Mid-term Results of the Ross Procedure

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ABSTRACT **Although the Ross procedure has been performed for over three decades, its role in the management of patients with aortic valve disease is not well established. This study reviews our experience with this operation. From 1990 to 1999, 155 patients underwent the Ross procedure. The mean age of 106 men and 49 women was 35 years. Most patients (85%) had congenital aortic valve disease. The pulmonary autograft was implanted in the subcoronary position in 2 patients, as an aortic root inclusion in 78, and aortic root replacement in 75. The follow-up extended from 9 to 114 months, mean of 45 ± 28 months, and it was complete. All patients have had Doppler echocardiographic studies. There was only one operative and one late death. The survival was 98% at 7 years. The freedom from 3+ or 4+ aortic insufficiency was 86% at 7 years and the freedom from reoperation on the pulmonary autograft was 95% at 7 years. Dilation of the aortic annulus and/or sinotubular junction was the most common cause of aortic insufficiency. One patient required three reoperations on the biological pulmonary valve. Most patients (96%) have no cardiac symptoms. The Ross procedure has provided excellent functional results in most patients, but progressive aortic insufficiency due to dilation of the aortic annulus and/or sinotubular junction is a potential problem in a number of patients.** *(J Card Surg 2001;16:338-343)*

The feasibility of using the native pulmonary valve to replace the aortic valve was first described in experimental laboratory by Lower, Stoffer and Shumway in 1960,[1] and clinically performed by Ross in 1967.[2] Mr. Ross remained practically the only surgeon performing that operation for the next two decades.[3] Mr. Ross had originally performed this operation by implanting the pulmonary valve autograft in the subcoronary position in the aortic root.[2,3] That was done in the days prior to the advent of intraoperative echocardiography, current knowledge of functional anatomy of the aortic root, and newer techniques of myocardial protection during aortic clamping. It was a long and complex operation and postoperative low cardiac output syndrome and aortic insufficiency were major problems. The initial reports by Stelzer and Elkins in the late 1980's provoked a wave of interest in the Ross procedure.[4,5] The operative procedure was made simpler and more reproducible by using the aortic root replacement technique instead of subcoronary implantation in the native aortic root, and numerous surgeons began to perform it in the 1990s.[6] However, the Ross procedure remains associated with significant problems related to the operative technique, delayed development of aortic insufficiency, dilation of the pulmonary autograft, and stenosis of the pulmonary homograft.[7-16]

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PATIENTS AND METHODS

From December 1990 to July 1999, 155 patients underwent the Ross procedure at Toronto

General Hospital. There were 106 (68%) men and 49 (32%) women whose mean age was 34.6 ± 8.8 years, range 17 to 57 years. The electrocardiogram showed sinus rhythm in all patients. Preoperatively, 25 (16%) patients were in New York Heart Association (NYHA) functional class 1, 102 (66%) in class 2, 20 (13%) in class 3, and 8 (5%) in class 4.Thirty-three patients (21%) had previous cardiac surgery: 14 had had aortic valve repair, 11 aortic valve replacement, 2 mitral valve repair, and 4 had operations for congenital heart defects. Aortic stenosis was the predominant lesion in 79 patients (51%), aortic insufficiency (AI) in 56 patients (36%), and mixed lesion in 20 patients (13%). Only one patient had active infective endocarditis, which was limited to the cusps of the aortic valve. Coronary angiography was performed in 39 patients but none had evidence of occlusive coronary artery disease. Six patients had severe mitral regurgitation preoperatively. Left ventricular ejection fraction was ≥ 60% in 87 (56%) patients, it was 40%-59% in 54 (35%), and 21%-39% in 14 (9%).

The aortic valve was congenitally bicuspid in 119 patients (76.8%), other congenital valve disease in 13 (8.4%), prosthetic aortic valve in 11 (7%), tricuspid aortic valve with annuloaortic ectasia in 7 (4.5%), rheumatic in 4 (2.6%), and endocarditis in an otherwise normal tricuspid valve in one patient. The ascending aorta diameter exceeded 45 mm in 18 patients, all with bicuspid aortic valve.

Operative techniques

Operations were performed with the use of normothermic cardiopulmonary bypass (34-35°C), and myocardial protection was provided by continuous or intermittent cold blood cardioplegic solution delivered directly into the coronary arteries. The ascending aorta was always opened through a transverse aortotomy a few millimeters above its sinotubular junction and the aortic valve cusps were excised. The pulmonary artery was transected just before its bifurcation and the valve inspected. If the valve was normal, the pulmonary root was circumferentially dissected and excised. Abnormal pulmonary valve cusps were found in 6 out of 161 patients in whom the Ross procedure was offered. Obviously, these 6 patients did not have the Ross procedure.

Starting with the fifth patient in this series, the sinotubular junction of the pulmonary root was measured in all subsequent patients with metric sizers (Toronto SPV—St. Jude Medical, St. Paul, MN, USA) and the pulmonary annulus was assumed to be 10-15% larger than the diameter of the sinotubular junction. The diameters of the aortic annulus and sinotubular junction were also measured. If the diameter of the aortic annulus was 2 mm or larger than the diameter of the pulmonary autograft, a reduction aortic annuloplasty was performed before the autograft was secured to the left ventricular outflow tract.[17] The same thing was done to the sinotubular junction at the completion of the operation.

Only two patients had the pulmonary autograft implanted in the subcoronary position. Aortic root replacement was used in 75 (48%) patients and the aortic root inclusion technique in 78 (50%). Since 1997, we have used almost exclusively the technique of aortic root inclusion, and a circumferential band of Dacron fabric was applied on the outside of the aortic root at the level of the sinotubular junction and secured to the arterial wall with a few full-thickness interrupted sutures. This Dacron band was 3 mm wide and as long as the diameter of the sinotubular junction multiplied by Π (pi) plus 2 mm (to correspond to the thickness of the arterial wall). Eighteen patients, all with bicuspid aortic valve, also had replacement of the ascending aorta because of dilation or aneurysm.

A pulmonary valve homograft was used to reconstruct the right ventricular outflow tract in all but the first patient in this series who had an aortic valve homograft. The diameter of the pulmonary homograft used was always larger than the diameter of the pulmonary autograft. No pulmonary homograft of internal diameter of less than 24 mm was used. The distal anastomosis was performed before the proximal anastomosis and both were done with continuous 4-0 polypropylene sutures.

Table 1 shows the operative data and perioperative complications.

Follow-up

Every patient has been followed at annual intervals and Doppler echocardiographic studies obtained. Most echocardiographic studies were performed in other institutions, however if any abnormality was reported, the patient was referred back to us for further investigation. Thus, every patient with more than mild AI or dilation of

TABLE 1
Operations Performed and Mortality and Morbidity

Reduction of diameter:	
None	61 (39.4)
Aortic annulus	44 (28.4)
Sinotubular junction	21 (13.5)
Both	29 (12.7)
Implantation of the pulmonary autograft:	
Subcoronary	2 (1.3)
Root replacement	75 (48.4)
Root inclusion	78 (50.3)
Pulmonary valve replacement:	
Aortic homograft	1 (0.6)
Pulmonary homograft	154 (90.3)
Other procedures:	
Mitral valve repair	3 (2)
Replacement of ascending aorta	18 (11.6)
Coronary artery bypass	2 (1.3)
Aortic clamping time (min. ± SD) (range)	126 ± 16 (96 to 188)
Cardiopulmonary bypass time (min. ± SD) (range)	145 ± 24 (110 to 310)
Intensive care unit stay (hours ± SD)	30 ± 61 (0 to 721)
Hospital stay (days ± SD>)	7.3 ± 2.8 (3 to 20)
Mortality and morbidity:	
Death	1 (0.6)
Reexploration for bleeding	7 (4.5)
Perioperative myocardial infarction	4 (2.5)
Complete heart block	1 (0.6)
Transient ischemic attack	1 (0.6)
Coronary artery bypass	1 (0.6)
Replacement of the pulmonary autograft	1 (0.6)

the pulmonary autograft had an echocardiographic study in our hospital. Similarly, patients with evidence of gradients greater than 30 mm across the pulmonary homograft were also referred back for further investigation. The follow-up was complete and extended from 9 to 114 months, mean of 45 ± 28 months.

Statistical analysis

Survival and freedom from valve-related events were calculated by the product-limit method of Kaplan-Meier.

RESULTS

Early and late mortality

There was one operative death. This patient died suddenly on the fourth postoperative day. Autopsy showed an extensive acute anterior myocardial infarction with patent coronary arteries including the first septal perforator. There was one late death due to a mountain climbing accident. The Kaplan-Meier estimate of survival was 98.3% ± 1% at 7 years as illustrated in Figure 1.

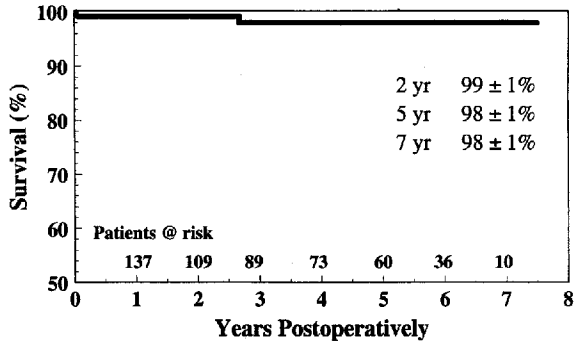

Figure 1. *Kaplan-Meier estimate of survival following the Ross procedure.*

Function of the pulmonary autograft

Eleven patients have developed moderate or severe AI. The remaining patients have none, trace or mild AI. The freedom from moderate or severe AI was 98% ± 1%, 90% ± 3% and 86% ± 5% at 2, 5, and 7 years, respectively, as shown in Figure 2. The freedom from moderate AI at 5 years was 91% ± 4% for aortic root replacement, and 86% ± 6% for aortic inclusion technique (p = 0.6). Of 72 patients who had aortic root replacement with pulmonary autograft, 14 patients

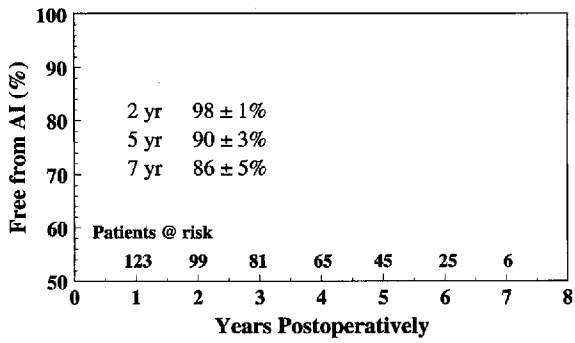

Figure 2. *Freedom from moderate (3+) or severe (4+) aortic insufficiency after the Ross procedure.*

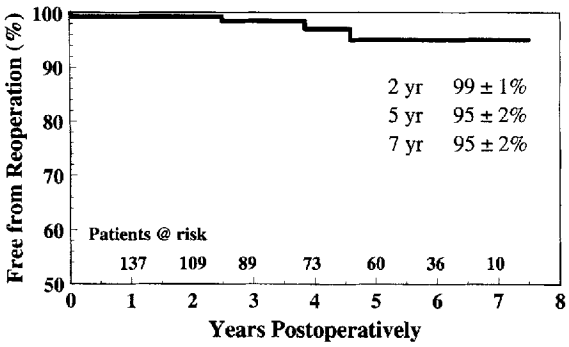

Figure 3. *Freedom from reoperation on the pulmonary autograft.*

had sinuses of Valsalva greater than 40 mm in diameter (41 to 52 mm).

Reoperations on the pulmonary autograft

Five patients have required reoperations on the autograft: three because of AI and two because of detachment of the autograft from the left ventricular outflow tract. The first reoperation was at 2 weeks postoperatively in a patient who developed moderate AI due to acute dilation of the autograft. The autograft was replaced with an aortic homograft. The other two patients developed moderate to severe AI because of dilation of the annulus and sinotubular junction and required aortic root replacement 4 to 5 years postoperatively.

The pulmonary autograft became detached from the left ventricular outflow tract in two patients: the first had had complete aortic root replacement and the second aortic root inclusion. The first patient developed a false aneurysm between the mitral valve and the pulmonary autograft, which was successfully repaired 6 months after the initial operation with preservation of the pulmonary autograft. The second patient required aortic valve replacement.

The freedom from reoperation in the pulmonary autograft was 95% ± 2% at 7 years as shown in Figure 3. The freedom from reoperation was similar after root replacement and root inclusion techniques.

Function of pulmonary homograft

At the latest follow-up, 113 patients had peak systolic gradients below 20 mmHg, 29 had gradients of 20 to 30 mmHg, and 8 patients had gradients of 31 to 55 mmHg. Moderate pulmonary insufficiency was detected in 17 patients (11%).

Reoperations on the pulmonary homograft

Only one patient has required replacement of the pulmonary homograft. This patient has a complex immune disorder and has had three reoperations in 9 years of follow-up. At the last reoperation, a porcine bioprosthesis was used because the previous pulmonary homograft became stenotic in less than 2 years after implantation.

Other complications

There were two transient ischemic attacks early postoperatively in the same patient who was treated with coumadin for 3 months. There has been no late thromboembolic complications. Only one patient is on coumadin because antiphospholipid antibody syndrome and multiple arterial thromboses. No patient has had infective endocarditis.

Functional class

At the latest follow-up, 150 patients were alive and had their pulmonary autograft. Most patients are asymptomatic; 5 patients have cardiac symptoms and are in NYHA functional class 2.

DISCUSSION

Mr. Ross' initial series of 131 hospital survivors of the pulmonary autograft operation was published in 1997.[18] Those patients were operated on from 1967 to 1984 and their outcomes determined to 1994. The mean age of patients at operation was 32 years, range 11 to 52 years, and 109 were male. The autograft was implanted in the subcoronary position in 107 patients, as an aortic root replacement in 20, and mounted in a Dacron graft in 2. Pulmonary valve homograft was used to reconstruct the right side of the heart in 113 patients, fascia lata valves in 8, and miscellaneous valves in the remaining patients. There were 53 deaths by 1994, mostly valve or cardiac related. The survival was 85% and 61% at 10 and 20 years, respectively. Patients with autografts in the subcoronary position had similar survival to those who had the autograft as an aortic

root replacement. Of 35 patients who had reoperations on the pulmonary autograft, regurgitation was the indication in 30. Pulmonary autograft regurgitation appeared to be primarily technical in nature, usually due to cusp prolapse. Degeneration of the autograft valve was found in only 3 of 30 explanted autografts. The freedom from reoperation on the pulmonary autograft was 88% and 75% at 10 and 20 years, respectively.

Dr. Elkins probably has accumulated the largest experience with the Ross procedure in the world.[19] He performed this operation in 328 patients from 1986 to 1998. The technique of aortic root replacement was used in 242, aortic root inclusion in 60, and subcoronary implantation in 26 patients. Patients' mean age ranged from 10 days to 62 years, median 20 years. Dr. Elkins has favored the aortic root replacement technique because it has been associated with the best functional results in his experience.[9] The operative mortality was 4.6% and the survival at 8 years was 89% ± 5%. The freedom from reoperation on the pulmonary autograft at 8 years was 85% ± 5% and the freedom from replacement of the pulmonary autograft was 94% ± 3%. The freedom from moderate AI (3+) at 8 years was 88% ± 7% after aortic root replacement and 77% ± 8% after intraaortic implantation of the pulmonary autograft.

Steltzer and colleagues reported their experience with 145 adults.[12] They used exclusively the technique of aortic root replacement. The survival at 7 years was 84.5% and the freedom from reoperation on the pulmonary autograft was 88.6%.

In our series, the survival at 7 years was exceptionally high at 98%. However, the failure rate of the pulmonary autograft was similar to other series with a freedom from reoperation of 95% at 7 years. Dilation of the aortic annulus and/or sinotubular junction was the main reason for the development of AI, and the freedom from moderate or severe AI was 86% at 7 years.

Dilation of the pulmonary autograft is a problem in a small proportion of patients after the Ross procedure.[13] In our experience, 14 out of 72 patients who had aortic root replacement with pulmonary autograft were found to have a neoaortic root diameter of 40 mm or more. The techniques of aortic root inclusion and subcoronary implantation appear to prevent dilation.

In addition to problems related to the pulmonary autograft, patients who had the Ross procedure also have a biological valve in the pulmonary position, usually a pulmonary homograft, which can also fail. In the Ross series, the freedom from reoperation on the pulmonary valve was 89% and 80% at 10 and 20 years, respectively.[18] In Elkins' experience, the freedom from reoperation on the pulmonary valve was 90% at 8 years.[19] In our present study of 155 patients, only one patient with a complex immune disorder had three reoperations to replace the biological pulmonary valve (one aortic and two pulmonary homografts). At the last reoperation, a stented porcine aortic valve was implanted in the pulmonary position.

We recently reported on a study that tried to identify the predictors of late pulmonary homograft performance in a series of 109 patients who had the Ross procedure.[16] We found a significant increase in peak systolic gradients across the pulmonary homograft from 5.9 mmHg at one week postoperatively to 14.5 mmHg during a mean follow-up period of 39 ± 20 months. Twenty-nine percent of the patients had peak systolic gradients in excess to 20 mmHg, and 3.8% in excess to 40 mmHg. We found that calcification of the conduit with thickening of the cusps was the most common cause of dysfunction. Homograft insufficiency was present only in association with pulmonary calcification and stenosis. The independent predictors of late pulmonary homograft stenosis were a younger donor age, a shorter duration of cryopreservation, and a smaller homograft size. We used almost exclusively pulmonary homograft to replace the pulmonary valve because it is believed to be more durable than aortic homograft.[14,15,20]

The Ross procedure has been particularly useful in children because the pulmonary autograft appears to grow with the child.[21-23] Elkins et al. reported on a group of 150 children with a mean age of 12 years (range 7 days to 21 years) with a median follow-up 2.8 years. At 8 years, the survival was 97%, the freedom from reoperation of the autograft was 90% and the freedom from reoperation on the pulmonary valve was 94%.

Although the Ross procedure has also been used in older patients,[12,24] we believe that other biological valves, particularly the stentless porcine valve, may offer a simpler alternative if the purpose is to avoid oral anticoagulation. There is no evidence that patients who have the Ross procedure have better late survival or lower rates of valve-related complications than those who have aortic valve replacement with other types of valves.

The Ross procedure is a complex operation that provides excellent functional results in most patients but it is not free of complications. It is an excellent choice for children and young adults to avoid anticoagulation and provide normal hemodynamics across the left ventricular outflow tract.

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