

Effects of Transcatheter Closure of Fontan Fenestration on Exercise Tolerance

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Abstract Baffle fenestration is associated with a significantly better outcome in standard and high-risk patients undergoing completion of Fontan. We report the effects of subsequent transcatheter closure of fenestration on exercise capacity and oxygen saturation. Sixteen patients with a mean age of 10.3 years underwent Amplatzer septal occluder (ASO) device transcatheter closure of Fontan fenestration. All had a fenestrated Fontan operation 6 months to 8 years prior to the procedure. A stress test was performed before and after device closure of fenestration in 14 patients (2 patients did not tolerate stress test before the procedure). The fenestrations in all patients were successfully occluded with the use of the Amplatzer device occluder. No complications occurred during or after the procedure. O₂ saturation increased from a mean $85.1 \pm 7.89\%$ to $94.5 \pm 3.63\%$ ($p < 0.01$) at rest and from $66.2 \pm 12.86\%$ to $87.2 \pm 8.64\%$ ($p < 0.01$) following exercise. Exercise duration has also increased from 8.22 ± 2.74 min to 10.29 ± 1.91 min ($p < 0.05$). Transcatheter closure of Fontan fenestration increases the duration of exercise capacity and increases O₂ saturation at rest and after exercise.

Keywords Fontan procedure · Fenestration closure · Transcatheter closure

Introduction

Three- to-six-millimeter fenestration of the Fontan is associated with better early survival and less perioperative complications after a Fontan operation [1, 2, 6]. This is attributed to the reduction of systemic venous pressure and to the augmentation of the systemic ventricular preload in the presence of high pulmonary artery pressure [1, 6, 8]. However, these short-term benefits come at the expense of systemic oxygen saturation and the potential hazards of right-to-left shunt such as endocarditis and paradoxical embolism, in the long term. Delayed postoperative transcatheter closure of Fontan fenestration is considered an option to prevent such long-term sequelae [4, 9]. The effects of such a procedure on exercise duration and oxygen saturation at rest and following exercise are reported here.

Materials and Methods

Patient Population

The study was approved by the Internal Review Board at the Prince Sultan Cardiac Centre. The mean age was 10.3 years (6–13 years) and a mean weight of 34.1 kg (15.6–61.7 kg). All participated in the study 6 months to 8 years from the date of operation. The pre-operative diagnosis is summarized in Table 1. Patients had bidirectional Glenn shunts constructed 2–8 years before the completion of Fontan. The Fontan operation consisted of using direct bicaval cannulation and aortic return, keeping the heart perfused and beating while allowing mild systemic hypothermia. All existing aortopulmonary shunts were closed and the main pulmonary artery (MPA) was transected. The pulmonary artery confluence was enlarged with a bovine

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pericardial patch that extended well into the undersurface of the right pulmonary artery (RPA). An 18–22-mm polytetrafluoroethylene (PTFE) (Gortex[®]) tube conduit of appropriate length is chosen depending on the patient's weight. One end was anastomosed end-to-side to the undersurface of the enlarged RPA onto the bovine pericardial patch used for its enlargement. The other end of the conduit was anastomosed end-to-end to the transected end of the inferior vena cava (IVC). A 3–6-mm fenestration was created between the side of the conduit and the lateral wall of the right atrium (RA) by direct side-to-side anastomosis at the end of the procedure.

Patients underwent stress test using the modified Bruce protocol before and after the catheter procedure. The modified Bruce protocol was used while monitoring the ECG, blood pressure (BP), a pulse oximeter, and the duration of exercise.

Cardiac Catheterization

Cardiac catheterization was performed under general anesthesia, with transesophageal echocardiography

guidance, in eight patients, and under local anesthesia, utilizing intracardiac ultrasound (ICE), in the last eight patients. After complete hemodynamic assessment as previously described [9], balloon test occlusion was accomplished in 5 patients using a BALT 7 Momenah sizing balloon (Extursion Febrication de Catheters, Montmorency, France). During the procedure, saturation and cardiac output were monitored for a period of 15 min to ensure adequacy of systemic pressure and cardiac output; the balloon was then deflated. Subsequently, an angiography in the Fontan connection was performed to identify the anatomy and to measure the size of the fenestration. Transcatheter closure was performed using the Amplatzer ASO device (AGA Medical, Golden Valley, MN) as previously described [2]. In the last 11 patients, test occlusion was done with the Amplatzer device itself.

Twenty-four hours after the procedure, all patients underwent chest radiograph, ECG, and two-dimensional (2D) echocardiography study to assure the position of the device and rule out a significant residual shunt. The patients were discharged with a follow-up appointment at 6 weeks time for evaluation, including a stress test with saturation monitoring. All patients were on an adjustable

Table 1 Diagnosis and stages of surgery

	Diagnosis	Primary surgery and intervention	Age of Fontan
1	DORV, hypoplastic LV, TGA, COA	PAB and COA repair at 2 weeks; Glenn shunt at 2 years; coiling of collaterals at 6 years	7 years
2	DILV, D-TGA	No previous intervention	7 years
3	D-TGA, large VSD, IAA	Repair of interrupted aortic arch and PAB at 3½ months; Damus-Kaye Stansel operation and right BTS at 3 years; bidirectional Glenn at 5 years	9 years
4	PA, TA, VSD, rudimentary RV	Right BTS at 13 days	5 years
5	D-TGA, left AV valve atresia	BAS and Right BTS at 2 weeks	6 years
6	PA, TA, IVS, hypoplastic RV	BAS at 2 days; right BTS at 3 days; bidirectional Glenn shunt and closure of right BTS at 4 years; left BTS at 10 years	13 years
7	DILV, D-TGA, PS	PAB at 11 months	4 years
8	L-TGA, DILV, COA	COA repair and PAB at 2½ months; Glenn shunt at 2 years	5½ years
9	Dextrocardia, TGA, PA	Left BTS at 2 months; Glenn shunt at 3 years	10½ years
10	TA, PS, sub PS, small VSD	Right BTS; bidirectional Glenn shunt at 2 years	5 years
11	DILV, TGA	BAS; PAB; atrial septectomy, Glenn shunt and transection of MPA at 9 years	11½ years
12	PA, unbalanced AVSD	Right BTS at 5 days; Glenn shunt and closure of right BTS at 3 years	9 years
13	Dextrocardia, DORV, TGA, small LV	Right BTS; Glenn shunt and closure of right BTS at 2 years	6 years
14	TA with VSD	BAS; Glenn shunt at 3 years	11 years
15	TA, VSD, NRG	BAS; atrial septectomy and PAB; Glenn shunt at 3 years	9 years
16	Dextrocardia, interrupted IVC, PA and large VSD	Right BTS; hemi-Fontan and closure of right BTS at 2 years	4 years & 10 months

DORV = double outlet right ventricle; AV = atrioventricular valve; LV = left ventricle; RV = right ventricle; TGA = transposition of great arteries; AVSD = atrio-ventricular septal defect; COA = coarctation of aorta; IAA = interrupted aortic arch; TA = tricuspid valve atresia; IVS = intact ventricular septum; PA = pulmonary atresia; DILV = double inlet left ventricle; SV = single ventricle; PS = pulmonary stenosis; VSD = ventricular septal defect; PAB = pulmonary artery banding; NRG = normally related great arteries; IVC = inferior vena cava; BAS = balloon atrial septostomy; BTS = Modified Blalock Taussig shunt; LPA = left pulmonary artery; MPA = main pulmonary artery

dose of warfarin to maintain the international normalizing ratio (INR) between 1.8 and 2.5.

Statistical Analysis

Data are expressed as the mean value ± SD. Comparisons of results before and after closure of the fenestration were performed using the paired Student’s *t*-test. Statistical significance was defined as *p* < 0.05.

Results

All patients underwent successful occlusion of the fenestration with the use of the Amplatzer ASO device for closure of an atrial septal defect. There was no device embolization or other complications during hospital admission. Six to 12 weeks later, transthoracic 2D echocardiography and color-Doppler revealed complete occlusion of the fenestration. The pulmonary artery pressure measured before fenestration closure was a mean of 11.68 ± 3.47 and the postfenestration closure mean was 13.93 ± 2.46.

The mean oxygen saturation at rest increased from 85.12 ± 7.89% before closure of the fenestration to 94.56 ± 3.63% after the procedure (*p* < 0.01) (Fig. 1). The mean oxygen saturation following exercise increased from 66.21 ± 12.86% before to 87.21 ± 8.64% after the procedure (*p* = < 0.01) (Fig. 2). The duration of mean exercise also increased from 8.22 ± 2.74 min before to 10.29 ± 1.91 min following the procedure (*p* = 0.05) (Fig. 3).

Discussion

The introduction of a fenestration to the Fontan circuit allows a right-to-left shunt as a vent maintaining cardiac output [1, 6, 8]. This effect is achieved at the cost of decreasing systemic oxygen saturation [4, 9]. This procedure can be useful, especially in the early postoperative phase when there is a relative increase in pulmonary vascular resistance [1, 8]. Beyond the acute postoperative stage, the presence of fenestration might not be desirable [3, 5, 7]. Others have reported successful percutaneous closure of a Fontan fenestration in a number of cases without detailed analysis of the effects of closure of the fenestration on exercise tolerance and oxygen saturation before and after exercise [4, 9]. In this study, we found that closure of a fenestration in a patient with a fenestrated Fontan beyond 6 months does not only improve oxygen saturation but also enhances exercise performance. The timing of intervention is not well defined; we have elected

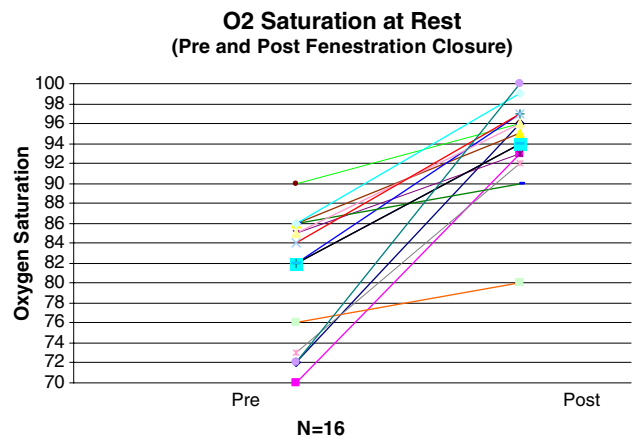


Fig. 1 Effect of fenestration closure on oxygen saturation at rest

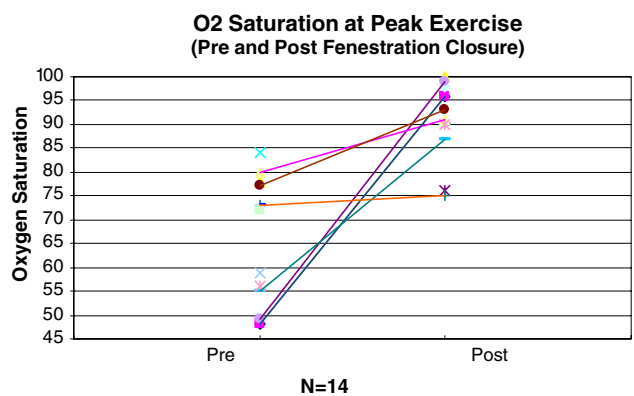


Fig. 2 Effect of fenestration closure on oxygen saturation at peak of exercise

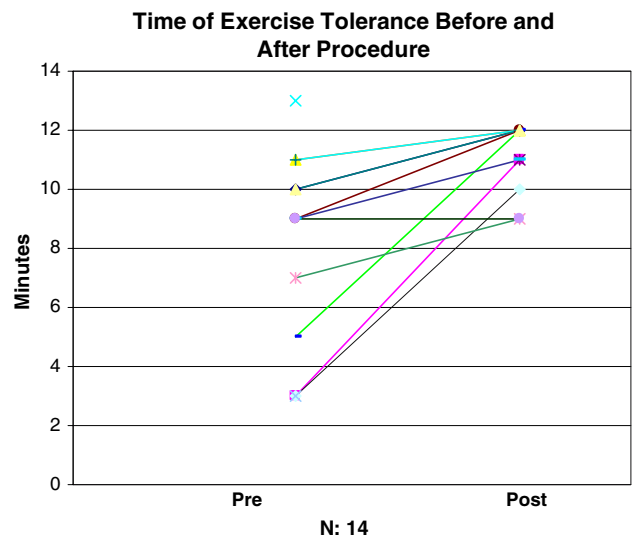


Fig. 3 Effect of fenestration closure on exercise tolerance

to wait for 6 months postoperatively, as for the majority of these patients the fenestrations can close spontaneously within the first 1 year after surgery [10]. Studies of acute

hemodynamic changes, oxygen-carrying capacity, and $\text{VO}_{2\text{max}}$ could not be done in this study.

In summary, closure of a fenestration using the Amplatzer ASO device can be done with minimal risk. It increases oxygen saturation and improves the ability to exercise by preventing a right-to-left shunt. Long-term follow-up is recommended to evaluate the benefits versus the risks of fenestration closure.

References

1. Bridges ND, Mayer JE Jr, Lock JE, et al. (1992) Effect of baffle fenestration on outcome of the modified Fontan operation. *Circulation* 86(6):1762–1769
2. Fontan F, Baudet E (1971) Surgical repair of tricuspid atresia. *Thorax* 26:240–248
3. Giannico S, Hammad F, Amodeo A, et al. (2006) Clinical outcome of 193 extracardiac Fontan patients: the first 15 years. *J Am Coll Cardiol* 47(10):2065–2073
4. Hijazi Z MD, Fahey J MD, Kleinman C MD, et al. (1992) Hemodynamic evaluation before and after closure of fenestrated Fontan. An acute study of changes in oxygen delivery. *Circulation* 86:196–202
5. Jacobs ML, Pelletier G (2006) Late complications associated with the Fontan circulation. *Cardiol Young Suppl* 1:80–84
6. Lemler M, Scott W, Leonard R, et al. (2002) Fenestration improves clinical outcome of the Fontan procedure. A prospective randomized study. *Circulation* 105:207–212
7. Ono M, Boethig D, Goerler H, Lange M, et al. (2006) Clinical outcome of patients 20 years after Fontan operation: effect of fenestration on late morbidity. *Eur J Cardiothorac Surg* 30(6): 923–929
8. Petrossian E, Reddy VM, Collins KK, et al. (2006) The extracardiac conduit Fontan operation using minimal approach extracorporeal circulation: early and midterm outcomes. *J Thorac Cardiovasc Surg* 132(5):1054–1063
9. Sommer RJ, Recto M, Golinko RJ, Griep RB (1996) Transcatheter coil occlusion of surgical fenestration after Fontan operation. *Circulation* 94(3):249–252
10. Toefig M, Walsh K P, Chan C, Ladusans E, Gladman G, Arnold R (1998) Occlusion of Fontan fenestration using the Amplatzer septal occluder. *Heart* 79:368–370