

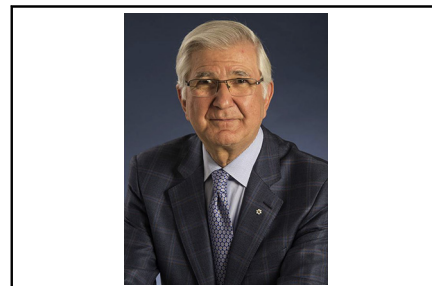
# Reimplantation valve-sparing aortic root replacement is the most durable approach to facilitate aortic valve repair



Tirone David, MD

## ABSTRACT

Reimplantation of the aortic valve has been performed for 3 decades, and experience shows that patient selection and meticulous operative technique are crucial to provide excellent clinical outcomes and stable aortic valve function for decades. More than the type of the Dacron graft used for the reimplantation (straight graft or Valsalva graft), we believe that attention to certain technical aspects of this operation is key to a successful and durable aortic valve reconstruction. This article describes the operative procedure as we believe it should be performed based on a learned experience with several hundred cases and summarizes the latest outcomes in a large cohort of patients followed prospectively during the past 3 decades. (JTCVS Techniques 2021;7:72-8)



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## CENTRAL MESSAGE

Reimplantation of the aortic valve provides excellent clinical outcomes and stable aortic valve function for decades in patients with aortic root aneurysm and normal or mildly diseased aortic cusps.

See Commentaries on pages 79 and 81.

Aortic valve-sparing operations (reimplantation of the aortic valve and remodeling of the aortic root) were initially introduced to treat patients with aortic root aneurysm or ascending aortic aneurysm with dilated aortic sinuses.<sup>1,2</sup> As experience with these operations increased, it became evident that patients with aortic root aneurysms and aortic insufficiency (AI) frequently have dilated aortic annulus or at least have a mismatch between the area that the aortic cusps and the area of the aortic orifice that the cusps have to seal, making reduction of the diameter of the aortic annulus an important component of these operations.<sup>3-6</sup> Although there are several methods to accomplish this reduction in

the diameter of the aortoventricular junction,<sup>2-5</sup> we believe that reimplantation of the aortic valve provides the most stable and lasting aortic valve function.<sup>7</sup>

## OPERATIVE TECHNIQUE

The principles of reimplantation of the aortic valve have not changed since its original description,<sup>1,2</sup> but we have learned some important lessons worth describing. We start the operation by transecting the ascending aorta at its mid-portion. The aortic sinuses are excised from the aortic root, leaving 3 to 5 mm of aortic sinuses attached to the aortic annulus and around the coronary artery orifices, as illustrated in [Figure 1](#). If a coronary artery orifice is only 2 or 3 mm from the aortic annulus, we leave it attached to the aortic root and dissect the artery circumferentially and from the surrounding tissues, as seen in [Figure 2](#). This anatomic variation is more common in patients with bicuspid aortic valve (BAV) than it is in tricuspid aortic valve. We dissect the aortic root from surrounding structures down to a level below the aortoventricular junction by at least 5 mm. This may not be possible in certain areas such as the insertion of the atria in the subcommissural triangles of the noncoronary aortic cusp, and we leave those attachments intact. On the left side of the aortic root,

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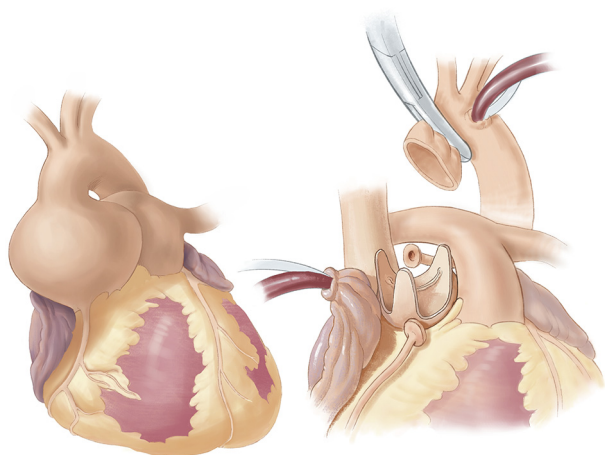
This study was supported by a donation from Honey and Jeffrey Rubenstein to the Cardiovascular Research Fund of Toronto General Hospital.

Received for publication Dec 2, 2020; accepted for publication Dec 2, 2020; available ahead of print Jan 28, 2021.

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JTCVS Techniques 2021;7:72-8  
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<https://doi.org/10.1016/j.jtc.2020.12.042>



**FIGURE 1.** The aortic sinuses are excised, leaving 3 to 5 mm of arterial wall attached to the aortic annulus and around the coronary artery orifices.

from the lateral fibrous trigone to the membranous septum, the pulmonary root and the right ventricular wall must be separated from the muscular interventricular septum. We start by dividing the aortopulmonary ligament and if the correct plane is identified, it is possible to extend the dissection down to 5 to 8 mm from the aortoventricular junction without entering the pulmonary root or right ventricular cavity. If the right ventricle is entered during this dissection, we do nothing until the aortic valve is reimplanted into a Dacron and only then is the right ventricular wall sutured to the Dacron graft. This deep dissection in the septum is a very important part of reimplantation of the aortic valve.<sup>6</sup>

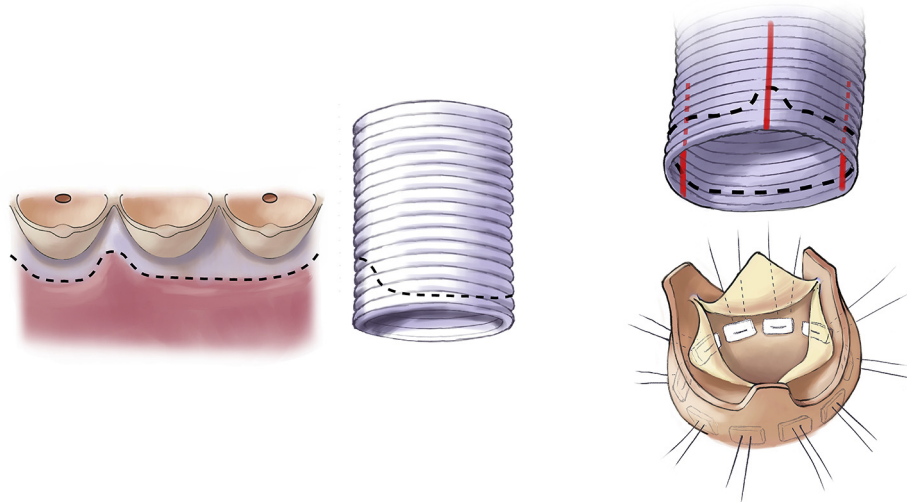
Sizing the Dacron graft for this operation remains difficult but our original formula is not a bad one.<sup>1</sup> We measure

the diameter of the aortic annulus, the ideal diameter of the sinotubular junction by pulling the 3 commissures upward and approximating them until the cusps touch each other, the height of the cusps, and the height of the commissure between the left and noncoronary cusps. We believe that cusp height is the most important measurement and usually we estimate the ideal diameter of the aortic annulus as being the average heights of the aortic cusps multiplied by two-thirds. The graft size is this value plus 6 to 8 mm to correspond to the thickness of the left ventricular outflow tract just beneath the aortoventricular junction.<sup>1</sup> When in doubt between 2 sizes, we have always taken the larger one. Most grafts used have been of sizes 26 to 34 mm for tricuspid aortic valve and 30 to 34 mm for BAV, largely depending on the heights of the aortic cusps. We do not believe reimplantation of the aortic valve is a good operation for patients with cusp heights of less than 13 to 14 mm. The good thing is that these patients seldom have annuloaortic ectasia and remodeling of the aortic root is probably a more appropriate type of aortic-valve sparing operation given the relatively small cusps size and aortic annulus.

Figure 3 illustrates the placement of the sutures in the left ventricular outflow track. When we first started doing this operation, we used simple mattress sutures, but we had a couple of complications (perforation of the anterior leaflet of the mitral valve and of the membranous ventricular septum), and changed to sutures with soft Teflon felt pledgets. We now use 2-0 polyester sutures and 9 to 12 horizontal mattress sutures are placed from the inside to the outside of the outflow tract. We try to place them along a single horizontal plane as much as possible but often we have to put them a bit higher in the subcommissural triangles of the



**FIGURE 2.** If a coronary artery originates close to the aortic annulus, it is safer to leave it attached to the aortic root and dissect the artery away from the aortic root and surrounding tissues (*left panel*). The graft is incised vertically in the area of the retained coronary artery before being secured to the left ventricular outflow tract (*right panel*).

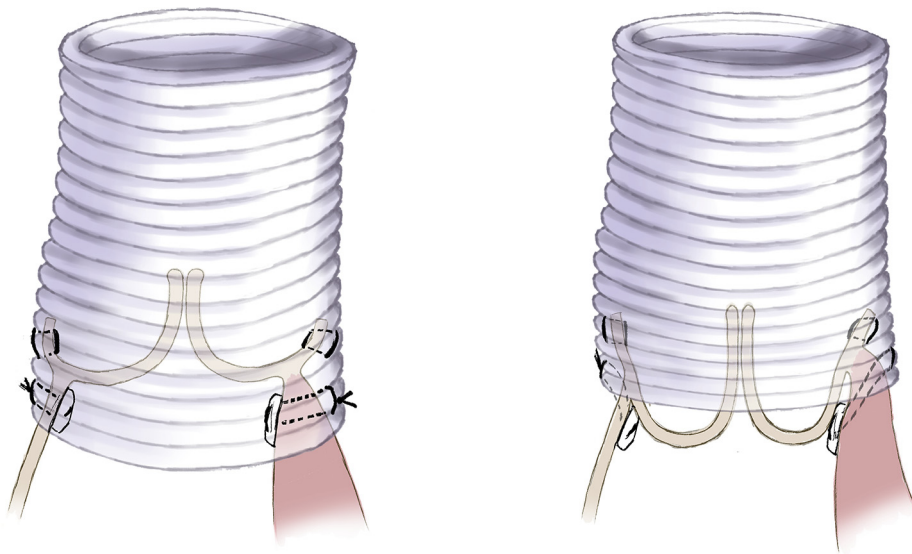


**FIGURE 3.** The aortic annuloplasty stitches are passed from the inside to the outside of the left ventricular outflow tract through a single horizontal plane except for the area of right coronary cusp, where it may have to be placed into its subcommissural triangles (*left panel*). The bundle of His should be avoided and that space left without a suture. These suture line must be spatially placed in the Dacron graft using the same spatial distribution as in the left ventricular outflow tract (*right panel*).

right coronary cusp, as shown in the left panel of [Figure 3](#). These sutures are passed through the atria walls in the areas of the subcommissural triangles of the noncoronary cusp because they are placed at a lower level than the insertion of the atria in the outflow tract. We leave the area of the bundle of His without a suture. Determining where the bundle crosses the muscular septum can be difficult in BAV because the membranous septum is often abnormal and sometimes absent. The 3 cusps are examined and if they are of similar sizes, we divide the Dacron graft in 3 equal thirds and distribute the annuloplasty sutures accordingly. Often the left aortic cusp is smaller than the other two, and its intercommissural distance should be proportionally smaller. The annuloplasty sutures must be passed through the graft following the same degree of scalloping as they were placed in the left ventricular outflow tract, as illustrated in the right panel of [Figure 3](#). If the aortic annulus is grossly dilated, most of the reduction should be beneath the commissures of the noncoronary cusp. This even distribution of the sutures is crucial to prevent distortion of the graft or tears in intervalvular fibrous body. This is prevented by placing the sutures in the graft using the same spatial distribution (height and width) as they were placed in the left ventricular outflow tract. The annuloplasty sutures are tied on the outside of the graft. This part of the annuloplasty is not a hemostatic suture line but the graft and outflow tract must be firmly attached to each other. In addition, the entire aortoventricular junction must lie in the inside of the graft, as illustrated in left panel of [Figure 4](#). If the dissection was not deep enough or if the spatial distribution of the sutures through the graft were incorrect, the aortic annulus may lay

at the same level as the annuloplasty or may even be inverted, as shown in right panel of [Figure 4](#). This technical error has been associated with early failures of this operation, and we believe that when it happens it should be corrected before proceeding to the next stage of the operation.

Each commissure is pulled upward inside of the mildly stretched graft and a 4-0 polypropylene suture with a soft Teflon felt is used to temporarily secure it to the graft. The same is done with the other 2 commissures and by pulling outward on these 3 sutures the aortic cusps are inspected within the Dacron graft. They must meet each other centrally and be well above the aortic annulus. More often than not, we have to move 1 or more commissures upward or downward, to the left or to the right until the 3 commissures are perfectly aligned within the graft, and the commissures must be on straight lines with the sub-commissural triangles. These sutures are tied and each arm used to secure the remnants of aortic sinuses to the Dacron graft starting at the commissure and ending at the nadir of the aortic sinus, as shown in left panel of [Figure 5](#). This suture line should be performed by transfixing sutures, that is, the suture is passed in and out of the graft. We pass the needle from the inside to the outside right at the junction between annulus and remnant sinus wall and bring it back from the outside to the inside through the sinus wall, a few millimeters from the previous one. This second suture line must be 5 to 10 mm above the first one in the nadir of the aortic sinuses ([Figure 4](#), left panel), and it has to be hemostatic. The coronary arteries are reimplanted into their respective sinuses. If one coronary artery was left attached to the aortic annulus, its reimplantation is done from within the graft

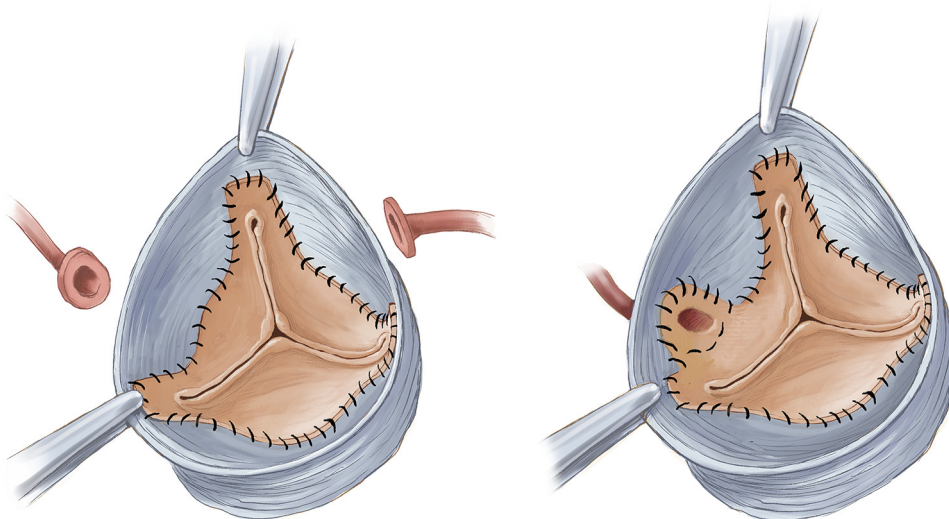


**FIGURE 4.** Once the annuloplasty is completed, the aortoventricular junction must lay inside the Dacron graft, as illustrated in the sketch on the *left panel*. If the graft lies at the same level as the aortic annulus or above it as shown on the *right panel*, early failure is likely to occur. This is largely due to inadequate dissection of the outflow tract and placement of the sutures.

by incising it longitudinally, making a round opening 3 to 4 mm wider the orifice of the coronary artery (right panels of [Figures 2](#) and [5](#)), and suturing the aortic wall around the orifice of the artery into the graft. The longitudinal incision made in the graft beneath the anomalous coronary artery should be closed with a couple of interrupted sutures to support the reconstructed aortic root and annulus.

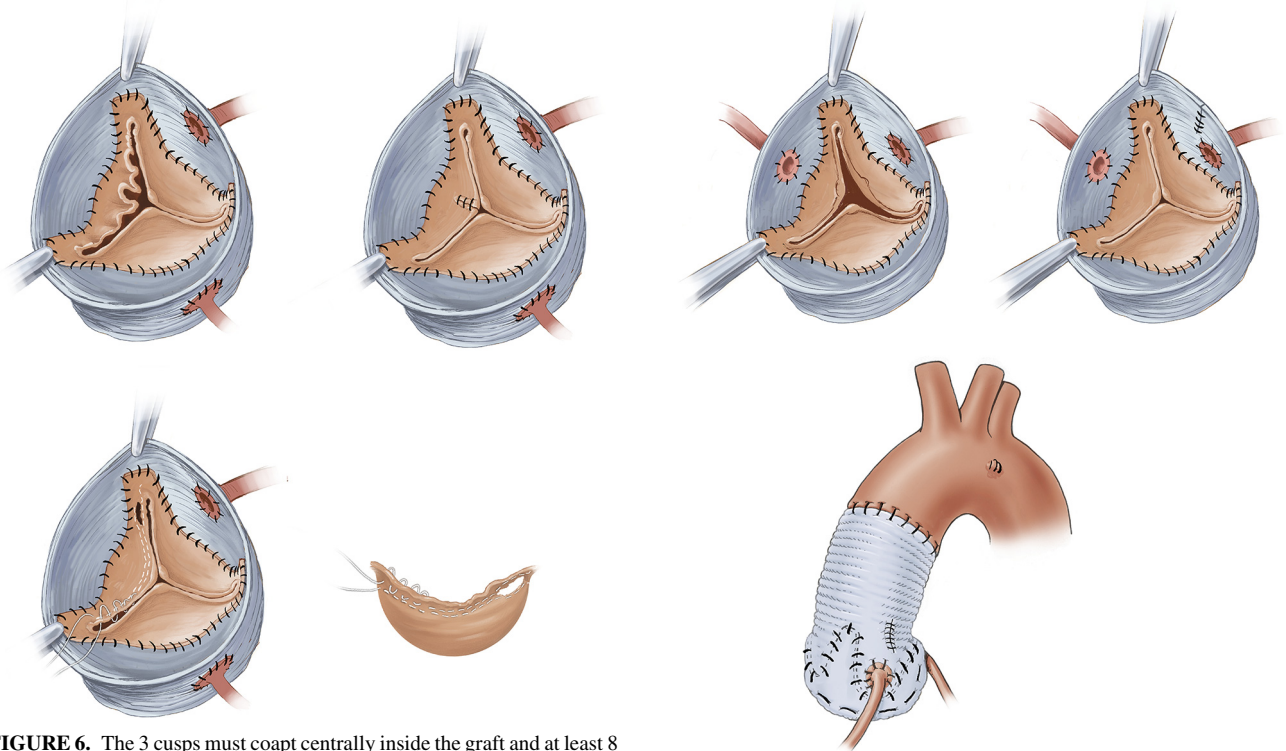
Finally, the free margins of the cusps are inspected inside the graft. They must lay above the nadir of the annulus by at least 10 mm and touch each other in the

center of the aortic orifice. If one or more free margin appears too long, it should be shortened by plication of the nodule of Arantius, as shown in the upper panel of [Figure 6](#). We believe that cusps with stress fenestration in the commissural areas should be reinforced by weaving a 7-0 expanded polytetrafluoroethylene suture along its free margin. This is done in 2 layers the first layer is weaved in and out of the free margin without going over it and the second layer a couple of millimeters below and along the lower limb of the fenestration, as shown in



**FIGURE 5.** The remnants of the aortic sinuses are secured to the Dacron graft starting at the commissures and moving down toward the nadir of the annulus (*left panel*). This suture line must be at least 8 mm above the previous one in the left ventricular outflow tract. If a coronary artery was left attached to the commissure, the arterial wall around its orifice is sutured to the graft, as illustrated in the *right panel*. The incision in the graft beneath this artery should be closed with a couple of interrupted sutures.





**FIGURE 6.** The 3 cusps must coapt centrally inside the graft and at least 8 to 10 mm above the aortic annulus. Elongated free margins are shortened by plicating centrally along the nodule of Arantius, as shown in the *upper panel*. Free margin of cusps with large stress fenestration is reinforced with a double layer of 7-0 expanded polytetrafluoroethylene suture, one above and the second a millimeter or 2 beneath the free margin (*lower panel*).

the lower panel of [Figure 6](#). The ends of the sutures are tied on the outside of the graft.

Sometimes we overestimate the size of the graft and one or more cusps barely touch the others centrally, as illustrated in upper panel of [Figure 7](#). If this occurs, we plicate the Dacron graft in the center of the intercommissural distance, at the level of the new sinotubular junction, as illustrated in [Figure 7](#). This plication extends 2 or 3 mm above and below the sinotubular junction and the fold in the graft should be on the outside. Geometrically speaking, for every 3 mm of horizontal plication, the diameter of the graft is reduced by 1 mm.

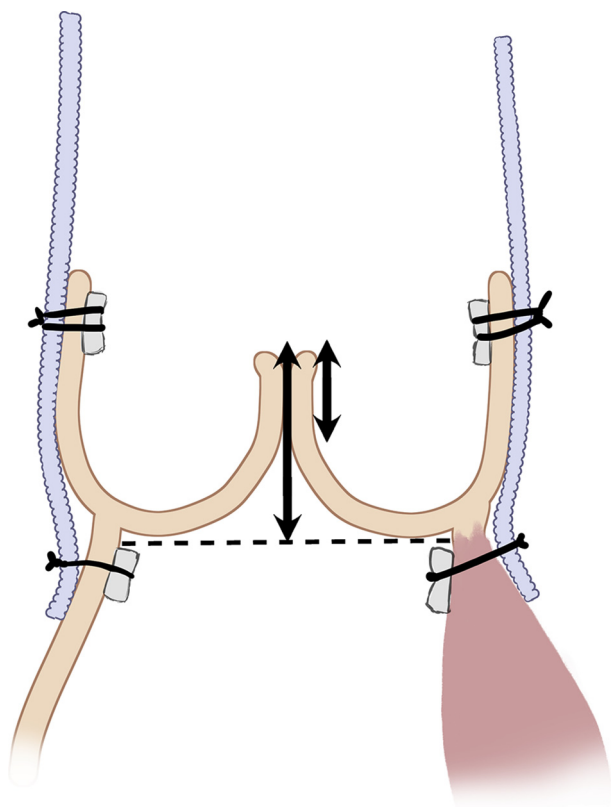
Once the reconstruction of the aortic root is completed, we clamp the graft and inject cold blood cardioplegia under high pressure (100 mm Hg) and observe the unvented left ventricle. It has been our experience that mild degree of AI causes ventricular distension. If the ventricle remains empty, the aortic valve is competent or may have trivial AI but very seldom more. Obviously, intraoperative echocardiography is indispensable to assess aortic valve function at the completion of the operation. The cusps coaptation must well within the graft, as illustrated in [Figure 8](#). We believe that a correctly performed reimplantation of the aortic should result in a coaptation height greater

**FIGURE 7.** If one or more cusps do not easily reach the central portion of the graft to coapt with the others, the intercommissural distance can be shortened by plicating the graft from the outside, as shown in the *upper panel*. This creates a neo-aortic sinus. The complete repair is illustrated in the *lower panel*.

than 8 mm and coaptation length greater than 4 mm, and no or trivial AI.

### CLINICAL OUTCOMES

We recently published an update on our clinical outcomes in the *Journal*.<sup>7</sup> From August 3, 1989, to December 31, 2018, 465 consecutive patients had reimplantation of the aortic valve. Patients' mean age was  $47 \pm 5.1$  years, and 78% were men. The aortic root aneurysm was associated with Marfan syndrome in 164 patients, Loeys–Dietz syndrome in 13, BAV in 67, and type A aortic dissection in 33. Preoperative AI was greater than mild in 298 (64%) patients. Concomitant procedures were performed in 105 patients (aortic arch procedure, coronary artery bypass and mitral valve repair were the most common ones). Patients have been followed prospectively since surgery and echocardiograms obtained before discharge from hospital and every 2 to 5 years in most patients. The mean follow-up was  $10 \pm 6$  years. There were 5 operative and 51 late deaths. The cumulative proportion of deaths from any cause at 20 years was 24.8%. Only age by 5-year increments was associated with postoperative death by multivariable analysis. [Figure 9](#) shows event-free survival and cumulative incidences of death from any cause and reoperation on the

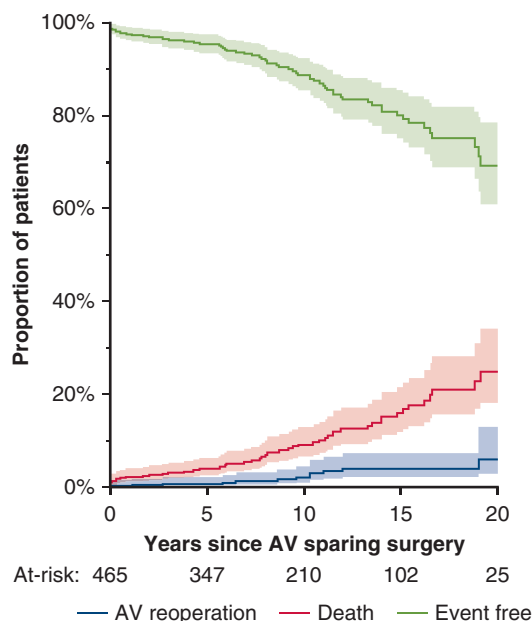


**FIGURE 8.** At the completion of the reimplantation procedure, transesophageal echocardiography should show the cusps entirely inside the reconstructed aortic root and the coaptation height (*larger arrow*) should be at greater than 8 mm and the coaptation length (*smaller arrow*) greater than 4 mm.

aortic valve. At 20 years, 69.1% of patients were alive and free from aortic valve reoperation, and the cumulative probability of aortic valve reoperation with death as a competing risk was 6.0%. The cumulative probability of developing moderate or severe AI was 10.2% at 20 years. Only time per 1-year interval was associated with the development of postoperative AI by multivariable analysis. The presence or absence of neo-aortic sinuses had no influence on the development of AI over time. BAV was associated with probability of reoperation by univariable analysis but not by multivariable analysis likely due to a relatively small sample size. BAV may fail due to AI as well as aortic stenosis. Gradients across the BAV increased in 5 patients, and 1 required reoperation for aortic stenosis (actually 2 because one more patient had reoperation recently).

Distal aortic dissections occurred in approximately 6% of all patients, but the risk was substantially greater in patients with associated genetic syndromes.

Four patients developed infective endocarditis (3 aortic root abscess and 1 graft infection 1-23 years after surgery) and all required reoperation. One patient died. The cumulative risk of infective endocarditis in the aortic valve at



**FIGURE 9.** Estimates of event-free survival, death of any cause, and reoperation on the aortic valve over the years after reimplantation of the aortic valve. AV, Aortic valve. Reproduced from David and colleagues,<sup>7</sup> with permission from Elsevier.

20 years was 2.5%. Three other patients developed endocarditis of the mitral valve and 2 were medically treated and 1 had mitral valve repair. All 3 survived. Eleven patients suffered a stroke (4 died) and 15 had one or more transient ischemic attacks. The cumulative proportion of thromboembolism at 20 years was 8.8%. Nine patients required implantation of permanent transvenous pacemaker while in hospital, and 13 patients had during the follow-up period. The cumulative proportion of patients requiring pacemaker was 2.2% at 1 year and 6.0% at 20 years.

## DISCUSSION

In our experience reimplantation of the aortic valve has provided excellent results with stable aortic valve function during the first 2 decades of follow-up in most patients. The development of AI over time appears to be slow and progressive, but by end of 20 years, only 10% of the patients have developed moderate or severe AI. We believe this degenerative process of the aortic valve is more due to the abnormal environment where the aortic cusps are placed (a rigid, noncompliant Dacron graft) than due to the elimination of aortic sinuses. Actually, we could not demonstrate any benefit in recreating aortic sinuses during reimplantation of the aortic valve but it is possible that it would take longer than a mean follow-up of 10 years to show the benefit of neo-aortic sinuses.<sup>7</sup> We have never used commercially available Valsalva

grafts because the sinuses are spherical and the normal aortic cusps are anchored into a cylindrical structure with bulges in between commissures. The correct shape can be accomplished by using a larger tubular Dacron graft than needed, then reducing its diameter by plicating the areas corresponding to the center of the cusps in the end of the graft corresponding to the subannular suture line, and also the intercommissural space at the sinotubular junction. Conversely, one can use the Valsalva graft described by Oechtering and colleagues,<sup>8</sup> which is cylindrical with 3 bulges similar to the normal aortic root.

A careful examination of patients who developed AI revealed that the cusps were either grossly abnormal at the time of surgery (eg, BAV) or that we made a technical error during surgery. Several technical pitfalls were described under operative technique in this article. A correctly performed aortic annuloplasty is crucial in this operation. We firmly believe that in addition of a deep dissection of the left ventricular outflow tract, a complete annuloplasty with 9 to 12 stitches correctly placed are necessary to stabilize the aortic annulus. Influenced by surgeons that suggested that 3 sutures in the nadir of the aortoventricular junction were adequate to secure the graft beneath the aortic annulus<sup>9</sup> we used this approach in a small number of patients and every single one has developed AI during the first 10 years of follow-up. Interestingly the same surgeons that proposed that technical modification of the annuloplasty have reported the development of subaortic aneurysms in patients with Loeys–Dietz syndrome.<sup>10</sup> We disagree with the notion that annuloplasty is unnecessary and annuloaortic ectasia is a “misnomer.” Two recent reports on this subject suggested that the aortic annulus does not dilate after remodeling of the aortic root and that annuloplasty is unnecessary.<sup>11,12</sup> However, in both studies the mean follow-up was too short to demonstrate postoperative dilatation of the annulus. In our patients with Marfan syndrome, it took 12 to 15 years for annular dilatation to become apparent by echocardiography.<sup>13</sup> Another important aspect of reimplantation of the aortic valve is something identified by early adopters of this technique,<sup>14</sup> that it, the aortic cusps must coapt inside the Dacron graft, as illustrated in [Figure 8](#). This is due to incorrect annuloplasty, the use of small graft, and lack of correction of cusp prolapse, all preventable technical errors.

After a surgeon has mastered the operative technique, the outcomes will be dependent on the quality of the aortic cusps. Pliable, elastic cusps with minor elongation of the free margins are ideal for this operation. Cusp repair by plication of the free margin or repair with fine expanded polytetrafluoroethylene sutures do not seem to have adverse effects on the durability of this operation and certainly

expand its indication.<sup>7</sup> Thickened, shortened, sclerotic, inelastic, overstretched, and calcified cusps should not be preserved.

In summary, reimplantation of the aortic valve is an excellent option to treat patients with aortic root aneurysms and annuloaortic ectasia. When correctly performed, the aortic valve functions satisfactorily for decades.

### Conflict of Interest Statement

The author reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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**Key Words:** aortic valve, aortic insufficiency, aortic valve repair, David operation, aortic root aneurysm