortic wall in a semilunar fashion with the attachment of each leaflet rising to its zenith at the sinotubular junction and being at its nadir just below the ringlike junction of the aortic wall and the ventricle (anatomic ventriculoaortic junction).⁸⁻¹⁰ The base of the normal leaflet is approximately 1.5 times longer than is

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Table I. Clinical characteristics of the patients

No. of patients	13
Age (y)	
Mean	54.2
Range	14-77
Marfan syndrome	4
Aortic dissection	
Type A	2
Type B	1
Aortic arch aneurysm	1
NYHA functional class	
Class II	5
Class III	6
Class IV	2
Diameter of aortic root (mm)	
Mean	58
Range	49-78
Aortic regurgitation	
Grade 1	1
Grade 2	5
Grade 3	4
Grade 4	3
Coronary artery disease	1
Mitral regurgitation	1
Tricuspid regurgitation	1
Ischemic VSD	1

NYHA, New York Heart Association; VSD, ventricular septal defect.

its free margin.¹¹ This arrangement of the leaflets results in optimal coaptation of the aortic valve during diastole and ensures unobstructed flow of blood during systole. The aortic root has the shape of a truncated cone, the diameter of which at the level of the sinotubular junction is approximately 15% smaller than that at the anatomic ventriculoaortic junction (at aortic "anulus").^{9,11-13} The height of the sinuses corresponds approximately to 60% to 70% of the diameter of the aortic anulus.¹¹⁻¹³ The noncoronary sinus is slightly larger than the left and right sinuses. In the aortic root, the fibrous skeleton forms the posterior wall of the left ventricular outflow tract in the area where the aortic leaflets are in fibrous continuity with those of the mitral valve. The 2 ends of this area of fibrous continuity are thickened to form the left and right fibrous trigones. The right fibrous trigone is continuous with the membranous part of the septum, and the latter 2 structures form the central fibrous body through which the atrioventricular conduction tissue penetrates to pass from the muscular atrioventricular septum to the crest of the ventricular septum.

Isolated aortic root dilatation is a degenerative process that is localized in the aortic sinuses (predominantly the noncoronary sinus) and at the sinotubular junction. It is commonly related to increased age and systemic hypertension. Dilatation of the sinotubular junction prevents the leaflets from coapting, with consequent AR. The aortic anulus remains normal or dilates minimally. In annuloaortic ectasia the diameter of the aortic anulus increases out of proportion to the size of the aortic leaflets.⁶ The increase in annular diameter and dilatation of aortic sinuses occur along the fibrous components of

Table II. Operative data

Diameter of graft (mm)	
Median	26
Range	22-30
Aortic crossclamping time (min)	
Mean	61
Range	45-220
CPB time (min)	
Mean	98
Range	61-450
Additional procedures	
Replacement of aortic arch	1
Reconstruction of aortic arch	1
Replacement of aortic arch and descending aorta	1
Mitral valve reconstruction	1
Tricuspid valve reconstruction	1
CABG	2
Closure of ischemic VSD	1

CABG, Coronary artery bypass grafting; CPB, cardiopulmonary bypass; VSD, ventricular septal defect.

the left ventricular outflow tract.⁵ Eventually this results in dilatation of the sinotubular junction and AR.⁶

Clinical data. From January 1995 to July 1998, 13 patients (7 female and 6 male patients) with aneurysms of the ascending aorta and aortic root and associated AR underwent reconstruction of the aortic root with preservation of the native aortic valve and sinuses. The mean age of the patients was 54 ± 21 years (range 14 to 77 years). All patients had a preoperative Doppler echocardiographic study, which quantitated the AR from 0 (none or trace) to 4 (severe). The median grade of AR was 3. In 10 patients the AR was primarily caused by dilatation of the sinotubular junction. Four patients had Marfan syndrome, 3 of whom had additional annuloaortic ectasia. Aortic dissection was present in 3 patients (type A in 2 patients and type B in 1). Tables I and II summarize the preoperative clinical data and the operative data, respectively. All patients had a Doppler echocardiographic study before discharge from the hospital, 2 to 3 months later, and annually thereafter.

Operative techniques. Cardiopulmonary bypass is established by cannulating the proximal aortic arch or the femoral artery and the right atrium. The systemic temperature is lowered to 32°C or to 24°C in patients with aortic root dilatation and associated aortic arch disease. After aortic crossclamping, continuous antegrade infusion of cold crystalloid cardioplegic solution is used for myocardial protection. The left ventricle is vented with a cannula inserted through the right superior pulmonary vein and mitral valve. The ascending aorta is transected just beyond the aneurysmal dilatation (Fig 1, A). The aortic root is inspected with particular attention directed toward the state of the leaflets and the degree of dilatation of the sinuses and the sinotubular and ventriculoaortic junctions. The leaflet heights (length from midportion of the free margin to midportion of attachment margin) are measured and averaged. The coronary ostia are excised with small buttons of aortic wall. If a coronary ostium (particularly the left one) is

Fig 1. Technique of aortic root reconstruction with preservation of native aortic valve and sinuses and replacement of ascending aorta. **A**, The *dashed lines* indicate the incisions. The coronary ostia are excised with small buttons of aortic wall. **B**, Triangular pieces of dilated sinus wall are excised. The degree of excision varies with the redundancy of the sinus wall and usually is most extensive in the noncoronary sinus. **C**, Reconstruction of the aortic root. **D**, Replacement of the ascending aorta with Dacron graft, which is secured to the aortic anulus with multiple interrupted sutures. The edge of the reconstructed aortic root is secured to the graft with a continuous suture. The coronary ostia are reimplanted.

in such proximity to the anulus that this prevents sufficient cephalad mobilization and reimplantation of the ostium (thus rendering reconstruction of that particular sinus with native tissue impossible), then that sinus may have to be resected and the aortic root remodeled according to the method of David and associates^{5,6} or Sarsam and Yacoub.⁷ From each sinus of Valsalva triangular pieces of dilated sinus wall are excised (Fig 1, *B*). The extent of the excision varies with the degree of dilatation of the sinuses and the sinotubular junction and is estimated as follows: first, the desired internal diameter of the ventriculoaortic junction is calculated by assuming that the internal radius of the ventriculoaortic junction is two thirds of the leaflet height.¹¹⁻¹³ For instance, if the leaflet height is 15 mm, the desired internal radius of the ventriculoaortic junction is 10 mm and the desired internal diameter of the ventriculoaortic junction thus equals 20 mm. The desired internal circumference of the ventriculoaortic junction is 3.14 times the desired internal diameter, thus, in this case, 63 mm. Assuming that the desired internal circumference of the aortic root is the same for the ventriculoaortic junction as for the sinotubular

junction, the calculated internal circumference of the aortic root at the ventriculoaortic junction is subtracted from the internal circumference of the aortic root at the sinotubular junction. For instance, if the measured internal diameter of the sinotubular junction is 32 mm, the internal circumference of the aorta at the sinotubular junction is 3.14 times 32 mm, which equals 100 mm. The length of redundant tissue is then 100 mm minus 63 mm, which equals 37 mm. Assuming that a rim of 3 mm of sinus wall is needed bilaterally for reconstruction of 1 excised sinus segment, approximately 6 mm of sinus wall is needed for reconstruction of 1 sinus, equaling 18 mm for 3 sinuses. The total amount of sinus wall that is to be excised in this example then is 37 mm minus 18 mm, which equals 19 mm. It is a matter of judgment as to how much tissue needs to be excised per sinus. Inasmuch as the aortic sinuses dilate, particularly in areas above the fibrous skeleton of the heart (noncoronary sinus and the medial halves of the right and left sinuses), in the majority of cases the excision is more extensive in the noncoronary sinus, followed by the right and left sinuses.

Fig 2. Transesophageal echocardiogram (transverse [A] and sagittal [B] views) of reconstructed aortic root with preservation of the native aortic valve and sinuses and replacement of the ascending aorta. Note the excellent coaptation of the aortic valve leaflets (*arrow*) and the symmetric reconstruction of the aortic sinuses. *Ao*, Ascending aorta; *LV*, left ventricle; *RV*, right ventricle.

In the absence of annuloaortic ectasia, multiple interrupted horizontal mattress sutures of 4-0 polyester are passed from inside to outside the left ventricular outflow tract. These sutures are placed in a horizontal plane that corresponds to the lowest level of the leaflet attachments. In the presence of annuloaortic ectasia, these sutures are strategically placed to allow for correction of annuloaortic ectasia. On the right side of the ventriculoaortic junction, which is fibrous, the sutures are placed in a horizontal plane that corresponds to the lowest level of the leaflet attachments. On the left side of the ventriculoaortic junction, where the aortic valve is attached to ventricular muscle, the sutures follow the scalloped line of insertion of the right and left leaflets. Subsequently, all 3 aortic sinuses are reconstructed with continuous 5-0 polypropylene sutures (Prolene, Ethicon, Inc, Somerville, NJ) using an everting suturing technique (Fig 1, C). A collagen-impregnated tubular Dacron graft (Hemashield Woven Double Velour grafts, Meadox Medicals, Inc, Oakland, NJ) is selected whose

Table III. Latest postoperative Doppler echocardiographic study

	No. of patients
Aortic regurgitation	
Grade 0	4
Grade 1	5
Grade 2	1
Grade 3	0
Grade 4	0
Total	10

diameter is equal to the calculated external diameter of the ventriculoaortic junction (Fig 1, D). The calculated external diameter of the ventriculoaortic junction is obtained by adding 4 to 6 mm (the thickness of the aortic wall) to the calculated internal diameter of the ventriculoaortic junction. In the presence of annuloaortic ectasia, a scalloped segment of the Dacron graft is excised to correspond to the commissure of the right and left leaflets. In this circumstance, care is taken to space the sutures in such a fashion as to correct the annuloaortic ectasia. The reconstructed aortic root is placed inside the Dacron graft and all sutures are tied outside.

Three stay sutures are put into the edge of the reconstructed aortic root above each commissure. A gentle pull on these sutures results in a restoration of the sinus height and a reduction of commissural diameter, with resultant coaptation of the leaflets. The edge of the reconstructed aortic root is subsequently sewn to the Dacron graft at the appropriate level with a continuous 4-0 or 5-0 Prolene suture. The coronary arteries are reimplemented in the Dacron graft with a continuous 5-0 Prolene suture. The upper end of the Dacron graft is then anastomosed to the ascending aorta with a continuous 4-0 Prolene suture. All aortic and coronary ostial anastomoses are secured externally by the application of fibrin glue. After release of the aortic crossclamp, aortic valve competence is determined by transesophageal Doppler echocardiography.

Results

The aortic crossclamping time was 61 ± 18 minutes. The duration of stay in the intensive care unit was 2.9 ± 1.5 days. In-hospital mortality was 2 of 13 (15.3%) patients; both deaths were related to complications of aortic dissection. In both patients the cardiopulmonary bypass time and aortic crossclamping time had been prolonged (up to 450 minutes and 220 minutes, respectively). The first patient, who had aortic root dilatation and additional type A aortic dissection, died on the first postoperative day of low cardiac output after aortic root reconstruction with replacement of the ascending aorta and aortic arch. Because of acute ischemic changes of the left ventricle resulting from the aortic dissection, the left anterior descending and circumflex coronary arteries had been bypassed with saphenous vein grafts; subsequent weaning from cardiopulmonary bypass had

been difficult. The second patient, with type B aortic dissection, had been subjected to additional replacement of the aortic arch and descending aorta. He died on the sixth postoperative day of cerebral infarction.

Early postoperative echocardiographic studies demonstrated complete competence of the aortic valve in 6 patients. Five patients had AR grade 1, in 1 of whom the AR increased to grade 3, necessitating aortic valve replacement 2 weeks after the operation. No other valve-related complications have occurred. At a mean follow-up of 2.1 years (range 4 to 44 months), the remaining 10 patients with aortic root reconstruction have had stable aortic valve function without evidence of progressive AR (median grade of AR was 1) or aortic stenosis (Table III, Fig. 2). All patients were free of symptoms and the mean New York Heart Association functional class was 1.2. None of the patients with successful aortic root reconstruction was prescribed anticoagulants.

Discussion

With the decline in prevalence of rheumatic fever, noninflammatory aortic root dilatation has become the most common cause of isolated AR.¹⁴ In patients with aneurysms of the aortic root and the ascending aorta and normal aortic valve anatomy, replacement of the ascending aorta and all 3 aortic sinuses with a Dacron graft as reported by David and coworkers^{5,6} and Sarsam and Yacoub⁷ potentially results in an excellent hemodynamic status with preservation of native aortic valve function and avoidance of long-term anticoagulation. Although this complication has not been reported as yet, the main concern relating to these techniques is the potential for mechanical damage to the aortic valve leaflets in the long term, which may be induced by their contact with the rough texture of the Dacron graft. The technique that we propose allows exact adaptation of the sizes of the sinotubular junction and (if dilated) the ventriculoaortic junction and symmetric reconstruction of the aortic sinuses, thus optimizing coaptation and maintaining structural integrity of the aortic valve leaflets. Prevention of contact of the aortic valve leaflets with the rough surface of the Dacron graft may result in superior preservation of aortic valve function and hence increased durability of the repair. As in other aortic root remodeling techniques, aortic sinus function may become somewhat restricted because of the implantation of the sinuses into a rigid cylinder. In our experience and that of others, dilatation of the sinotubular junction is most often associated with dilatation of the noncoronary sinus of Valsalva, followed by dilatation of the right and left sinuses, respectively.⁶ As a result of this, to achieve symmetric reconstruction of

the aortic root, the excision of redundant tissue was most extensive in the noncoronary sinus, followed by that in the right and left sinuses, respectively. Reimplantation of the coronary ostia into the Dacron graft has not posed a problem in any of the 13 patients in this series. In 10 of the 11 surviving patients in this series, at a follow-up of up to 44 months, aortic valve function has been stable without any evidence of leaflet damage. Further follow-up is necessary to evaluate the long-term results of our modified technique.

In summary, our modified technique of aortic root reconstruction allowed preservation of the native aortic valve, preservation and symmetric reconstruction of the aortic sinuses, and adaptation of the diameters of the sinotubular and ventriculoaortic junctions, with resultant excellent aortic valve function. This modification prevents contact of the aortic valve leaflets with the Dacron graft. Further follow-up will clarify whether this technique enhances the durability of the valve repair.

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