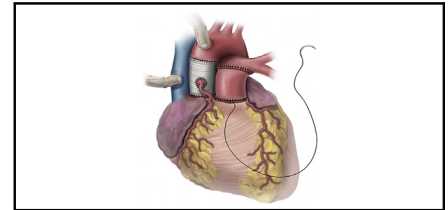


The Ross procedure utilizing the pulmonary autograft inclusion technique in adults



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▶ Video clip is available online.



Completed Ross procedure with left ventricular outflow reconstructed with the pulmonary autograft encased in a woven polyethylene terephthalate (Dacron) conduit and right ventricular outflow tract reconstruction with a pulmonary homograft.

CENTRAL MESSAGE

The pulmonary autograft inclusion technique allows the Ross procedure to be applied to a wider spectrum of patients.

See Commentaries on pages 377, 379, and 381.

The Ross procedure's role in adults in need of aortic valve or aortic root replacement has been unclear and sometimes controversial, particularly as it relates to age and valve morphology.^{1,2} A recent series demonstrated that despite different preoperative profiles, the Ross procedure offered similar benefits in patients older than age 50 years compared with those younger than age 50 years, with excellent hemodynamic parameters, survival, and a low risk of reintervention.^{3,4} Also, our group recently demonstrated favorable outcomes in a pure bicuspid valve population.⁵

EVOLUTION OF THE ROSS PROCEDURE

Since the original description of the Ross procedure by Donald Ross in 1967, the procedure has undergone several modifications, motivated by undesirable reintervention rates due to progressive dilatation of the aorta, aortic root, or autograft.^{6,7} In fact, late autograft failure and secondary valve incompetence became the Achilles' heel of the Ross procedure.^{8,9}

Donald Ross originally described the Ross procedure as a subcoronary technique, implanting the pulmonary autograft inside the aortic root.¹⁰ Due to this technique's complexity, a modification was introduced where a full pulmonary root (the main pulmonary artery with its valve) was utilized as a conduit to replace the proximal ascending aorta,

reimplanting the coronary ostia into the pulmonary trunk.¹¹ Although this improved the reproducibility of the root replacement technique, autograft dilatation remained a concern.⁷ The majority of surgeons performing the Ross procedure in the current era use the full root replacement technique with various modifications for pulmonary autograft support.¹²

Our surgical approach to the Ross procedure in adults has also evolved. In our initial experience, we used the unsupported autograft root replacement technique.¹³ In 2001, we adopted the pulmonary autograft inclusion technique in which the pulmonary autograft is reinforced within a woven polyethylene terephthalate (Dacron) conduit (Hemashield Platinum Double Velour Graft, Getinge AB, Gothenburg, Sweden), sized to the aortic annulus and pulmonary autograft (Video 1). The rationale is to provide external support for the pulmonary autograft, stabilize the aortic root, and prevent progressive dilatation, and autograft failure over time. This technique renders the Ross procedure as durable, reproducible, and teachable as a standard root replacement or David procedure. Moreover, this technique facilitates concomitant replacement of ascending aortic aneurysms, often present with bicuspid aortic valve disease. We routinely use the pulmonary autograft inclusion

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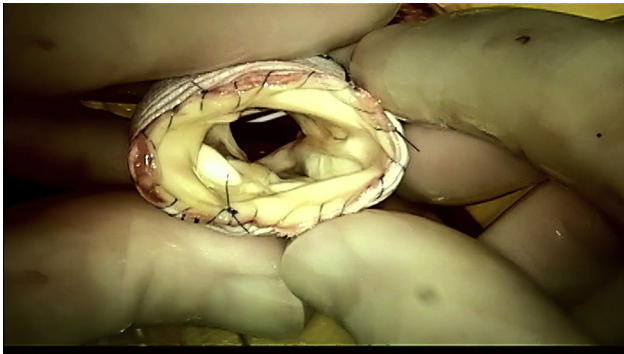
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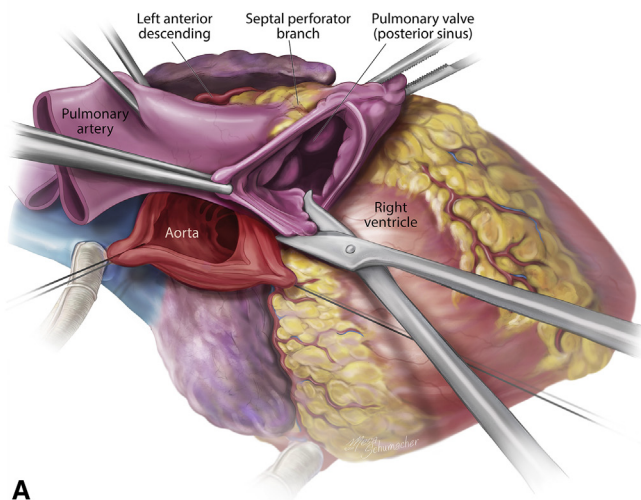
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VIDEO 1. The Ross procedure utilizing the pulmonary autograft inclusion technique in a 29-year-old male patient with critical bicuspid aortic valve stenosis and a 6 cm ascending aortic aneurysm at the level of the sinus of Valsalva. The pulmonary autograft was inserted in a 28-mm polyethylene terephthalate tube graft and another 26-mm polyethylene terephthalate tube graft was placed distally to create a sinotubular junction. Written informed consent was obtained from the patient from which this video was created. Video available at: [https://www.jtcvs.org/article/S2666-2507\(21\)00386-2/fulltext](https://www.jtcvs.org/article/S2666-2507(21)00386-2/fulltext).

technique when the autograft is sufficiently large to accommodate adult cardiac output (19 mm in size).⁵ This repair is versatile because it can be applied to patients with aortic stenosis and insufficiency. Most importantly, this repair technique stabilizes the aortic root creating a durable repair with low autograft failure rates.

1. EXCISION OF PULMONARY VALVE



A

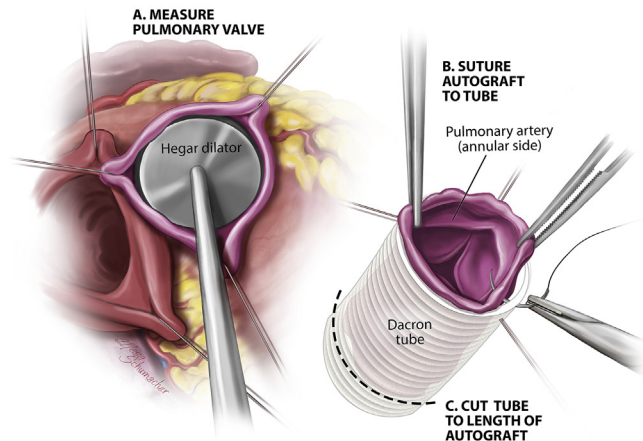
PATIENT SELECTION

Those who stand to benefit the most from the Ross procedure include patients with an active lifestyle, athletes, women of childbearing age, those with aortic valve endocarditis, and patients in whom anticoagulation therapy is contraindicated. Although many centers have utilized stringent criteria for patient selection, our approach for the Ross procedure using the pulmonary autograft inclusion technique has been broader and inclusive. For instance, we have never excluded patients with bicuspid aortic valves or those with concomitant ascending aortic aneurysms.^{14,15} In general, we offer this procedure to younger (ie, younger than age 50 years) adult patients requiring aortic valve or aortic root replacement who wish to avoid anticoagulation therapy, without regard to valve morphology (bicuspid or tricuspid), valve pathophysiology (stenosis or insufficiency), dilated annulus, or the presence or absence of ascending aortic aneurysm pathology. Our exclusions to the Ross procedure have traditionally been to those with abnormal pulmonary valves, immune complex-mediated diseases with known valvular sequelae, or complex connective tissue disorders. These exclusions have not changed since we started using the pulmonary autograft inclusion technique.⁵

SURGICAL TECHNIQUE

This technique is performed through a median sternotomy. Cardiopulmonary bypass with moderate systemic

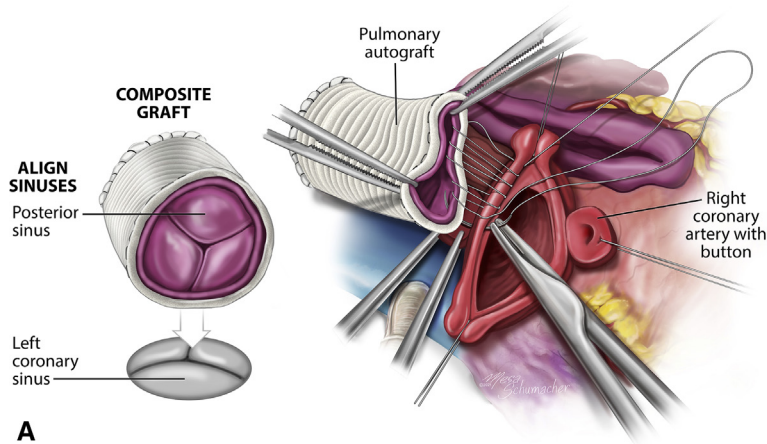
2. COMPOSITE GRAFT



B

FIGURE 1. A, Excision of the pulmonary autograft. After cardioplegic arrest is established, the aorta is transected above the sinotubular junction, aortic valve excised, aortic annulus debrided, and coronary artery buttons are developed. The pulmonary trunk is divided, followed by separation of the pulmonary valve from the right ventricular outflow tract. The key incision begins 1.5 cm below the infundibular area, ensuring a circumferential 3- to 4-mm rim of musculature below the pulmonary valve. It is critical to protect the left main, left anterior descending, and first and second septal perforator coronary arteries during this dissection because they are very close to the pulmonary artery's root. B, Following the pulmonary autograft excision, a Hegar dilator is used to determine the size of both the autograft and aortic annulus. A polyethylene terephthalate graft 2 to 4 mm larger than the pulmonary autograft is chosen to mitigate potential narrowing and distortion of the pulmonary autograft. The pulmonary autograft is placed in the polyethylene terephthalate tube and secured first at the pulmonary root using a running horizontal mattress suture. The polyethylene terephthalate tube is cut to the pulmonary autograft length, and the distal end of the pulmonary autograft is sutured to the polyethylene terephthalate tube with a running polypropylene suture.

3. GRAFT ATTACHED TO AORTIC ANNULUS



4. CORONARY BUTTONS

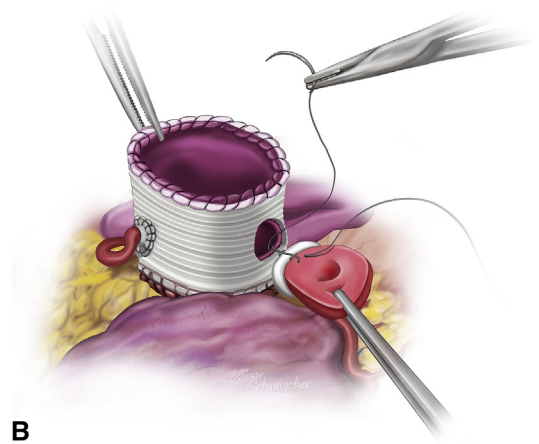


FIGURE 2. A, After creating the composite pulmonary autograft and polyethylene terephthalate graft, the pulmonary autograft root is secured to the aortic annulus with a 3-0 polypropylene suture. B, Coronary buttons reimplantation in both the autograft and polyethylene terephthalate graft.

hypothermia is initiated with bicaval cannulation and aortic cannulation near the innominate artery or in the proximal aortic arch. The aorta is then crossclamped, followed by cardioplegic arrest. Cardioplegic agents can be administered via an antegrade ascending aortic needle in the absence of significant aortic regurgitation or directly into the coronary ostia with handheld cannulas following aortic transection in the presence of aortic regurgitation. With the

heart arrested, the aortopulmonary window is completed separated. The aorta is divided just above the sinotubular junction, the aortic valve leaflets are excised, and the annulus is debrided and measured to determine its size.¹⁶

Coronary artery buttons are created, followed by dissection between the pulmonary valve and aortic root. The pulmonary trunk is divided and removed en bloc from the right ventricular outflow tract with the pulmonary valve. Separation of the pulmonary valve from the right ventricular outflow tract begins with an incision in the infundibular area, 1.5 cm below the pulmonary valve (Figure 1, A). There should be a 3- to 4-mm rim of musculature kept on the pulmonary autograft to assist with implantation into the left ventricular outflow tract. This incision is continued in a curvilinear fashion made the same distance from the valve throughout, so it is symmetrical circumferentially. The incisional plane is above the first septal perforator, typically located adjacent to the first diagonal artery branching off the left anterior descending artery. Troublesome venous plexuses frequently exist posterior to the pulmonary valve as well, making hemostasis important in this area.

Once the autograft is excised, it is important to select the correct size polyethylene terephthalate graft, which is sized using a Hegar dilator based on the pulmonary autograft and aortic annular dimensions. A graft 2 to 4 mm larger than the pulmonary autograft is chosen (Figure 1, B). Upsizing the graft mitigates potential narrowing and distortion of the pulmonary autograft. In the presence of ascending aortic aneurysm disease, we often sew a smaller polyethylene terephthalate graft to the supported pulmonary autograft to form a sinotubular junction and facilitate the anastomosis to the distal aorta. The autograft is attached to the polyethylene terephthalate graft at the annular level with a running 4-0 polypropylene horizontal mattress suture to evert the muscle skirt. This facilitates the proximal anastomosis,

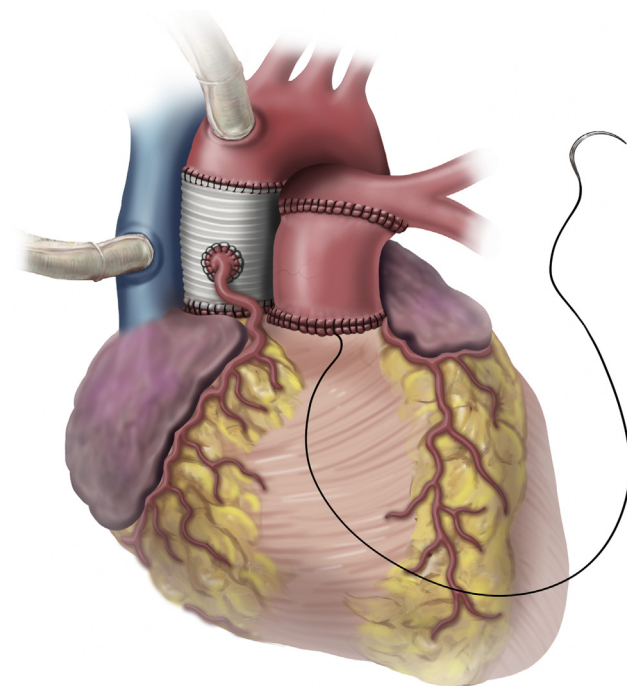


FIGURE 3. Completed Ross procedure with left ventricular outflow reconstructed with the pulmonary autograft encased in a woven polyethylene terephthalate conduit and right ventricular outflow tract reconstruction with a pulmonary homograft.

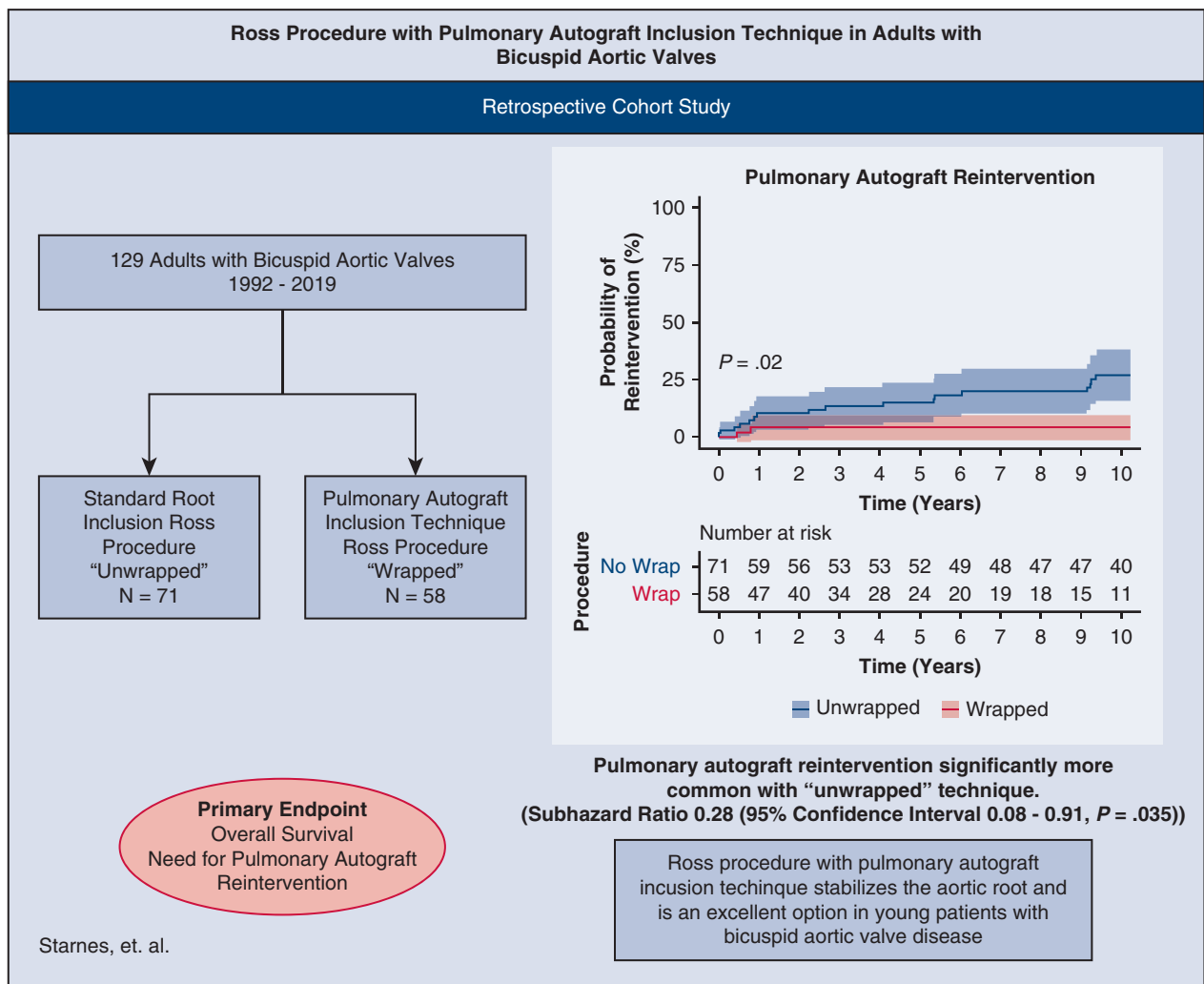


FIGURE 4. A retrospective cohort study was conducted in which 129 adult patients with bicuspid aortic valves underwent the Ross procedure with either a standard root inclusion technique or a modified technique whereby the pulmonary autograft is wrapped in a vascular conduit. Primary outcomes were survival and the need for pulmonary autograft reintervention. Competing risk analysis demonstrated the wrapped technique reduced pulmonary autograft reintervention. Reprinted with permission from Elsevier.

ensuring that both polyethylene terephthalate graft and the muscle skirt are included in each stitch. At the distal end of the autograft, we place stitches initially at each of the commissures to make it symmetrical; then, we use a running 4-0 polypropylene suture to secure the distal end. We then anastomose this composite graft to the aortic annulus with a 3-0 polypropylene suture taken through the graft and muscle skirt, completing the left ventricular outflow tract reconstruction (Figure 2, A). These must be placed symmetrically with proper spacing. The valve is then tested for competence. This is followed by reimplantation of the coronary buttons in both the autograft and the polyethylene terephthalate graft, followed by the distal anastomosis. (Figure 2, B). Because the noncoronary sinus remains unsupported by the coronary buttons, we typically place a piece of autologous aortic tissue inside the autograft to prevent hematoma formation between the autograft wall

and the polyethylene terephthalate graft. A pulmonary homograft is then used to reconstruct the right ventricular outflow tract, being careful not to choose one that is undersized (Figure 3).

DISCUSSION

We recently examined surgical outcomes of the Ross procedure in adults with bicuspid aortic valves (Figure 4).⁵ Over 30 years, we operated on 129 adult patients; 71 underwent an unsupported Ross procedure (unwrapped), and 58 underwent the pulmonary autograft inclusion operation (wrapped). Median follow-up was 10.3 years. Pre- and intraoperative characteristics as well as 30-day morbidity or mortality did not differ between cohorts. Survival at 1, 5, and 10 years, respectively, was 97.2%, 97.2%, and 95.6% in the unwrapped cohort and 100%, 100%, and 100% in the wrapped cohort ($P = .15$). Autograft failure

occurred in 25 (35.2%) of the unwrapped and 3 (5.2%) of the wrapped patients. Competing risk analysis demonstrated the wrapped cohort to have a lower need for autograft reintervention (subhazard ratio, 0.28; 95% confidence interval, 0.08-0.91; $P = .035$). The cumulative incidence of autograft reintervention with death as a competing outcome at 1, 5, and 10 years, respectively, was 10.2%, 14.9%, and 26.8% in the unwrapped cohort and 4.0%, 4.0%, and 4.0% in the wrapped cohort. The Ross procedure performed utilizing the pulmonary autograft inclusion technique described in this article provides excellent and reproducible results in carefully selected patients.

Conflict of Interest Statement

The authors 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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