

# Resequenced Ross pulmonary autograft procedure: Novel approach with beating heart predominance to minimize cross-clamp and cardiopulmonary bypass times



John A. Farag, MD,<sup>a,b</sup> Katherine G. Verdi, MD,<sup>b</sup> Gabe Weininger, MD,<sup>b</sup> and Y. Joseph Woo, MD,<sup>b,c</sup>  
Stanford, Calif

From the Departments of <sup>a</sup>Surgery and <sup>b</sup>Cardiothoracic Surgery, Stanford University School of Medicine, Stanford, Calif; and <sup>c</sup>Department of Bioengineering, Stanford University, Stanford, Calif.

Institutional Review Board approval was not required. All patients provided informed written consent for publication.

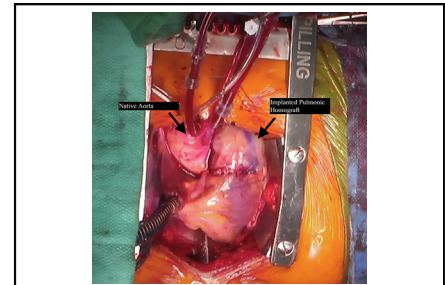
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Address for reprints: Y. Joseph Woo, MD, Department of Cardiothoracic Surgery, Falk Cardiovascular Research Center, Stanford University School of Medicine, 300 Pasteur Dr, Stanford, CA 94305 (E-mail: [Joswoo@stanford.edu](mailto:Joswoo@stanford.edu)).

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Cannulated heart weaned from CPB after the completion of pulmonic homograft implantation.

## CENTRAL MESSAGE

By altering the operative sequence of the Ross procedure and using beating heart techniques, cross-clamp and cardiopulmonary bypass times can be reduced significantly.

▶ Video clip is available online.

The Ross procedure is a technically complex operation consisting of multiple left-sided and right-sided elements with movement back and forth between them depending on anatomic exposure advantages. A typical operative sequence might entail aortic root resection, pulmonary autograft harvest, autograft implantation into aortic position, pulmonic homograft anastomosis to pulmonary artery and posterior right ventricle, aortic interposition graft anastomosis, and finally completion of the homograft anastomosis to the anterior RV.<sup>1</sup> This may be further extended with subaortic annuloplasty or autograft inclusion in a Dacron graft to prevent late autograft dilatation.<sup>2</sup> Reported cross-clamp times range from 150 to 250 minutes, and cardiopulmonary bypass (CPB) times range from 200 to 300 minutes.<sup>3,4</sup> Prolonged cross-clamp and CPB times are known to increase the risk for early morbidity and mortality due to an increased risk of right ventricular (RV) dysfunction and other issues.<sup>5</sup> We previously published a beating heart autograft harvest strategy for reducing the Ross procedure cross-clamp time.<sup>6</sup> Here we present a new operative technique and a case series of our first 5 consecutive patients in which we markedly altered the sequence of the Ross operation components to further shorten CPB time. Institutional Review Board approval

was not required. All patients provided informed written consent for publication.

## CASE SERIES

Five consecutive patients with severe aortic stenosis and no concomitant aortic regurgitation underwent our modified Ross procedure. Their median age was 51 years (range, 47-61 years), and 3 were women. Four patients had a bicuspid aortic valve. One patient underwent a concomitant maze procedure. All patients had a normal aortic annular size and no left ventricular outflow tract obstruction.

## OPERATIVE TECHNIQUE

The operative approach is demonstrated in [Video 1](#).

### Cannulation, Initial Dissection, and Pulmonic Homograft Preparation

The operation begins with a standard sternotomy with aortic and right atrial cannulation and antegrade and retrograde cardioplegia lines. Before initiation of CPB, the initial pulmonary artery and aortic root dissection is



**VIDEO 1.** Video demonstration of the operative steps for the resequenced Ross procedure. Video available at: [https://www.jtcvs.org/article/S2666-2507\(24\)00510-8/fulltext](https://www.jtcvs.org/article/S2666-2507(24)00510-8/fulltext).

performed, and the pulmonic homograft is thawed and trimmed.

### Beating Heart Autograft Explantation and Pulmonary Homograft Implantation

CPB is initiated, and the distal pulmonary arteriotomy is performed. The pulmonic valve leaflets are inspected, and the autograft is harvested from the beating heart.<sup>4</sup> The autograft is then placed in cool saline, after which hemostasis is obtained along the posterior right ventricle, usually with electrocautery and saline bipolar radiofrequency (Aquamantys). The homograft is brought to the field and with the heart still beating, the pulmonary artery anastomosis is completed using running 4-0 Prolene suture. The right ventricular anastomosis is started posteriorly with a running 3-0 Prolene suture and a strip of the excess homograft pulmonary arterial tissue for reinforcement. The right heart is deaired as the suture line is completed anteriorly, and the

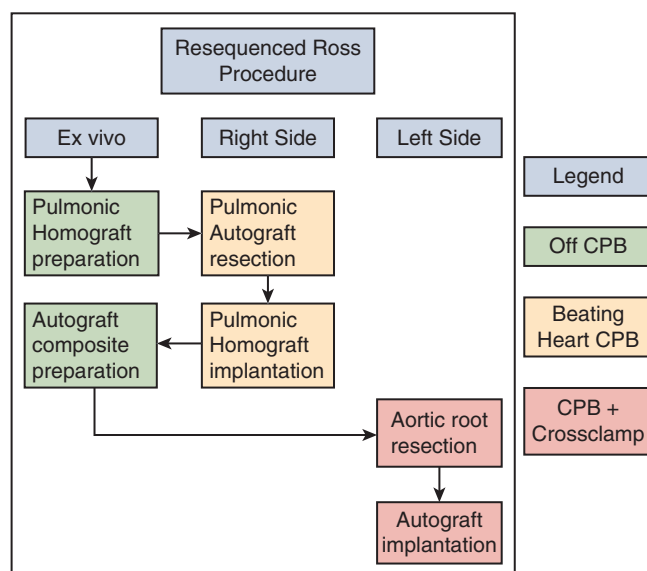
patient is weaned from CPB. Notably, the cannulas are left in place and intermittently flushed or aspirated by the perfusionist (Figure 1).

### Autograft Composite Preparation

The autograft is then prepared ex vivo by trimming excess tissue and implanting it within a Dacron straight graft with running 5-0 Prolene sutures proximally and distally. The distal portion of the Dacron graft is narrowed slightly with 3 interrupted 5-0 Prolene sutures placed at each anti-commissural location to help accommodate the usual size differential between the proximal and distal portions of the autograft.<sup>4</sup> The proximal portion of the Dacron graft now serves as an autograft annular support, and the distal portion serves as an interposition graft. Neosinuses are created by incising small circular defects in the Dacron, facilitating later positioning of the coronary ostia in the autograft. The autograft composite is placed back in cool saline

### Autograft Composite Implantation

CPB is reinitiated, the aortic cross-clamp is applied, the heart is arrested with antegrade and retrograde Del Nido cardioplegia, and the aortic root is resected using the American one-cut technique.<sup>7</sup> Then the coronary buttons are prepared, the valve leaflets are excised, and the annulus is debrided of dense calcification. Interrupted horizontal mattress 4-0 Prolene sutures are placed into the aortic annulus in a planar manner, either intra- or supra-annularly, depending on the size of the aortic annulus relative to the autograft composite. Then the sutures are placed into the autograft composite, ensuring that the needles pass through both the Dacron graft and the autograft muscle. The



**FIGURE 1.** Flow chart showing the operative steps of the resequenced Ross procedure.

left and then the right coronary buttons are reimplanted with running 5-0 Prolene suture

At this point, a pressure test is performed by placing the antegrade cardioplegia line in the distal Dacron graft and occluding the opening. This allows for evaluation of valvular insufficiency and the coronary button anastomoses. Next, the distal aortic anastomosis is completed with a running 4-0 Prolene suture, and the cross-clamp is removed.

## RESULTS

The median aortic cross-clamp time for these five operations was 72 minutes (range, 69-89 minutes), and the median CPB time was 134 minutes (range, 130-221 minutes). One patient underwent a concomitant maze procedure and left atrial appendage closure. On post-CPB transesophageal echocardiography, one patient had trace autograft valve regurgitation, and the other four patients had no regurgitation. The median postoperative autograft mean gradient was 3 mm Hg (range, 2-5 mm Hg).

Only one patient required perioperative blood transfusion. One patient with severe aortic valve annular calcification had postoperative heart block necessitating implantation of a permanent pacemaker. The median hospital length of stay was 7 days (range, 6-16 days).

## DISCUSSION

Interest in the Ross procedure has increased in recent years because of its favorable long-term survival benefits and freedom from valve-related complications compared to aortic valve replacement.<sup>8</sup> However, its complexity and prolonged ischemic times have limited widespread adoption except in specialized centers.<sup>9</sup> By reorganizing the sequence of the Ross procedure, using beating heart CPB for the pulmonary autograft harvest and homograft implantation, and ceasing CPB during autograft composite preparation, we have been able to significantly reduce both cross-clamp and CPB times.

Our approach also effectively compartmentalizes the Ross procedure into 3 distinct stages: the right-sided operation, the ex vivo autograft preparation, and the left-sided operation. Of note, this sequence would not be possible in a patient with a small aortic annulus requiring a Konno procedure. This contrasts with the traditional method, which involves multiple transitions between the left and right sides of the heart. The use of these distinct stages simplifies the process and enhances efficiency. In our four patients who underwent an isolated Ross

Procedure, we achieved an average cross-clamp time of 72 minutes and an average CPB time of 134 minutes, which are roughly one-third to one-half the times typically reported for the Ross procedure and, notably, even shorter than the Society of Thoracic Surgeons database–reported mean cross-clamp time for isolated aortic valve replacement of 78 minutes.<sup>3,4,10</sup>

The resequenced Ross procedure not only reduces ischemic and bypass times, but also allows patients to benefit from the excellent outcomes associated with the Ross procedure while potentially enabling additional procedures with less risk of morbidity and mortality. This streamlined approach has potential as a supplemental technique for experienced centers.

## 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.

## References

- David TE, Woo A, Armstrong S, Maganti M. When is the Ross operation a good option to treat aortic valve disease? *J Thorac Cardiovasc Surg.* 2010;139(1): 68-75. <https://doi.org/10.1016/j.jtcvs.2009.09.053>
- Starnes VA, Bowdish ME, Cohen RG, Baker CJ, Elsayed RS. The Ross procedure utilizing the pulmonary autograft inclusion technique in adults. *JTCVS Tech.* 2021;10:372-376. <https://doi.org/10.1016/j.xjtc.2021.05.019>
- Ryan WH, Squiers JJ, Harrington KB, et al. Long-term outcomes of the Ross procedure in adults. *Ann Cardiothorac Surg.* 2021;10(4):499-508. <https://doi.org/10.21037/acs-2021-rp-fs-28>
- Ibrahim ME, Lawrence KM, Bavaria JE, et al. Results of a multimodal approach for the launch of a Ross program. *Ann Thorac Surg Short Rep.* 2023;1(1): 210-213. <https://doi.org/10.1016/j.atssr.2022.11.015>
- Shultz B, Timek T, Davis AT, et al. Outcomes in patients undergoing complex cardiac repairs with cross-clamp times over 300 minutes. *J Cardiothorac Surg.* 2016;11(1):105. <https://doi.org/10.1186/s13019-016-0501-4>
- Zhu Y, Wang H, Woo YJ. Beating heart pulmonary autograft harvest and modified inclusion technique with anti-commissural plication for the Ross procedure. *JTCVS Tech.* 2022;17:52-55. <https://doi.org/10.1016/j.xjtc.2022.10.009>
- Zhu Y, Paulsen MJ, Woo YJ. American one-cut ascending and aortic root resection technique. *JTCVS Tech.* 2023;19:10-11. <https://doi.org/10.1016/j.xjtc.2023.03.004>
- El-Hamamsy I, Toyoda N, Itagaki S, et al. Propensity-matched comparison of the Ross procedure and prosthetic aortic valve replacement in adults. *J Am Coll Cardiol.* 2022;79(8):805-815. <https://doi.org/10.1016/j.jacc.2021.11.057>
- El-Hamamsy I, Laurin C, Williams EE. The Ross procedure in adolescence and beyond: are there still contraindications? *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu.* 2023;26:50-55. <https://doi.org/10.1053/j.pcsu.2022.12.010>
- Phan K, Tsai YC, Di Eusanio M, Yan TD. Sutureless aortic valve replacement: a systematic review and meta-analysis. *Heart Lung Circ.* 2015;24:e46. <https://doi.org/10.1016/j.hlc.2014.12.096>