

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.

We thank Dr Ismail El-Hamamsy for his extremely valuable advice on the editing of the manuscript.

References

- Ross DN. Replacement of aortic and mitral valves with a pulmonary autograft. *Lancet*. 1967;2:956-8.
- Stelzer P, Jones DJ, Elkins RC. Aortic root replacement with pulmonary autograft. *Circulation*. 1989;80:III209-13.
- Rankin JS, Hammill BG, Ferguson TB Jr, Glower DD, O'Brien SM, DeLong ER, et al. Determinants of operative mortality in valvular heart surgery. *J Thorac Cardiovasc Surg*. 2006;131:547-57.
- Reece TB, Welke KF, O'Brien S, Grau-Sepulveda MV, Grover FL, Gammie JS. Rethinking the Ross procedure in adults. *Ann Thorac Surg*. 2014;97:175-81.
- Mazine A, El-Hamamsy I, Verma S, Peterson MD, Bonow RO, Yacoub MH, et al. Ross procedure in adults for cardiologists and cardiac surgeons: JACC state-of-the-art review. *J Am Coll Cardiol*. 2018;72:2761-77.
- Buratto E, Shi WY, Wynne R, Poh CL, Larobina M, O'Keefe M, et al. Improved survival after the Ross procedure compared with mechanical aortic valve replacement. *J Am Coll Cardiol*. 2018;71:1337-44.
- Ghoneim A, Bouhout I, Losenno K, Poirier N, Cartier R, Demers P, et al. Expanding eligibility for the Ross procedure: a reasonable proposition? *Can J Cardiol*. 2018;34:759-65.
- Stelzer P. Reoperation for dilatation of the pulmonary autograft after the Ross procedure. *J Thorac Cardiovasc Surg*. 2002;124:417-8; author reply 418.
- Spindel SM, Yanagawa B, Mejia J, Levin MA, Varghese R, Stelzer PE. Intermittent upper and lower body perfusion during circulatory arrest is safe for aortic repair. *Perfusion*. 2019;34:195-202.
- Mihaljevic T, Nowicki ER, Rajeswaran J, Blackstone EH, Lagazzi L, Thomas J, et al. Survival after valve replacement for aortic stenosis: implications for decision making. *J Thorac Cardiovasc Surg*. 2008;135:1270-8; discussion 1278-9.
- El-Hamamsy I, Eryigit Z, Stevens LM, Sarang Z, George R, Clark L, et al. Long-term outcomes after autograft versus homograft aortic root replacement in adults with aortic valve disease: a randomised controlled trial. *Lancet*. 2010;376:524-31.
- Martin E, Mohammadi S, Jacques F, Kalavrouziotis D, Voisine P, Doyle D, et al. Clinical outcomes following the Ross procedure in adults: a 25-year longitudinal study. *J Am Coll Cardiol*. 2017;70:1890-9.
- Stelzer P, Varghese R. The Ross outlasts its critics and competition. *J Am Coll Cardiol*. 2017;70:1900-1.
- Stelzer P, Itagaki S, Varghese R, Chikwe J. Operative mortality and morbidity after the Ross procedure: a 26-year learning curve. *J Heart Valve Dis*. 2013;22:767-75.
- Nelson J, Maul T, Wearden P, Najm HK, Baloglu O, Johnston D, et al. Aortic valve replacement in young and middle-aged adults: current and potential roles of TAVR. *Ann Thorac Surg*. August 5, 2020 [Epub ahead of print].
- Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. *J Thorac Cardiovasc Surg*. 2007;133:1226-33.
- Yoon SH, Kim WK, Dhoble A, Milhorini Pio S, Babaliaros V, Jilaihawi H, et al; Bicuspid Aortic Valve Stenosis Transcatheter Aortic Valve Replacement Registry Investigators. Bicuspid aortic valve morphology and outcomes after transcatheter aortic valve replacement. *J Am Coll Cardiol*. 2020;76:1018-30.
- Chikwe J, Kamath A, Stelzer P. Ross procedure. *Multimed Man Cardiothorac Surg*. 2011;2011:mmcts.2009.004176.

Key Words: Ross procedure, pulmonary autograft, aortic root replacement

Discussion

Presenter: Dr Paul Stelzer



Dr Joseph S. Coselli (Houston, Tex).

Dr Stelzer, you are to be congratulated for bringing us up to date on your truly extensive experience with the Ross operation extending over 3 decades. You mentioned the STS database, and as you well know, it's not a popular operation for valve replacement in the

STS database. The Ross procedure has garnered variable enthusiasm over the years.

In your series of 702 patients, you encountered a rather notable low operative mortality rate (<1%). Although remarkable, it's not too dissimilar from a recent report by Tirone David on 212 consecutive patients undergoing the Ross operation, where he encountered only 1 death.

Recently in several publications, both you and others have shown truly excellent early results, particularly in younger patients who are undergoing this procedure for aortic valve pathology. When compared to alternative approaches for valve replacement (such as mechanical, biological with either stented or stentless valves, and homograft options) the Ross operation has a lower incidence of bleeding complications, thromboembolism, endocarditis, and, very importantly, in some series, a long-term survival rate that closely approximates the normal population.

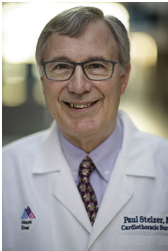
However, there is a concern that the Ross procedure turns a single-valve operation into a double-valve operation, and as a consequence, overall complexity is increased. I have a few scenarios I'd like you to comment on further. Although this presentation is primarily on the early results, I wonder if you could comment, at least somewhat, on your long-term survival and reoperation.

For instance, as you well know, the Achilles heel of this operation is not only its increased complexity at the initial procedure, but also concerns regarding long-term survival both with and without reoperation. This was highlighted in a recent publication in *Circulation: Cardiovascular Quality and Outcomes* by Etnel and colleagues in Rotterdam (Etnel J, Huygens S, Grashuis P, Papageorgiou G, Roos Hesselink J, Bogers A, et al. Bioprosthetic aortic valve replacement in nonelderly adults. A systematic review, meta analysis, and microsimulation. *Circ Cardiovasc Qual Outcomes*. 2019;12:e005481), where they looked at 99 publications and over 13,000 patients and pointed out that an important drawback of the Ross procedure was late structural valve deterioration of both the autograft and the valve substitute within the right ventricular outflow tract.

Additionally, Etnel and coauthors found that reintervention rates were highly age-dependent. The lifetime risk of

autograph reintervention ranges from 94% in children to 32% for 55-year-olds. For the right ventricular outflow tract conduit, the lifetime reintervention rate was 100% in children and 14% in 55-year-olds. Importantly, this operation is primarily (in most series) focused on patients in a younger age group.

Of course, the importance of your current experience really lies in the broadening of traditional indications to include patients with endocarditis, prior sternotomy, and concomitant operations. Clearly, over 30 years, you've developed extensive technical skill, and I wonder if you might share your thoughts on annular stabilization. What technique do you use? When do you use it? Do you modify the operation for bicuspid pulmonary valves? And certainly, you've had to reoperate on patients who had failed Ross operations. Where do you think the aortic valve-sparing techniques described by Tirone David fit in? Finally, because many of your patients have bicuspid valves and ascending aortic aneurysms, what are your criteria for concomitant repair with the ascending aorta? And, would you use a Dacron graft to replace this section or instead perform aortoplasty? As pertains to the aortic diameter, where's your threshold cutoff (4, 4.5, or 5 cm)? And again, thanks for your amazing contribution. Excellent results and a wonderful presentation.



Dr Paul Stelzer (New York, NY).

Thank you very much, Joe, for your comments. These are good questions. I think you really hit the nail on the head that this is a more complex procedure. It takes longer to do, and you have to have a great deal of patience to go about doing these operations.

Don't be in a big hurry; learn how to protect the heart and also learn how to be more selective when you start doing these operations—and then add the more complex things. Sometimes you don't have a lot of choice, but again, fundamental skills in other aortic surgery before you try to do this is key; for example, an aortic homograft root replacement is a “training wheels” Ross. It takes time to get the hang of it.

As to your comments about the double-valve complexity: Yes, it is more complex, but putting a homograft to the right side is something that you can get the hang of, and that's not the more difficult part of the procedure. That holds true, but commenting on the long-term, I thought the problem was going to be the homograft, and it's not.

I've done fewer than 20 reinterventions in this whole time. Fewer than 20 patients this whole time in my series that I know about have had anything done to that homograft. The left side, on the other hand, that was a problem. But it took me over a decade to realize that the ascending aorta could dilate. And in fact, it wasn't just the ascending aorta; it was the autograft—we left too much of the original pulmonary artery behind, and we didn't stabilize the sinotubular junction.

You asked about stabilizing the annulus, and yes, that's important, and I do that every single time, and I make sure that the autograft dictates the new diameter of the aortic annulus by circling that with a little Teflon felt. But I should have done that to the sinotubular junction as well. As Tirone David says, if you stabilize the sinotubular junction and the annulus, and the valve function is good, it's going to stay that way no matter what happens to the sinus portion. But the cardiologists get a little nervous about the root looking bigger. When it gets to 5 cm, they freak out and say you have to reoperate. I've never seen one rupture. I've seen a couple of localized dissections in the noncoronary sinus, and the one I let get the biggest was 7.5 cm, at which point he had moderate aortic regurgitation, so I re-replaced his aortic root.

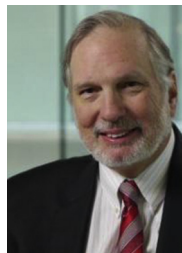
You are correct to remind us that the ascending aorta itself can dilate, and so you asked about the threshold for intervening on that at the initial procedure. My principle is: I don't want anybody to leave the OR with an aorta bigger than 3.5 cm. So if it's between 3.5 and 4.5 cm, I'll do a plication. I'll bring it down to less than 3.5. If it's 5 cm, it's going to get replaced, and I'm not going to cheat just to save circulatory arrest by leaving a 4.5-cm segment proximal to the arch. I'll just go right smack-dab into the hemiarch and do the whole thing—get rid of that tissue. If the aorta is between 4.5 and 5 cm, that's where I evaluate the tissue. If the tissue is really thin, replace the thing. If the tissue is good quality, go ahead and plicate that. The younger the patient, the more likely I am to choose plication to preserve flexibility.

Valve sparing for redo operations: yes, if you can do so, that would be a reason to go back sooner rather than later. If you think you're not going to be able to spare the valve, then wait as long as you can until the patient is symptomatic. Cardiologists are always hot to reoperate on somebody with aortic regurgitation who's asymptomatic. But why? They don't want to operate in the first place until symptoms or the ventricle trigger the need for surgery.

But anyway, when you do reoperate, try to spare that living valve. I think that living valve is a major part of the secret to the long-term success of the Ross operation; you want to preserve that if you can. The question was asked about how many of these reops I have done. I'll have to say conservatively, I've done 65 of them. I did not do the original Ross in all of these. There were some that Ron Elkins had done in Oklahoma and that came to see me after he retired.

In about half of them, I was able to save the autograft. In the other half, I replaced it. But it's a difficult operation, and there are principles. One is: never try to get between the autograft and the homograft, especially before you have a cross-clamp on. Don't try to develop that plane. There is usually a spot right up high underneath the proximal belly of the arch, right where the aorta turns the corner into the arch. You can get into that plane in most redo cases very

easily. Put your clamp up there and try not to mess with that space between the autograft and homograft. That's how you get into trouble.



Dr Joseph E. Bavaria (*Philadelphia, Pa*). Paul, nice presentation. Could you elaborate on how you approach the patient? Because the bottom line is, you have an STS score of less than 1 for most of these patients, and you just stated that you had a 7.5% major complication and death risk in these

patients. It seems to me that the STS total score would be quite a bit less than that. And in this day of TAVR, where say you have a 40-year-old guy who could be a Ross candidate, you put in one of these brand-new tissue valves and it's going to be a 15-year valve, plus you're going to add an extra 8 to 10 years if you get a big valve in any way with a TAVR. Really what you've got is a 20- to 25-year biological construct, and then you do a redo at 65, and a lot of us on this panel, anyway, can do a redo AVR with less than a 1% mortality rate. So how do you talk to your patients about that option versus a Ross procedure?

Dr Stelzer. That's a good question, and certainly the decrease in older patients that we saw in the last decade was because we thought we don't have to do this operation in people over 50 anymore—we're going to be able to put in tissue valves and then rescue those with TAVR. Driving that down into the 40s, it's a little bit harder for me to believe that's going to happen.

And a lot of these patients don't have a big annulus (especially the young women with stenosis); you're not going to get a big valve in there. And that's a big problem. Those are the ones that really benefit greatly from the hemodynamic efficiency of the Ross. So you need to get a good-sized valve in if you're not going to do a Ross. And you have to really be a believer in this valve-in-valve stuff. At this point they call 3-year follow-up on valve-in-valve "long-term" results—you gotta be kidding me.

So I think the other side of the age coin is that if you if you take somebody and you do a Ross on them when they're 50, they may never need another operation. In the recurrence rates paper that Dr. Coselli is talking about, certainly the lowest reoperation rates were in the older patients who had a Ross. That's it. Talk about "one and done," like we used to say for mechanicals. Maybe it's better to present it that way when offering a Ross to a 50-year-old.

It's always been ironic to me that people believe in doing the Ross for kids but not for young adults. But it's the kids that are all going to have to get redos for their homografts because they outgrow them. This has been well documented, and they have a high likelihood of living long enough to develop this complication. I think that's part of the advantages/disadvantages of the operation. You have very good long-term survival, so you have a high likelihood of needing further intervention—but you won't need a reoperation if you're not alive to have it.