A new aortic Dacron conduit for surgical treatment of aortic root pathology

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Key words:
Aortic valve; Aorta; Aortic dissection; Aortic aneurysm; Aortic regurgitation; Aortic valve replacement.

Background. **This article describes a new aortic Dacron conduit that has been designed for use in all types of surgery of the aortic root. Its use is aimed at facilitating the surgical procedure and obtaining a natural anatomical configuration of the aortic root.**

Methods. **The modified Dacron conduit is obtained by adding a smaller piece of Dacron tube that is resilient in the horizontal plane to one end of a standard Dacron conduit. Upon implantation, this small piece of Dacron conduit will stretch in the horizontal plane creating pseudosinuses and a new sinotubular junction. This modified conduit has been used in 4 cases for a Bentall operation in association with a mechanical or a biological valve, in 4 cases in a Yacoub type of valve sparing procedure and in 1 case in a David type I of valve sparing procedure. All patients had aortic root aneurysm with severe aortic regurgitation. There were 6 males and 3 females with a mean age of 61 ± 16 years. In most cases a 28 mm Dacron conduit was used.**

Results. **All surgery was carried out without mortality or morbidity. The creation of pseudosinuses was confirmed intraoperatively by visual inspection. Transesophageal echocardiography in patients who had undergone the Bentall operation showed a normally functioning valve prosthesis with a suitably shaped aortic root. In patients who had undergone the valve sparing procedures it showed a competent aortic valve, the creation of pseudosinuses of normal shape and depth, and the presence of a well defined sinotubular junction. Angiography confirmed that the prosthetic aortic root perfectly resembled the normal root anatomy.**

Conclusions. **This modified new aortic root conduit appears to perfectly reproduce a normal root anatomy without the need of modifying the original techniques.**

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Introduction

The standard surgical approach in patients with ascending aortic aneurysm or dissection involving the aortic root and associated with aortic valve disease is the replacement of the aortic valve and ascending aorta by means of a composite valved graft onto which are reattached the two coronary arteries as originally described by Bentall and DeBono in their classical paper[1]. The "open" (Carrel button) method of coronary reimplantation was later recommended to decrease the tension on the coronary ostia while minimizing the risk of late false aneurysm formation. A modification of the standard technique was also introduced by Cabrol et al.[2] for those cases of difficult anatomical presentation (low lying coronary ostia, calcified coronary ostia, tissue fibrosis in redo cases) where the coronary ostia are reattached to the aortic conduit by interposition of a smaller Dacron graft.

If the aortic valve leaflets are normal, a valve-sparing aortic root remodeling procedure is a reasonable alternative in certain individuals. David and Feindel[3] described a surgical technique where the dilated aortic root is replaced with a Dacron graft and the native aortic valve is integrated within the graft. However, the lack of sinuses in a straight tube graft was found to negatively influence proper valve function, with the consequent risk of decreasing valve longevity[4]. Further refinement of the technique consisted in trimming one end of the aortic tube graft to produce three separate extensions designed to replace the three sinuses. The reshaped Dacron tube was then sutured to the aortic valve remnants[5] to obtain a final configuration resembling the native aortic root more closely. This latter technique is virtually identical to that described by Sarsam and Yacoub[6] several years ago.

This article describes a new Dacron graft that has been designed to potentially fit all types of surgical procedures that are currently performed to treat pathology of the aortic root. This modification was aimed at facilitating the surgical procedure and obtaining an anatomical configuration that could resemble the natural aortic root more closely with consequent functional benefits.

Methods

A standard Dacron aortic conduit is horizontally corrugated in order to have a certain degree of compliance or adaptability in the longitudinal direction. The tube can be stretched to significantly increase its length (Fig. 1). The modified aortic conduit was conceived and designed by one of us (RDP) and manufactured by Sulzer Vascutek (Sulzer Vascutek, Renfrewshire, Scotland). It consists of suturing a smaller piece of the same Dacron tube that has corrugations in the longitudinal direction to one end of the graft (i.e. at 90° with respect to the rest of the tube). This smaller piece of Dacron tube, referred as a "skirt", has a compliance or adaptability in the horizontal plane (Fig. 2), while the rest of the graft keeps its compliance in the longitudinal plane. This additional piece of Dacron tube (longitudinally corrugated) is obtained from a piece of a standard Dacron tube whose length is calculated in order to obtain a compliance of the "skirt" of about 30% (Fig. 3).

The length of the "skirt" is approximately equal to the height of a natural aortic root and therefore it is long enough to be trimmed according to the patient's anatomy. Since the height of the aortic root is approximately equal to 60% of its base[4], a "skirt" with a length equal to the diameter of the Dacron graft was selected.

This modified Dacron tube has been designed for use in all types of aortic valve sparing operations without tangible modifications of the original surgical techniques. When an aortic valve prosthesis is attached to the end of the "skirt" a modified composite valved graft to be used in the Bentall types of operation (Fig. 4) is obtained.

With this small modification (either in the valved or non-valved version) the prosthetic graft conduit is thought to resemble the natural aortic root more closely. The connection between the two sections of Dacron (with their corrugation oriented at a 90° angle) will act as a natural "sinotubular junction" since there will be a natural narrowing of the aortic diameter compared to its lower section. Since the tissue in the "skirted" section of the graft is resilient, under the pressure of blood, it will stretch in the horizontal plane resembling the sinuses of Valsalva.

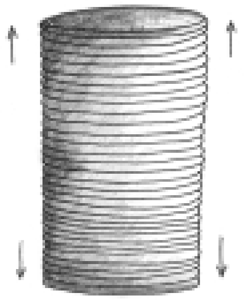


Figure 1. *A standard Dacron aortic conduit is horizontally corrugated. It has a significant compliance in the longitudinal direction but none in the horizontal plane.*

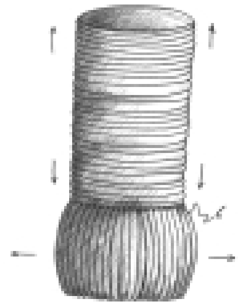


Figure 2. *The modified Dacron aortic conduit has a small portion longitudinally corrugated that allows a certain degree of compliance in the horizontal plane. While the lower part of the graft ("skirt") has a compliance in the horizontal plane, the rest of the graft keeps its compliance in the longitudinal plane. The length of the skirt is approximately equal to the diameter of the Dacron conduit considered (see text).*

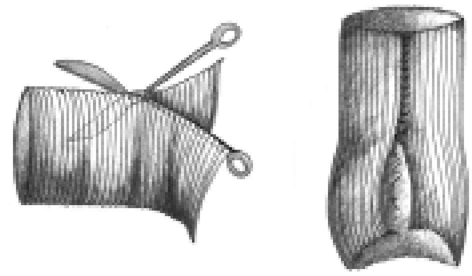


Figure 3. *Method of manufacturing: a portion of a standard Dacron aortic conduit with a length approximately equal to its circumference is cut open longitudinally and resutured laterally to obtain a longitudinally corrugated conduit. Next, a portion of the longitudinally corrugated conduit ("skirt") can be sutured to the standard Dacron conduit to obtain the modified aortic conduit as in figure 2.*

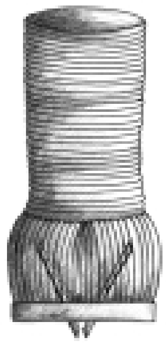


Figure 4. *The modified Dacron aortic conduit in its valved version. The valve prosthesis is attached to the end of the "skirt" in a standard fashion.*

Application of the modified aortic root conduit to the various surgical techniques. *Composite valve graft replacement (Bentall operation).* The use of the Dacron aortic conduit modified as in figure 4 does not require any changes in the standard surgical technique. After the valve has been sutured to the aortic annulus, the coronary ostia are reattached to the graft by using either the classical technique or the "open" technique (Carrel button) at the surgeon's discretion. The presence of the portion of graft longitudinally corrugated (skirt) has several advantages over a standard Dacron graft tube. The Dacron being more resilient in its proximal part, a reduced tension on the coronary ostia anastomoses will be present not only during suturing but, more importantly, after the graft has been pressurized at the end of surgery. As a consequence, the modified aortic conduit results particularly advantageous in cases where the coronary ostia are difficult to mobilize, difficult to reach (low lying coronary ostia) or when they are severely calcified. Furthermore, at the end of the procedure, any undue tension along the long axis of the graft, instead of being directly transmitted to the coronary anastomoses, will be dampened by the suture connecting the two sections of Dacron as the lower portion of the graft (the new aortic root) is pulled as a whole (Fig. 5).

Valve sparing operation. • Tirone David type I procedure. The operation is carried out as originally described by the authors[3] using the Dacron aortic conduit modified as in figure 2. Briefly, the three sinuses of Valsalva are excised leaving 5 mm of arterial wall attached to the aortic valve and around the two coronary ostia, and multiple horizontal mattress sutures are passed below the aortic valve and then through the end of the modified Dacron graft. The graft is tailored so that the top of the three commissures will correspond to the "new sinotubular junction" (i.e. the junction between the two portions of Dacron) or a few millimeters above. The graft is then cut 2 to 3 cm above the commissures that are then properly spaced and secured to the Dacron graft with pledget-supported 4/0 sutures. Next, the valve is secured to the graft in a manner similar to that for implanting a free-hand, subcoronary homograft aortic valve. Finally, the coronary ostia are reimplanted onto the graft.

Once the tube is pressurized at the end of the surgical procedure, the lower part of the tube (longitudinally corrugated) will expand circumferentially creating new sinuses of Valsalva. The three commissures, being fixed to the portion of tube that does not expand circumferentially, will maintain their correct spacing and orientation (Fig. 6). The presence of a new sinotubular junction and of artificial sinuses of Valsalva will ensure the creation of eddy currents with a more physiological opening and closure of the valve leaflets.

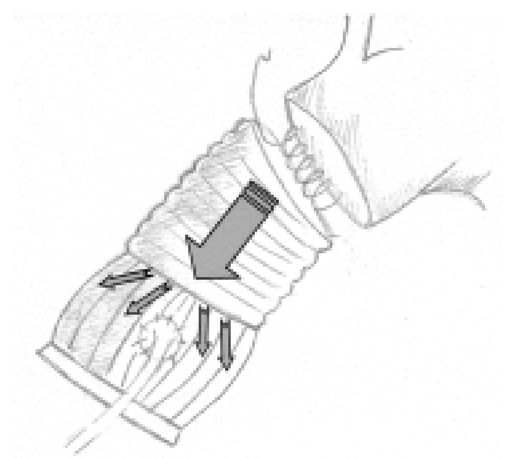


Figure 5. *Once the conduit is stretched to perform the aortic distal anastomosis, the traction is not transferred longitudinally toward the right coronary anastomosis, as with a standard Dacron conduit, but it is dampened at the level of the new sinotubular junction. The new aortic root appears to be pulled as a whole.*

Figure 6. *Completed placement of the modified Dacron aortic conduit after the T. David type I aortic valve sparing procedure. The top of the commissures is fixed at the level of the "new sinotubular junction" where the maintenance of their correct spacing and orientation is assured. When the modified Dacron conduit is pressurized the longitudinally corrugated portion ("skirt") will expand circumferentially with creation of pseudo-sinuses.*

• Yacoub or Tirone David type II procedure. Similarly, for the application of this surgical technique, the operation is carried out as originally described by the authors[6] using the Dacron aortic conduit modified as in figure 2. Briefly, the diseased aortic sinuses are excised down to the aortic annulus and an appropriately sized modified Dacron tube is chosen. The modified end of the Dacron tube is trimmed to produce three separate extensions, properly spaced, that will replace the sinuses. The height of the grooves is made so as to reach the "new sinotubular junction" or a few millimeters above. Next, the top of the three commissures is fixed to the apex of each groove in a proper orientation. The excess of Dacron is trimmed to precisely fit each sinus once it is sutured to the aortic annulus. Establishing the right length of the three extension is facilitated because this portion of Dacron ("skirt") does not stretch in the longitudinal direction. Finally, each extension is sutured to the remnants of arterial wall and aortic annulus surrounding the sinuses and then the coronary ostia are reimplanted onto the graft.

Compared to the standard Dacron graft tube, the use of the modified conduit offers the potential for a reduced tension on the coronary ostia anastomoses, and an optimized circumferential expansion of the three sinuses with better stress sharing between the leaflet and the artificial sinus wall. The sinotubular junction is well defined and the maintenance of a good leaflet coaptation is assured by fixation of the top of each commissure to the portion of graft that does not expand circumferentially.

Patients. Between February 2000 and May 2000 the modified conduit was used as a valved conduit in association with a mechanical (2 cases) or a biological valve (2 cases), in 4 cases it was used in the Yacoub type of valve sparing procedure and in 1 case it was used in the David type I of valve sparing procedure. Patient characteristics are shown in table I. All patients had aortic root aneurysm (> 5 cm) or pseudoaneurysm (1 case) with severe aortic regurgitation. The 4 patients who underwent the Bentall operation had either a bicuspid diseased valve or a massive valve prolapse or a tear in one leaflet (2 patients had previously been operated for acute dissecting aneurysm). They received a 23 mm CarboMedics valve prosthesis (Sulzer CarboMedics Inc., Austin, TX, USA), a 23 mm St. Jude valve prosthesis (St. Jude Medical Inc., St. Paul, MN, USA), a 25 mm Hancock II bioprosthesis (Medtronic, Minneapolis, MN, USA) and a 25 mm Carpentier-Edwards Perimount pericardial valve (Baxter, Irvine, CA, USA). The other 5 patients had an anatomically normal aortic valve and were selected for a valve sparing procedure.

Results

Our first preliminary results with this new type of aortic conduit have been excellent with no mortality and no morbidity. At 1-month follow-up all patients were in good clinical condition and rapidly recovering from the operation. The creation of a new aortic root was confirmed intraoperatively by visual inspection in all cases. All patients underwent transesophageal echocardiography immediately after the operation and transthoracic echocardiography before discharge and at first follow-up. Four days after the operation they were also evaluated with subtraction digital angiography. Echocardiography of the patients who had undergone a Bentall procedure showed a normally functioning valve prosthesis with a suitably shaped aortic root. The contour of the aortic root was better evaluated with angiography that confirmed the difference in diameter between the prosthetic aortic root and the prosthetic ascending aorta (Fig. 7). The angiographic aspect of the prosthetic aortic root appeared also to suggest a reduced tension on the coronary ostia that was also evident at the time of implantation. Transesophageal echocardiography of the patients who had undergone the Yacoub and the David I procedures showed no or trivial (2 cases) aortic regurgitation while it showed a perfectly shaped aortic root with pseudosinuses very similar to those of a normal aortic root (Fig. 8). A short-axis view of the aortic valve in its fully open position showed a space behind the leaflet sufficient to avoid any systolic contact of the leaflet with the aortic wall (Fig. 9). By using this new conduit and without any change in the original technique it has been possible to recreate a perfect anatomy with normal appearing pseudosinuses and a well defined sinotubular junction (Fig. 10). The echocardiographic aspect of this new conduit has been compared with that obtained after a Yacoub procedure using a standard Dacron tube. Although with a standard Dacron tube it was also possible to create pseudosinuses, the difference in the shape and depth of the pseudosinuses is strikingly evident (Fig. 11). Finally, the normal looking aspect of the aortic root was further confirmed by angiography (Fig. 12).

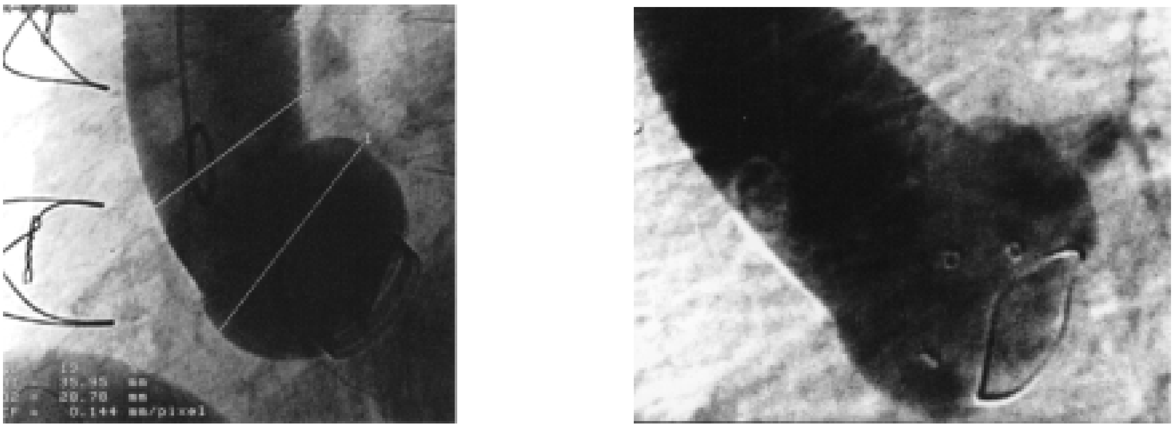
Discussion

The normal human aortic root has a consistent shape. Kunzelman et al.[4] measured the dimensions of non-pressurized human aortic roots at different levels and found that the diameters and orifice areas of the root are greatest at the level of the sinuses, they decrease slightly at the base attachment of the root and decrease by 20% at the level of the sinotubular junction. These differences are likely to increase once the root is under pressure.

The sinotubular junction or sinus ridge and the sinuses of Valsalva are crucial for the normal function of the aortic valve. Bellhouse[7,8] demonstrated the impor-

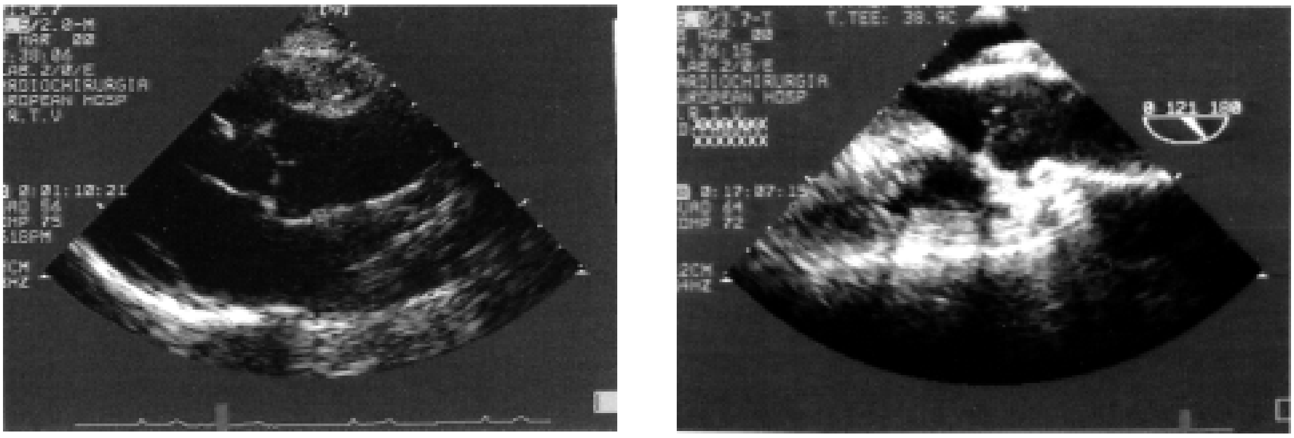
Table I. Clinical and operative data.

Patient	Age (years)	Sex	Marfan	Dissection	Reoperation	CPB time (min)	Ischemic time (min)	Type of operation	Diameter of modified Dacron conduit
1	58	F	-	-	-	105	71	Bentall	28
2	23	M	+	-	-	130	107	Yacoub	28
3	70	M	-	+	+	115	94	Bentall	30
4	53	F	-	-	-	130	100	Yacoub	28
5	59	M	-	+	+	125	100	Bentall	28
6	70	M	-	-	-	148	125	David	30
7	67	M	-	-	-	122	99	Yacoub	30
8	78	F	-	-	-	126	97	Yacoub	28
9	69	M	+/-	-	-	105	78	Bentall	28



A B

Figure 7. *Angiographic results of a Bentall procedure using the modified Dacron conduit along with a CarboMedics mechanical valve* (A) *and with an Hancock bioprosthesis* (B). *Note the near normal proportion between the aortic root and the new sinotubular junction. A reduced tension on the coronary anastomosis is likely to be present.*



A B

Figure 8. *Transesophageal echocardiographic view of an aortic root of a normal subject* (A) *and that of a patient after a Yacoub type of valve sparing procedure with the modified Dacron conduit* (B).

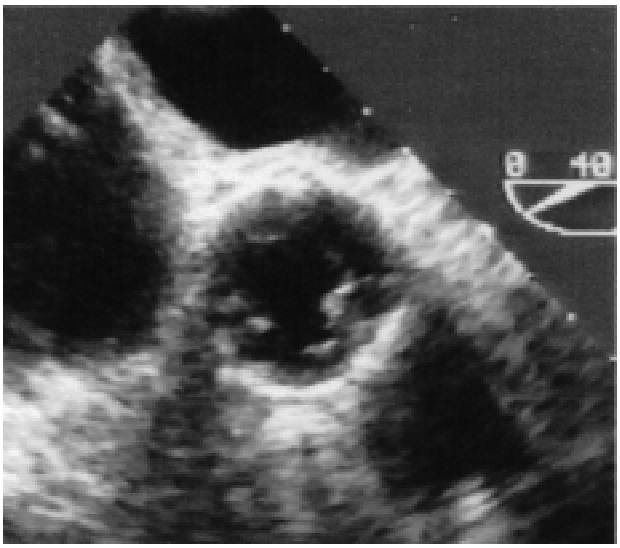
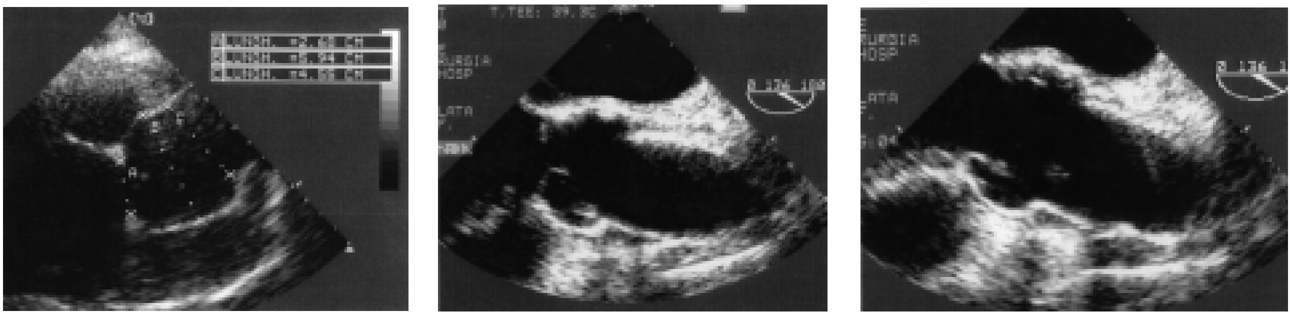


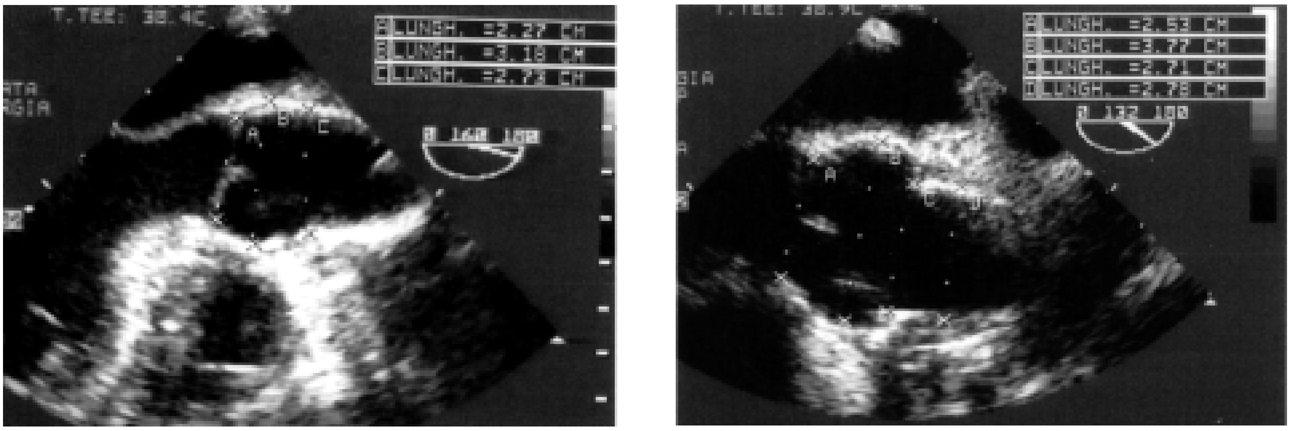
Figure 9. *Short-axis view of the aortic valve in its fully open position in a patient after a David I type of valve sparing procedure with the modified Dacron conduit. Note the clearance between the leaflet and the prosthetic aortic wall.*

tance of the sinotubular junction in causing initial fluid flow eddies inside the sinuses of Valsalva. These eddy currents that form already at the beginning of systole prevent the leaflets from impacting on the aortic wall. Furthermore, because of the presence of eddy currents inside the sinuses, the leaflets are almost closed toward the end of the systole. In this way valve closure is smooth and the diastolic stress on the leaflets is minimized. Thubrikar et al.[9] have also demonstrated how the presence of the sinus curvature is crucial in sharing the stress with the leaflet. They showed that during diastole the sinus adapts its geometry by changing the width of its circumferential curvature. Conversely, they noted that the longitudinal curvature of the sinus changed very little or did not change at all during the cardiac cycle. It appeared that the sinus moves up and down as a whole along the long axis of the aorta without changing its internal dimension. The modification of a standard Dacron conduit as described in this article appears to respect all these anatomical proportions



A B C

Figure 10. *Echocardiograms showing preoperative dilated aortic root and sinotubular junction* (A) *and postoperative aortic root after a Yacoub type of valve sparing procedure with the modified Dacron conduit during diastole* (B) *and during systole* (C). *Note the normal shape and proportion of the reconstituted aortic sinuses. A = measures taken at the annulus; B = measures taken at the pseudosinuses; C = measures taken at the sinotubular junction.*



A B

Figure 11. *Echocardiographic comparison of 2 patients who had undergone a Yacoub type of valve sparing procedure using a standard Dacron conduit* (A) *and the modified Dacron conduit* (B). *A good leaflet coaptation and valve competence is present in both cases. Although pseudosinuses are also created by using a standard Dacron conduit, the modified conduit allowed the reconstitution of a more normal anatomy of the aortic sinuses and sinotubular junction. A = measures taken at the annulus; B = measures taken at the pseudosinuses; C = measures taken at the sinotubular junction; D = measures taken at the ascending aorta.*

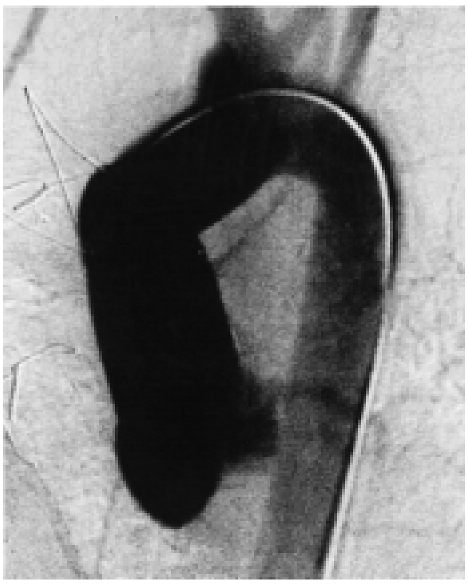


Figure 12. *Angiography of a patient after a Yacoub type of valve sparing procedure with the modified conduit showing a perfectly reconstituted root anatomy.*

as well as all theoretic physiological principles by allowing a near normal reconstitution of the aortic root with well defined pseudosinuses and a new sinotubular junction.

The major advantages of the modified conduit in its valved version is mainly technical since the anatomical and physiologic advantages of having artificial sinuses of Valsalva are unnecessary in the presence of a prosthetic valve. However, having a portion of the Dacron graft that is resilient in the horizontal plane facilitates surgery, especially in the more technically demanding cases where the coronary ostia are difficult to reach. Furthermore, once this portion of Dacron is filled with blood, it will adapt better to the anatomy and position of the coronary ostia, reducing the tension on the anastomotic sutures with consequent less postoperative bleeding and reduced incidence of pseudoaneurysm formation. Noteworthy, the introduction of the "open" technique (Carrel buttons) of coronary anastomoses has already greatly reduced the incidence of pseudoaneurysm formation mainly through the reduction of the tension on the ostial anastomoses[10]. It is therefore reasonable to expect that this simple conduit modification will produce a further reduction in the incidence of pseudoaneurysm formation. Finally, using a composite conduit modified as in figure 4 could be an alternative to the Cabrol technique or other forms of interposition graft that are currently preferred for patients who undergo reoperation or complicated repairs when tension on the ostial anastomoses may occur.

Conversely, the use of the modified Dacron aortic conduit for all types of aortic valve sparing procedures is indicated not only to facilitate the surgical technique but, more considerably, to recreate the anatomical and physiologic conditions of the natural aortic root. These very preliminary cases have clearly demonstrated that with this modified conduit it is possible to create an anatomical configuration similar to the natural aortic root with consequent benefits in the functioning and longevity of the aortic valve. Although the result of the Yacoub procedure using a standard Dacron graft can also be satisfactory, it is evident from our echocardiographic comparison (Fig. 11) that the use of the modified conduit guarantees a greater reproducibility of a natural aortic root. It is also possible that the use of this conduit could help in standardizing this particular technique by making it less dependent on the surgeon's technical skill of appropriately tailoring the conduit.

At present we have only one case report with the use of this modified conduit in a David type I of valve sparing procedure. However, our results suggest that it is possible to obtain the same anatomical reconstitution of the aortic root also by using this surgical technique. As a matter of fact, the David I technique is expected to benefit most from the use of this modified conduit. It has been clearly demonstrated that the use of a straight tube without a sinus component is responsible for an improper opening and closure of the native valve[4]. On valve opening the leaflets might have an impact on the graft and be potentially damaged. The simple use of the modified aortic conduit, without the need of modifying the surgical technique, creates pseudosinuses and a sinotubular junction completely avoiding the drawback of the David I operation using a standard Dacron conduit (Fig. 9). Thus, by using this conduit, the David procedure could even be preferred over the Yacoub technique given its known advantages in terms of better support of the aortic wall, routine annular stabilization and lesser risk of suture bleeding[11]. Long-term follow-up in a larger number of patients is now warranted.

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