The quest for a perfect heart valve substitute has been going on for half a century. In 1960, Lower et al described the feasibility of replacing the aortic valve of dogs with the native pulmonary valve. In 1967, Ross performed this procedure in humans. Ross transferred the pulmonary valve into the aortic root with the same technique used to implant aortic valve homografts (ie, the pulmonary sinuses of the pulmonary root were partially excised, and the pulmonary valve was secured in the recipient’s aortic root with 2 suture lines, 1 below and 1 above the aortic annulus, leaving the coronary artery orifices unobstructed). Although many surgeons gained experience with this type of aortic valve replacement using an aortic valve homograft, the Ross procedure did not gain widespread popularity until the late 1980s when the technique of aortic root replacement was described for this operation. In this approach, the aortic root is excised, the pulmonary root is sutured to the aortic annulus and ascending aorta, and the coronary arteries are reimplanted into the neoaortic root. This technique made the early outcomes more predictable than when the subcoronary technique was used, and enthusiasm for the Ross procedure increased during the 1990s. A voluntary international registry was developed, and thousands of patients were entered into that registry, but there have been no reports on long-term results. In the year 2000, we reported that the pulmonary autograft dilated and that the dilation was often accompanied by aortic insufficiency (AI) when the pulmonary autograft was used as a freestanding neoaortic root, whereas the techniques of subcoronary implantation and aortic root inclusion (pulmonary root inside of the aortic root) prevented dilation during a mean follow-up of 44 months. Other investigators confirmed our findings of dilation of the pulmonary autograft and AI after the technique of aortic root replacement. As the fallibility of the Ross procedure became apparent, fewer surgeons continued to perform it. Among those, Sievers et al demonstrated excellent valve function and lack of dilation of the aortic root after the Ross procedure using the subcoronary technique exclusively, but their mean follow-up was only 3.9 years.

The pooled early mortality was 3.04% in consecutive series of children and adults, 3.21% in adults, and 4.21% in children, but it varied widely among reports from <1% to as high as 6.8%. We believe that aortic valve replacement in young adults (≤50 years of age) should have an operative mortality of ≤1%. During the past 2 decades, 466 patients ≤50 years of age had isolated aortic valve replacement the at Toronto General Hospital, including 48 patients with coronary artery disease and 28 with active infective endocarditis, with only 1 early death. From 1990 to 2004, we performed the Ross procedure in 212 adult patients, with 1 early death. Obviously, the operative mortality in children with aortic valve disease and concomitant complex congenital anomalies is expectedly >1%. In the Takkenberg et al review, the late mortality was 0.48%/y, 0.64%/y, and 0.62%/y, respectively, according to age groups but it also varied widely among reports. However, in most reports on young adults, the survival at the end of the first decade was similar to that of the general population. Although this exceptionally high survival after aortic valve replacement could be due to patient selection, it more likely is due to the low risk of valve-related deaths and cardiac-related deaths because of the pulmonary autograft hemodynamic and biological features. Indeed, the risk of sudden unexpected death was very low.
In this review. This high late survival is one of the most important benefits of this operation. We recently analyzed the outcomes of 212 adults (mean age, 34±9 years) who had the Ross procedure in our institution and were followed up prospectively with annual echocardiograms for a mean of 9.7 years. Their survival at 15 years was 96.6±1.5% and was identical to the general population matched for age and gender.

In the Takkenberg et al10 review, structural failure and nonstructural failure leading to reoperation were analyzed together and ranged widely among the reports included in the study. They found that failure of the autograft was higher in children than in young adults. The pooled linearized rates were 1.15%/y in consecutive series of children and adults, 0.78%/y in adult patients, and 1.38%/y in pediatric series. In the experience of Klieverik et al12 with 146 patients with a mean follow-up of 8.7 years, the freedom from reoperation on the autograft at 13 years was 69.2±6.6% and significantly better in patients <16 years of age than older patients (92.1±5.4% versus 56.7±9.6%; P=0.02). In a recent report by Elkins and associates,11 who probably had the largest experience with the Ross procedure in North America, the freedom from pulmonary autograft failure was 86±2% at 10 years and 74±5% at 16 years and was similar for children and young adults. They found that preoperative AI and male sex were independent predictors of pulmonary autograft failure. Those investigators used mostly the technique of aortic root replacement. We recently reviewed our experience with the Ross procedure and found a freedom from reoperation in the pulmonary autograft of 93.0±2.2% at 15 years and a freedom from moderate or severe AI of 90±3%. Preoperative AI was the only predictor of late AI. The techniques of aortic root inclusion and modified subcoronary implantation were used in most of our patients.

The Ross procedure requires a biological valve to reconstruct the right ventricular outflow tract, which can also fail with time. Most surgeons use pulmonary valve homograft for this purpose. Age is the most important determinant of failure of the pulmonary homograft used for reconstruction of the right ventricular outflow tract.14,15 Pulmonary valve homograft appears to be more durable when used for the Ross procedure than for congenital anomalies of the right side of the heart.14,15 In the Klieverik et al12 report, freedom from reoperation on the pulmonary homograft was 87.1±5.5% at 13 years. In the Elkins et al11 report, freedom from failure of the pulmonary homograft was 90±2% at 10 years and 82±4% at 16 years. Young age was the only independent predictor of pulmonary homograft failure. In our series of Ross procedures, freedom from reoperation, transcatheter interventions, and peak systolic gradient ≥50 mm Hg across the pulmonary homograft was 88.8±2.6% at 15 years, but all our patients were ≥18 years of age.

Thromboembolism is uncommon in patients who had the Ross procedure and probably related more to other factors than to the valve itself. The pulmonary autograft and the pulmonary homograft are at risk of infective endocarditis, but the combined rates are low at 0.2%/y to 0.3%/y.10,11 No heart valve substitute is perfect, and the Ross procedure or any other type of aortic valve replacement or aortic valvuloplasty is a palliative operation.

The choice of heart valve substitute is particularly troublesome in neonates and young children. The congenital heart surgeons I surveyed before writing this editorial were divided on the usefulness of the Ross procedure in pediatric patients. Some vehemently oppose this procedure and prefer to palliate the aortic valve disease with aortic valvuloplasty using a variety of techniques, including cusp augmentation and creation of cusps with pericardium, whereas most congenital heart surgeons still use the Ross procedure. The technique of aortic root replacement is used in neonates and young children because the pulmonary autograft has the potential for growth. Actually, the autograft often becomes larger than what is expected for the somatic growth of the child, particularly along the neoaoartc sinuses.16 Neonates and young children often have other congenital heart defects that require surgical attention, further complicating the Ross procedure.16

Although longer follow-up with echocardiographic surveillance of the pulmonary autograft is needed, it seems that the Ross procedure as originally described is a good option to treat aortic valve disease in young adults (≥50 years of age), mostly because of excellent long-term survival and hemodynamic performance. It is an ideal aortic valve substitute for very physically active patients and women in childbearing years.

The Elkins et al11 data and our own data showed that preoperative AI with dilated aortic annulus is a marker for future dilation and failure of the pulmonary autograft when used as a freestanding neoaortic root. It is unknown whether a reduction in the aortic annulus and implantation of the pulmonary valve in the subcoronary position prevent valve failure in these patients. At present, I no longer recommend the Ross procedure in patients with AI and dilated aortic annulus. In our practice, most of these patients have a congenital bicuspid aortic valve.

Young adults with aortic stenosis and normal-size aortic root are the best candidates for the Ross procedure. Although further evaluation is needed, implantation of the pulmonary valve autograft inside the aortic root as originally described by Ross2 is probably a more durable operation than aortic root replacement.

Disclosures
None.

References


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