Repair of the aortic valve in patients with aortic insufficiency and aortic root aneurysm

Patients with aneurysms of the ascending aorta or aortic root frequently have aortic insufficiency despite normal aortic leaflets. The aortic valve dysfunction is caused by dilatation of the sinotubular junction, distortion or dilatation of the sinuses of Valsalva, annuloaortic ectasia, or a combination of these problems. In the case of annuloaortic ectasia, reconstruction of the aortic root is performed by reimplanting the aortic valve in a tubular Dacron graft (*reimplantation*). In the case of mild or no annuloaortic ectasia, reconstruction of the aortic root is performed by correcting the dilated sinotubular junction and replacement of the aortic sinuses if they are also dilated with an appropriately tailored Dacron graft (*remodeling*). From July 1989 to March 1994, 45 patients have had either *reimplantation* of the aortic valve (19 patients) or *remodeling* of the aortic root (26 patients). Fourteen patients had Marfan's syndrome, 11 had acute and five had chronic type A aortic dissection, and nine also had transverse arch aneurysm. There were two operative deaths, both in the *remodeling* group. One patient who had *reimplantation* needed composite replacement of the aortic valve and ascending aorta because of persistent aortic insufficiency after the repair. A young patient with Marfan's syndrome had progressive aortic valve dysfunction during a growth spurt and had aortic valve replacement 2 years after the initial operation. No other valve-related complication has occurred. The remaining 41 patients have only mild or no aortic insufficiency, and the repair remains stable from 1 to 58 months, mean 18 months. These two types of aortic valve reconstruction have provided excellent clinical results in carefully selected adult patients. (J THORAC CARDIOVASC SURG 1995;109:345-52)

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Aneurysms of the ascending aorta are frequently associated with aortic insufficiency (AI) despite normal aortic valve leaflets. The AI is due to loss of the

sinotubular junction,^{1,2} dilatation or distortion of one or more sinuses of Valsalva, annuloaortic ectasia, or a combination of these problems.³⁻⁶ Although replacement of the aortic valve with separate or composite replacement of the ascending aorta has been the treatment for this problem,^{7,8} it has been our experience that the aortic valve can be spared and the aortic root reconstructed in at least one third of these patients.^{9,10} This article is a description of the operative procedures we have used to repair the aortic valve in patients with AI and ascending aortic aneurysms and of the results we have obtained during the past 5 years.

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Fig. 1. Normal aortic leaflet. The length of its base is one and one-half times the length of the free margin (FM).

Methods and patients

From July 1989 to March 1993, 45 patients with aneurysms of the ascending aorta and/or aortic root and AI underwent reconstructive surgery of the aortic root with preservation of the native aortic valve by means of one of the following techniques. The prerequisite for preservation of the aortic valve is that the leaflets be normal or nearly normal.

The aortic root. An important feature of the normal aortic leaflet is that the length of its base be approximately one and one-half times longer than the length of its free margin, as illustrated in Fig. 1. The height of the aortic leaflets ranges from 13 to 15 mm in adults. The noncoronary leaflet is slightly larger than the right and left leaflets.¹¹⁻¹³ Another important anatomic feature of the normal aortic root is that the diameter of the sinotubular junction is approximately 15% smaller than the diameter of the aortic anulus.¹¹⁻¹³ The height of the aortic sinuses corresponds approximately to 60% to 70% of the diameter of the aortic anulus.¹¹⁻¹³ The noncoronary aortic sinus is larger than the right and left sinuses. When the leaflets are fully open the diameter of the left ventricular outflow tract at the base of the aortic leaflets is almost equal to the diameter of the sinotubular junction.

These measurements and relationships are lost in patients with aortic root aneurysms. In annuloaortic ectasia the diameter of the aortic anulus increases out of proportion to the size of the aortic leaflets. The normal aortic anulus should not exceed 25 to 27 mm in adults. Patients with annuloaortic ectasia frequently have an anulus of 30 mm or more. This increase in diameter occurs along the fibrous components of the left ventricular outflow tract. 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), and eventually the sinotubular junction dilates and prevents the leaflets from coapting with consequent aortic insufficiency. In other patients, particularly older ones, the degenerative process that causes aortic root dilatation is localized predominantly in the aortic sinuses and sinotubular junction.

The aortic anulus remains normal or minimally dilated.

Operative techniques

Reimplantation. Patients with annuloaortic ectasia but normal or minimally stretched aortic valve leaflets are treated with an aortic annuloplasty and *reimplantation* of the aortic valve in a tubular Dacron graft, as shown in Fig. 2 and recently reported by us in this JOURNAL.⁹ To determine whether a leaflet is overstretched, we suspend its commissures to a normal position and observe the leaflet; its free margin should lie in a level higher than its base. If the central portion of the leaflet prolapses during this maneuver, it is an indication that the leaflet is overstretched and the aortic valve probably should be replaced.

The diameter of the Dacron graft to be used is based on the height of the leaflets, as we described.⁹ The diameter of the graft should not exceed two times the height of the leaflets. Please refer to our original article for technical details of the *reimplantation* procedure.⁹

Remodeling. In patients with mild or no annuloaortic ectasia in whom the AI is due to loss of the sinotubular junction or to dilatation or distortion of one or more sinuses of Valsalva, but with a normal or mildly dilated aortic anulus, the aortic valve is repaired. This is done by replacing the ascending aorta with a Hemashield woven double-velour Dacron graft (Meadox Medicals, Inc., Oakland, N.J.) 10% smaller in diameter than the diameter of the aortic anulus (Fig. 3). When all three sinuses are dilated they are excised, with only 5 or 6 mm of arterial wall left attached to the aortic valve and a small button around each coronary artery orifice, as illustrated in Fig. 4. Three equidistant marks are made in one of the ends of the tubular Dacron graft and incisions are made for a length of approximately two thirds of the diameter of the graft, as illustrated in Fig. 5. The ends are scalloped to reproduce the crescentic shape of the aortic anulus. If the noncoronary leaflet is obviously larger than the right and left leaflets, the portion of the Dacron graft corresponding to the noncoronary aortic sinus should be made slightly

Fig. 2. Reimplantation: The aortic valve is reimplanted inside a Dacron graft.

larger. A double-armed 4-0 polypropylene suture is passed from inside to outside of the Dacron graft at the upper level of its scalloped end and also passed through the aortic valve commissure from inside to outside. The two arms of this suture are then passed through a small Teflon felt pledget and tied together. The same maneuver is carried out in each commissure. The three scalloped segments of the Dacron graft are sutured to the remnants of the sinuses of Valsalva all along the crescentic insertion of the aortic leaflets, leaving no more than 1 or 2 mm of sinus tissue between the Dacron graft and the leaflets. It is important to distribute the scalloped Dacron graft evenly along the crescentic shape of the aortic leaflets. The coronary arteries are reimplanted with continuous 5-0 polypropylene sutures. The anastomosis between the graft and the distal aorta is performed with continuous 4-0 polypropylene (Fig. 5).

Normal or mildly dilated aortic sinuses need not be replaced. Thus in certain cases only one or two sinuses may have to be replaced, as illustrated in Figs. 6 and 7. The most commonly affected sinus of Valsalva is the noncoronary sinus, followed by the right sinus and last by the left sinus.

Fig. 3. Remodeling: Correction of dilated sinotubular junction by simple replacement of the ascending aorta.

Reimplantation and *remodeling* procedures should be performed with intraoperative Doppler echocardiography to assess aortic valve function.

Clinical data. Table I shows the preoperative clinical data of patients who had reconstruction of the aortic root with replacement of the ascending aorta and preservation of the native aortic valve. All patients had a Doppler echocardiographic study before the operation. The transverse diameter of the ascending aorta and aortic root was measured only in patients with chronic aneurysms. The AI was quantitated from 0 (none or trace) to 4 (severe) by color Doppler echocardiography. Five patients had AI graded as 1+ but the aortic sinuses were dilated and required replacement; four of these patients had Marfan's syndrome. Table II shows the operative data. Patients had a Doppler echocardiographic study before discharge from the hospital, 2 to 3 months later, and annually thereafter. Only two patients who had mitral valve repair were discharged on a regimen of warfarin sodium. All other patients were discharged on a regimen of aspirin (325 mg daily).

Results

Two operative deaths occurred. A 44-year-old man with acute type A aortic dissection had the *remodeling* procedure with replacement of all three aortic sinuses and could not be weaned from cardiopulmonary bypass. The left anterior descending and the dominant circumflex arteries appeared to be extensively involved by atherosclerotic plaques and were bypassed with saphenous grafts, and it was possible to discontinue cardiopulmonary bypass. Se-

Fig. 4. *Remodeling:* All three aortic sinuses are excised, with only a small portion attached to the aortic anulus and around the coronary artery orifices.

Fig. 5. *Remodeling:* Correction of dilated sinotubular junction and replacement of all three aortic sinuses.

vere coagulopathy developed in this patient (he was supported by cardiopulmonary bypass for 222 minutes) and he died 6 hours after the operation. Autopsy demonstrated severe distal disease in all major coronary arteries. A 77-year-old man had the *remodeling* procedure with replacement of two aortic sinuses and triple coronary artery bypass. He died of pneumonia 40 days after the operation at another hospital.

The second patient to have the *reimplantation* procedure had persistent AI, and composite replacement of the aortic valve and ascending aorta was performed 2 days later. We failed to recognize that the aortic valve leaflets were overstretched.

One patient required reexploration of the mediastinum for bleeding. Another patient had a perioperative stroke; he had had replacement of the transverse aortic arch by the elephant trunk tech-

Table I. Clinical profile of all patients

	Reimplantation	Remodeling
No. of patients	19	26
Age (yr)	41.5	62.4
Mean range	14-68	35-77
Sex		
Male	14	18
Female	5	8
Marfan's syndrome	11	3
Acute type A dissection	5	6
Chronic type A dissection	1*	4*
Transverse arch aneurysm	3	6
NYHA functional class		
Class I	6	4
Class II	6	5
Class III	2	6
Class IV	5	11
Electrocardiogram		
Atrial fibrillation	0	2
Acute inferior MI	3	2
Echocardiography		
Mean diameter of aorta (mm)	56	60
Range (mm)	50-75	52-105
Color Doppler echocardiography		
AI grade 1	3	2
AI grade 2	5	8
AI grade 3	6	10
AI grade 4	5	6
Coronary artery disease	2	6
Mitral regurgitation	2	0

NYHA, New York Heart Association; MI, myocardial infarction.

*Four patients had had an operation for acute dissection and aortic valve resuspension; one had never had an operation.

Table II. Operative data

	Reimplantation	Remodeling
Coronary artery bypass	2	6
Mitral valve repair	3	0
Transverse aortic arch		
Proximal replacement	2	4
Complete replacement	1	6
Mean diameter of graft (mm)	27.3	25.8
Range (mm)	24-30	22-28
Aortic sinuses replaced		
None	0	8
Noncoronary	0	3
Noncoronary and right	0	7
All three	19	8
Aortic crossclamping time (min)	122	90
Mean range	88-167	40-176
Cardiopulmonary bypass time (min)	141	120
Mean range	102-203	75-222

nique and remodeling of the aortic root. He recovered and is scheduled to have the descending thoracic aorta replaced because of a large aneurysm.

Patients have been followed up from 1 to 58

Fig. 6. Remodeling: Correction of dilated sinotubular junction and replacement of the noncoronary aortic sinuses.

Fig. 7. Remodeling: Correction of the sinotubular junction and replacement of the noncoronary and right aortic sinuses.

months, mean 18 months. No patient has been lost to follow-up. The youngest patient in this series, a 14-year-old boy with Marfan's syndrome who had reimplantation of the aortic valve and mitral valve repair, had progressive aortic valve dysfunction with both AI and stenosis during a growth spurt of 35 cm in height. He underwent aortic valve replacement 2

Table III. Latest postoperative Doppler echocardiographic study

	<i>Reimplantation</i>	<i>Remodeling</i>
No. of patients	17	24
AI grade 0	11	14
AI grade 1	6	10
AI grade 2	1	0
AI grade 3	0	0
AI grade 4	0	0

years after the initial operation. At operation the repair was found to be intact but the aortic leaflets appeared to have grown inside the conduit, obstructing it and causing leaflet prolapse.

No other valve-related complications have developed. The other 41 patients remain free of symptoms, and periodic Doppler echocardiographic studies have shown stable aortic valve function without evidence of progressive AI or stenosis. Most patients have no AI, as shown in Table III.

Discussion

Anatomic studies of the aortic root indicate that the diameter of the aortic anulus is 10% to 20% larger than the diameter of the sinotubular junction.¹¹⁻¹³ The upper part of the commissures of the aortic valve is located immediately below the sinotubular junction. Thus dilatation of the sinotubular junction displaces the commissures outward, prevents the leaflets from coapting, and thus causes AI. This mechanism of AI in patients with normal leaflets has been known for more than one and one-half centuries.¹ In 1832 Corrigan¹ published an article titled "Permanent Patency of the Mouth of the Aorta," in which he described dilatation of the sinotubular junction as a cause of AI in patients with normal aortic valve leaflets. In 1986 Frater² referred to Corrigan's work and reported five cases in which the AI was abolished by correcting the dilated sinotubular junction.

The diameter of the sinotubular junction increases with age and with systemic hypertension.¹² From a surgical viewpoint, aneurysms of the ascending aorta are the most common cause of dilatation of the sinotubular junction. We have found that the noncoronary aortic sinus is the most frequently involved site of dilatation of the sinotubular junction, followed by the right sinus, and last the left sinus in patients with aneurysms of the ascending aorta and AI (Table II). AI is corrected by replacement of the ascending aorta with a Dacron tube

slightly smaller in diameter than the diameter of the left ventricular outflow tract at the level of the aortic anulus. This diameter can be measured by echocardiography or during the operation with metric valve sizers. We have found that the direct surgical measurements are slightly larger than the echocardiographic measurements. If the aortic sinuses are not dilated, correction of the sinotubular junction by anastomosing the Dacron graft immediately above the level of the commissures restores aortic valve competence. It is important to evenly distribute the three commissures of the aortic valve during the performance of the anastomosis between the Dacron graft and the upper part of the aortic sinuses. We make three equidistant marks in the graft and align each mark with one commissure during the anastomosis. Although the noncoronary cusp and its sinus are slightly larger than the right and left cusps and their sinuses,^{11, 12} the difference in size is negligible in most patients and need not be considered during *remodeling* of the sinotubular junction.

If one or more sinuses are dilated or a dissecting aneurysm separated the media of the sinuses, it is safer to replace them. Not all three sinuses have to be replaced to restore normal aortic valve function. Only the diseased sinuses are replaced. *Remodeling* of the aortic root with replacement of all three aortic sinuses was described by Yacoub and associates¹⁴ in 1983. They reported on 31 patients with ascending aortic aneurysm and AI in whom aortic valve competence was restored by replacing the ascending aorta and all three aortic sinuses, as illustrated in Fig. 5. In a more recent publication, Sarsam and Yacoub¹⁵ reported on 10 patients who also had this procedure: one died, one required aortic valve replacement 1 year later because of technical failure, and eight patients remained free of symptoms with stable aortic valve repair during a mean follow-up of 3.4 years but which extended up to 10 years.

Remodeling procedures of the aortic root as described have been extremely useful in patients with acute and chronic aortic dissections. The sinuses involved by the dissection can be completely excised and the graft is sutured to fairly healthy tissue. If the sinuses are dilated, we replace them even when not involved by the dissection.

Patients with Marfan's syndrome and its forme fruste have aortic root aneurysms with associated annuloaortic ectasia.³⁻⁶ The leaflets may be overstretched by the time these patients come to surgery, and composite replacement of the aortic valve and

ascending aorta remains the treatment of choice.^{7,8} However, if the leaflets are normal or minimally stretched, the aortic valve can be saved by performing an aortic annuloplasty and resuspending the aortic valve in a tubular Dacron graft.⁹ We believe that correction of the annular dilatation is an important part of the reconstructive procedure in these patients. The *reimplantation* procedure that we described corrects both the annuloaortic ectasia and the dilatation of the sinotubular junction and aortic sinuses.⁹ The principal shortcoming of this procedure is the absence of aortic sinuses, which may increase the mechanical stress on the leaflets and shorten their durability. To date, however, durability has not been affected. The first patient who had this procedure has a normally functioning aortic valve 58 months later.

REFERENCES

1. Corrigan DJ. Permanent patency of the mouth of the aorta. *Edinburgh Med Surg* 1832;37:111.
2. Frater RWM. Aortic valve insufficiency due to aortic dilatation: correction by sinus rim adjustment. *Circulation* 1986;74(Suppl):I136-42.
3. Weaven WF, Edwards JE, Brandenburg RO. Idiopathic dilatation of the aorta with aortic valvular insufficiency: a possible forme fruste of Marfan's syndrome. *Mayo Clin Proc* 1959;34:518-22.
4. Davies MJ. Pathology of cardiac valves. Toronto: Butterworths, 1980:37-61.
5. Edwards JE. Pathology of aortic incompetence. In: Silver MD, ed. *Cardiovascular pathology*. Edinburgh: Churchill Livingstone, 1983:619-31.
6. Olson LJ, Subramanian R, Edwards WD. Surgical pathology of pure aortic insufficiency: a study of 225 cases. *Mayo Clin Proc* 1984;59:835-41.
7. Bentall HH, DeBono A. A technique for complete replacement of ascending aorta. *Thorax* 1968;23:338-9.
8. Gott VL, Pyeritz RE, Magovern GJ Jr, Cameron DE, McKusick VA. Surgical treatment of aneurysms of the ascending aorta in the Marfan's syndrome: results of composite graft repair in 50 patients. *N Engl J Med* 1986;314:1070-4.
9. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. *J THORAC CARDIOVASC SURG* 1992;103:617-22.
10. David TE. Aortic valve repair in patients with Marfan's syndrome and ascending aorta aneurysms due to degenerative disease. *J Cardiac Surg* 1994; 9(Suppl):182-7.
11. Kunzelman KS, Grande KJ, David TE, Cochran RP, Verrier ED. Aortic root and valve relationship: impact on surgical repair. *J THORAC CARDIOVASC SURG* 1994;107:162-70.
12. Silver MA, Roberts WC. Detailed anatomy of the normally functioning aortic valve in hearts of normal and increased weight. *Am J Cardiol* 1985;55:454-61.
13. Reid K. The anatomy of the sinus of Valsalva. *Thorax* 1970;25:79-85.
14. Yacoub M, Fagan A, Stassano P, Radley-Smith R. Result of valve conserving operations for aortic regurgitation [Abstract]. *Circulation* 1983;68(Suppl):III321.
15. Sarsam MAI, Yacoub M. Remodeling of the aortic valve anulus. *J THORAC CARDIOVASC SURG* 1993;105: 435-8.

Discussion

Mr. Magdi Yacoub (*Harefield, England*). Like you, we have been impressed by the fact that in patients with aneurysm of the ascending aorta, including those with Marfan's syndrome, the disease process is confined to the media of the aortic wall whereas the aortic ring or anulus and the cusps appear to be normal, at least initially. Because of that, in 1979 we developed and routinely used, whenever possible, a technique of complete excision of the aneurysmal ascending aorta including the sinuses of Valsalva down to the aortic anulus, with suspension of the aortic valve and implantation of the coronary orifices. To date we have performed over 100 such procedures. We have been able to preserve the aortic valve in about 50% of all patients with aneurysms of the ascending aorta including those with Marfan's syndrome and severe aortic regurgitation. Our maximum follow-up now is just about 15 years. The reoperation rate has been low (about 8%), particularly for the patients who have a perfect result at operation.

We have been encouraged by the results to the extent that now we apply this operation prophylactically in patients with Marfan's syndrome if they have an aortic root of 4.5 to 5 cm, even in the absence of aortic regurgitation. We believe that the recurrence and the problem in the valve are due to stretching and if that is stopped, perhaps these patients will have a perfect, normal aortic valve for a longer time, ideally for life.

Dr. David. Thank you, Mr. Yacoub. I am a bit concerned about replacing only the sinuses and leaving the anulus undisturbed in patients with Marfan's syndrome. In this disease the whole fibrous skeleton of the heart may continue to dilate. It is interesting that you found that after 15 years the anulus did not dilate any further and the process may have stabilized once you corrected the sinotubular junction and the aortic sinuses.

We still prefer the first procedure, the reimplantation, in patients with Marfan's syndrome simply because it seems to be a more stable repair of the aortic anulus.

Dr. Hans G. Borst. (*Hannover, Germany*). Since November 1993 we have not used a conduit.

Dr. David. Good for you.

Dr. Borst. You said that one repair failed because the leaflet margin of one cusp equaled that of its insertion line. What do you do about leaflets with a marginal length below that quotient of 1.5? Do you make a compromise in such cases or do you take a conservative view?

Dr. David. I am not a biomedical engineer but Dr.

Karen Kunzelman, from Seattle, is and she has taught me a lot about the aortic root. The leaflets are its most important component. If they are normal and you know the relationships between their sizes and those of the aortic root, you can repair these incompetent valves by either the remodeling or the reimplantation technique.

Dr. Borst. What do you do if the anulus is very large, which is very uncommon? I think the term annulo aortic ectasia is actually a misnomer because most of the patients do not have annular enlargement.

The anulus size per se does not deter you from using your method?

Dr. David. No, it does not, Professor Borst. In annuloaortic ectasia the muscle does not dilate, and approximately half of the left ventricular outflow tract is muscle. Thus the dilatation is in the fibrous skeleton of the heart. It is possible to produce some puckering even resect part to make it smaller.

Our only exclusion criterion is abnormal leaflets. If only one leaflet is prolapsing and two are not, we do what Professor Carpentier described some years ago, that is, a triangular resection. If all three are prolapsing, I do a composite replacement of the aortic valve and ascending aorta.

Dr. Borst. Your operation looks very simple. However, we found one point to be extremely important, and that is to dissect deeply enough on the muscle of the right ventricular outflow tract and on the left free wall. We find that if the sutures are run absolutely horizontally through the aorta, a perfect valve is obtained. Conversely, if there is any bunching in the depths of the sinuses, the valve may be distorted. Do you agree with that?

Dr. David. Yes, I agree.

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