

Intermediate-Term Results of Medtronic Freestyle Valve for Right Ventricular Outflow Tract Reconstruction in the Ross Procedure

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Background and aim of the study: The Ross procedure has become the first choice for aortic valve replacement in children and young adults at many institutions. Since 1997, a lack of availability of homograft valves in Turkey has prompted the use of alternative substitutes for right ventricular outflow tract (RVOT) reconstruction during the Ross procedure.

Methods: Before April 2005, among 20 patients (age range: 14 months to 45 years) at the present authors' institution, the Ross procedure was performed in 14 and a Ross-Konno procedure in six. Sixteen patients underwent RVOT repair using alternative methods for homograft valve replacement. Fourteen patients received a Medtronic Freestyle valve and one patient a Medtronic Contegra bovine jugular vein conduit. An autologous RVOT repair was used in one patient. Ten of the Medtronic Freestyle valve patients were aged <16 years. In all patients who received a Medtronic Freestyle valve echocardiographic evaluations were conducted shortly after surgery and during follow up.

The long-term freedom from complications and reoperation associated with the Ross procedure has made this approach the modern choice for aortic valve replacement (AVR) in children and adults with a long life expectancy. The procedure is ideal for young women with aortic valve disease who plan to bear children, and for those individuals who have contraindications to anticoagulation. Changes in implantation techniques transitioning from subcoronary to total root replacement and performing annular support has led to a reduction in the incidence of pulmonary autograft regurgitation (1). Although the potential exists for an immune response with resultant pulmonary stenosis and possible early explantation of the pulmonary homograft, the overall results of the Ross procedure

Results: There was no early mortality. One patient died from pneumonia after six months, and another (asymptomatic) patient died suddenly at 34 months after surgery. Before hospital discharge the mean peak pressure gradient across the Freestyle valve was 12.1 ± 11.0 mmHg, and this increased to 24.1 ± 20.0 mmHg after a mean follow up of 51.2 ± 6.9 months (range: 6 to 101 months) ($p < 0.002$). Mild pulmonary regurgitation was seen in two patients. One asymptomatic adult patient was reoperated on at another center because of a 60-mmHg echocardiographic peak gradient at four years postoperatively.

Conclusion: Although long-term follow up is required to explain the durability of the Medtronic Freestyle valve, the present results show that the valve can be used with intermediate-term success in the Ross procedure - and even in children as an alternative - if homograft valves are not available.

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have been excellent and highly reproducible (2).

Despite the modern emphasis which is placed on organ donation, replacement homografts for the donated pulmonary valve remain relatively scarce. This lack of suitable alternatives for right ventricular outflow tract (RVOT) reconstruction has severely limited the wider application of the Ross procedure in many parts of the world. Many alternatives such as valveless conduits, stentless bioprostheses, synthetic valved conduits and autologous repair techniques to homograft replacement during the Ross procedure have been reported during the past few years (3-8). For example, Konertz et al. (9) published the first pulmonary autograft series using Medtronic Freestyle stentless bioprosthesis for RVOT in 1996. Unfortunately, in Turkey the difficulties encountered in obtaining homograft valves has forced surgeons to use the same technique in order to offer the well-known advantages of the Ross procedure to young patients with aortic valve disease.

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Clinical material and methods

Patients

Between March 1997 and April 2005, 16 patients underwent the Ross procedure for RVOT reconstruction at the authors' institutions, without the use of a homograft valve. Among these patients, one 18-month-old baby underwent RVOT reconstruction by his in-situ left atrial appendage tissue posteriorly and a pericardial patch with pericardial monocusp anteriorly, as described by Matsuki et al. (3). A second, 14-month-old, baby received a Medtronic Contegra bovine jugular vein conduit. The remaining 14 patients (10 males, four females; mean age 17.9 ± 13.3 years; range: 5 to 45 years) who received the Medtronic Freestyle valve formed the study group. Ten patients who received the Freestyle valve were children aged <16 years. The patient characteristics are listed in Table I.

Surgical technique

All operations were performed under standard cardiopulmonary bypass at 26°C with aortic and bicaval cannulation. Myocardial protection was achieved with intermittent isothermic antegrade or antegrade/retrograde blood cardioplegia. Ultrafiltration during rewarming was used in all patients. All operations were performed by a single surgeon (M.S.B.).

All patients underwent total root replacement by pulmonary autograft. Four of them required the Ross-Konno procedure, while aortic annular and wall diameter reduction prior to root replacement was required in one adult with a rheumatic etiology

Table I: Patient characteristics.

Parameter	Value
No. of patients	14
Age <16 years (n)	10
Gender ratio (M:F)	10:4
Predominant lesion	
AS	9
AI	3
AS+AI	2
Etiology	
Congenital	12
Rheumatic	1
HFHC	1
Severe left ventricular dysfunction	3
Associated pathologies	
Ventricular septal defect	3
Left coronary artery ostial and subaortic stenosis	1
Infundibular pulmonary stenosis	1
Dextrocardia	1

AI: Aortic insufficiency; AS: Aortic stenosis; HFHC: Homozygous familial hypercholesterolemia.

because of geometric mismatch. In children and in most adults, the pulmonary autograft was implanted using interrupted simple sutures in the proximal suture line. In order to maintain hemostasis and annular stabilization, the proximal suture line was reinforced with either a strip of Teflon felt or autologous pericardium in adult patients. In children, this technique was not used so as not to prevent annular growth. During the Ross-Konno procedure, the left ventricular outflow tract (LVOT) was enlarged with a polytetrafluoroethylene (PTFE) patch in one patient with infundibular pulmonary stenoses and ventricular septal defect (VSD), and with a right ventricular infundibular free wall muscular extension harvested in continuity with the pulmonary autograft in another three patients. In one child, the Konno incision was extended into the VSD; the right ventricular muscle extension was subsequently used to close the VSD and to enlarge the LVOT. Additional procedures are listed in Table II. Pericardial patching of the raw surface on the right ventricle after pulmonary autograft explantation has been performed in all the patients since 1998 (Fig. 1). The size of the Freestyle valve was based upon the size of the defect that resulted from harvest of the pulmonary autograft, except in one patient. In the first patient, aged 19 years, it was necessary to use a No. 21 Freestyle valve because of an unavailability of larger prostheses. Two patients required a pericardial extension tube graft between the Freestyle valve and pulmonary artery. It was also necessary to place a pericardial hood between the RVOT and the anterior wall of the proximal Freestyle valve in six patients, four of whom underwent the Ross-Konno procedure. In most patients the major part of the RVOT reconstruction (posterior patching, distal suture line of Freestyle valve and half of proximal suture line) was accomplished before release of the aortic cross-clamp. Transesophageal echocardiography was performed in most patients at the end of the procedure in order to evaluate the pulmonary autograft and Freestyle valve function.

Table II: Additional procedures.

Procedure	No. of patients
Ross-Konno	4
VSD closure	3
Pulmonary infundibular resection	1
Ostial plasty	1
Aortic annular and wall diameter reduction	1
Posterior patching	13
Pericardial hood	6
Pericardial tube extension	2

VSD: Ventricular septal defect

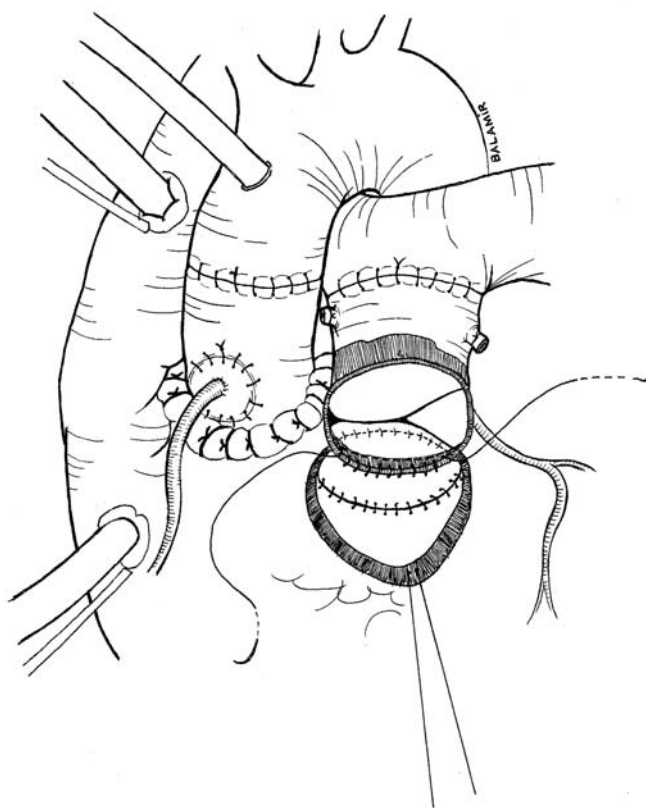


Figure 1: Pericardial patching of the raw surface on the right ventricle after pulmonary autograft explantation.

Patient follow up

Follow up by the referring cardiologist was available for all patients, and performed in the outpatient clinic with a physical examination, chest X-radiography, electrocardiogram and transthoracic echocardiography. Routine echocardiograms were obtained when indicated clinically, and the results were reviewed for the present study. None of the patients underwent postoperative cardiac catheterization. As anticoagulant, warfarin was administered for three months postoperatively, in addition to lifelong aspirin.

Statistical analysis

Data were described as frequencies, medians with ranges or means \pm SD as appropriate. Peak systolic gradients during the early postoperative period and at the last echocardiographic study were compared with a one-way paired Student's *t*-test.

Results

The mean cardiopulmonary bypass (CPB) and aortic cross-clamp times were 202 ± 27 min and 118 ± 18 min, respectively. The mean size of Freestyle valve implant-

Distribution of valve sizes by age of patient

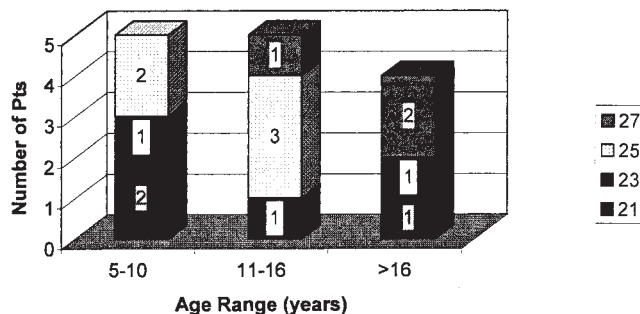


Figure 2: Distribution of valve sizes by age of patients.

ed was 24.1 ± 2.1 mm (range: 21 to 27 mm). The distribution of valve sizes by patient age is indicated in Figure 2.

There was no operative mortality; rather, all patients had an uneventful recovery without complications. No thromboembolic or hemorrhagic events occurred.

Two patients died during the follow up period. One nine-year-old boy died from severe pneumonia at six months after surgery, and a 45-year-old asymptomatic patient died suddenly from unknown causes after three years. The Freestyle valves of both patients were functioning normally at postoperative control echocardiography. One asymptomatic patient underwent a valved conduit replacement at another center because of pulmonary stenosis during the fourth postoperative year. All other patients are presently leading an unrestricted life and are in NYHA functional class I, as noted at a mean follow up period of 51.2 ± 6.9 months (range: 6 to 101 months). The girl who underwent surgery eight years ago has since had two successful pregnancies.

Before hospital discharge the mean peak pressure gradient across the Freestyle valve was 12.1 ± 11.0 mmHg. On transthoracic echocardiography, no calcification of the Freestyle valve was visible during follow up; echocardiography also demonstrated good autograft function, with no evidence of stenosis in any patient. Two patients showed trivial autograft regurgitation, and another two mild regurgitation. Stentless bioprostheses on the RVOT showed no significant stenosis more than 60 mmHg peak systolic gradient in any patient, and only two mild regurgitations. The calculated gradient of the stentless valves was clearly increased (mean 24.0 ± 20.0 mmHg; range: 4 to 60 mmHg; $p < 0.002$). The mean peak Doppler gradients across the RVOT during the follow up period are illustrated in Figure 3. The right ventricular function was well preserved in all patients.

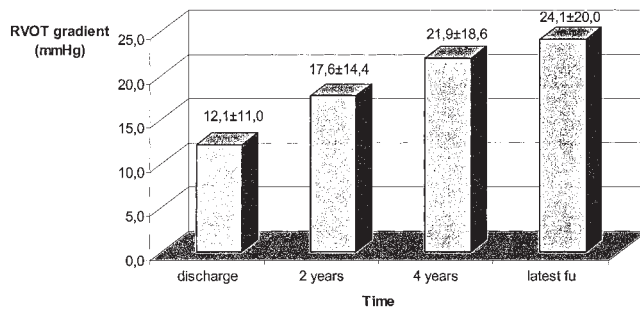


Figure 3: Mean peak Doppler gradients across the right ventricular outflow tract (RVOT) during follow up (fu).

Discussion

Despite 30 years having passed since the first Ross procedure was performed, its advantages have been clearly demonstrated in different centers worldwide, especially during the past 15 years. Although, it is a much more difficult and a challenging procedure compared to other AVR approaches, it has gained increasing popularity because there is no better method available for infants, young patients and intending mothers. The Ross procedure cannot be considered completely to resolve the problems associated with homografts implanted in the pulmonary position, however. Indeed, it was concluded by some that the outcome of aortic homografting in the pulmonary

position was not favorable compared to that with pulmonary homografts (10). Concern persisted that, over time, pulmonary homografts might develop stenoses secondary to low-grade immune reactions, and 15% of pulmonary homografts were found to contract or shrink within six months of implantation. Whilst this does not tend to cause any significant deterioration in function, early homograft degeneration can be encountered in infant patients (11), and more favorable results might be achieved if oversized pulmonary homografts were to be implanted in this patient group. Despite problems associated with longevity, the pulmonary valve homograft is considered to be the 'gold standard' for RVOT reconstruction. The main problem, however, is that homograft availability is strictly limited; in fact in many countries they are not only virtually unobtainable but also much more expensive than other valve substitutes. During the present study period, for example, pulmonary homografts for the Ross procedure were obtainable for only four patients.

These difficulties in pulmonary homografts availability, coupled to problems with their early degeneration, have led surgeons to seek alternatives for RVOT reconstruction in Ross operations. Newer-generation stentless bioprostheses have been used for this purpose in relatively small series that reported encouraging early-term results. The Medtronic Freestyle stentless porcine aortic root is glutaraldehyde-fixed, using zero-pressure fixation, and is treated with an

Table III: Reported series using bovine stentless bioprosthesis in the right ventricular outflow tract during the Ross procedure.

Parameter	Study Novick et al. (18)	Schmid et al. (20)	Tsukube et al. (19)	Dohmen et al. (21)	Kanter et al. (22)
No. of patients	11	15	9	7	56
Valve	Freestyle	Edwards Prima	Freestyle	4 Freestyle; 3 Edwards Prima	Freestyle; Ross: 5
Age (years)	13.9 ± 2.1 (4.6-16.4)	59 ± 5 (55-65)	40.4 (14-66)	40.7 ± 6.7 (31-51)	11.8 (1.6-29.9)
Follow up (months)	35 ± 9	37 (6-60)	<24	48-66	30 ± 20
Mean gradient (mmHg)	27 ± 20	8.8 ± 7.4	18.2 ± 3.5	Freestyle: 3.1 ± 2.4 (median 3); Edwards: 2-6	19.7 ± 15.4
Pulmonary stenosis >40 mmHg	3 patients with gradient >60 mmHg	No	Not reported	No	6
Pulmonary regurgitation	1 moderate	3 moderate	Not reported	1 trace, 1 mild	4 moderate
Conclusion	Possible alternative in children	Satisfactory treatment for aged patients	Considered to be an alternative	Intermediate term results encouraging	Excellent results in children

antimineralization agent (alpha-amino oleic acid) which reduces cusp calcification in animals (12). Despite evidence that the Freestyle valve calcifies in juvenile sheep (13) and deteriorates in growing pigs (14), many series have used the Freestyle valve to reconstruct the RVOT, with promising results (9,15). Excellent results using a stentless bioprosthesis for RVOT reconstruction during the repair of a wide spectrum of congenital heart pathologies were reported by Kanter et al., who compared 62 homografts with 38 porcine valves in children (mean age 9.5 years). The actuarial freedom from redo pulmonary valve replacement at eight years was 100% for porcine valves (mean follow up 3.8 years), but 68% for homograft valves (mean follow up 4.3 years). It was concluded that porcine valves might be superior to homografts in these children (16). The present authors' experience with the Freestyle valve in non-Ross patients showed a parallel with the data of Kanter et al., there being no need to replace conduit replacements among these patients until now. As the smallest commercially available Freestyle valve is 19 mm, they are not suitable for infant patients. Hence, the preference was for an autologous repair which preserved growth potential of the RVOT (as described by Matsuki et al.) in one baby, and the Medtronic Contegra bioprosthesis in a second baby.

The use of peak systolic gradient calculated by Doppler echocardiography to evaluate stenosis into the RVOT might lead to an overestimation (17). Echocardiographically, the mean transvalvular gradient rather than the peak systolic gradient corresponds more closely to the systolic gradient found at cardiac catheterization. This comparison could not be made among the present patients because none had a right heart catheterization. It is believed that if a patient has a peak systolic Doppler gradient >60 mmHg, then cardiac catheterization is necessary to visualize the "true" gradient to decide about reintervention. One 40-year-old patient in the present series had a conduit replacement at another center because of 60 mmHg peak systolic gradient measured by Doppler echocardiography four years postoperatively. However, the explanted conduit did not show any calcification and the leaflets were mobile. Bulging of the pericardial patch used for posterior patching might have been responsible for stenosis at the annular level in this patient. Another asymptomatic adult patient with this level of echo gradient had received a 21-mm Freestyle valve eight years previously and experienced two uneventful pregnancies two and six years ago. None of the other patients had a high postoperative echo gradient >40 mmHg.

Since 1998, the present authors have used a pericardial patch to cover the surface of the right ventricular

posterior wall after removal of the pulmonary root, in order to prevent bleeding. Indeed, no bleeding complications occurred among the present patients. This patch also simplifies suture removal from this vulnerable region where the septal arteries are in close proximity. Another advantage of the technique is that the proximal suture line of the Freestyle valve is replaced more cranially; this maneuver means that the Freestyle valve is sufficiently long to cover the area between the right ventricle and pulmonary artery. Normally, the Freestyle valve length is sufficient to make a construction without extending the tube graft. Novick et al. (18) used an extension pericardial tube graft in all of their patients, while Tsukube et al. (19) sutured a pericardial roll along the proximal end of the bioprosthesis to avoid kinking of the bioprosthesis. Among the present patients, a pericardial tube graft was required in only two cases, while a pericardial hood on the right ventricle was necessary in six patients, four of whom underwent the Ross-Konno procedure. The greater part of the RVOT reconstruction was accomplished before removing the aortic cross-clamp. It is believed that antegrade plus retrograde isothermic blood cardioplegia, given intermittently every 15-20 min, provides excellent myocardial protection. Thus, there was no need for any significant inotropic support while patients were weaned from CPB.

Details of previously conducted studies with stentless bovine valves after the Ross procedure are listed in Table III. Within these series, numbers of patients ranged from seven to 15, and the mean follow up from 2.5 to 5.5 years. The mean peak gradient ranged from 3.1 ± 2.4 to 18 ± 7 mmHg. Moreover, no patients underwent conduit replacement in this series, although some had a high peak gradients across the Freestyle valve. Significant pulmonary regurgitation has not been reported with the Freestyle valve.

In conclusion, the findings of the present study showed that the Freestyle valve can be implanted in the pulmonary position in the Ross procedure with good clinical outcome, though the small number of patients and single surgeon bias might have limited the results. Only one patient required conduit replacement and, during a mean follow up of 51.2 months, the valve appeared to show reasonable hemodynamic function. In the case of narrowing of the stentless bioprosthesis, transcatheter interventions may provide relief and delay surgery for some additional years. The appropriate time frame for determining the usefulness of a successful valve in the pulmonary position must exceed 10 years in this age group. Moreover, long-term follow up is mandatory in order to make a final decision regarding the performance of the Freestyle porcine aortic root in RVOT reconstruction. Use of the

Freestyle valve may represent a good alternative to the difficult-to-obtain homograft valve.

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