Results of Additional Pulsatile Pulmonary Blood Flow with Bidirectional Glenn Cavopulmonary Anastomosis: Positive Effect on Main Pulmonary Artery Growth and Less Need for Fontan Conversion

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ABSTRACT

Background: Additional antegrade pulsatile pulmonary blood flow obtained by leaving the main pulmonary artery patent during bidirectional cavopulmonary shunt has been shown to give additional benefits to the bidirectional Glenn cavopulmonary anastomosis. We retrospectively evaluated our 20-patient pulsatile Glenn series in order to find out whether these salutary effects were valid or not.

Methods: Between June 2007 and November 2011, 20 patients (11 girls and 9 boys) with single-ventricle physiology underwent bidirectional cavopulmonary anastomosis. The additional source of blood flow was through the unligated main pulmonary artery in all patients. A retrospective review of our surgical experience was performed focusing on the role of additional pulmonary flow. Medical records and perioperational and postoperative follow-up data including clinical outcomes were retrospectively retrieved and analyzed.

Results: Two patients died in the early postoperative period. One patient died in the follow-up period. Mean follow-up time was 23.9 ± 15.7 months. No superior vena cava syndrome and no increase in pulmonary vascular resistance were observed. Improvement of partial oxygen pressure after pulsatile Glenn has been shown in all patients (P = .00). At a mean interval of 22.9 months, main pulmonary artery size continued to increase after pulsatile Glenn cavopulmonary anastomosis (P = .028). Only 1 patient was converted to Fontan type circulation after pulsatile Glenn cavopulmonary anastomosis.

Conclusions: The pulsatile cavopulmonary shunt is a useful procedure in the early and intermediate term management of patients with a functional univentricular heart. It improves partial oxygen pressure and the impact of pulsatility on the main pulmonary artery.

INTRODUCTION

Anastomosis of the superior vena cava (SVC) to the right pulmonary artery as therapy for cyanotic heart disease was first reported by Meshalkin in 1956 (as reported by Bickford and Edwards) and then by Glenn in 1958 [Meshalkin 1956; Glenn 1958; Bickford 1960]. Bidirectional Glenn cavopulmonary anastomosis (BDG) has been used as an intermediate palliation stage in patients with single ventricle physiology since the 1960s. This operation is useful when there is no possibility of constructing a 2-ventricle circulation. Glenn cavopulmonary anastomosis makes a partial separation of the pulmonary and systemic circulations possible.

BDG has several physiological advantages. It increases pulmonary blood flow without increasing volume load, leading to improved mechanical efficiency, causes less pulmonary artery distortion, and prevents pulmonary hypertension [Caspi 2003; Gray 2007].

Beyond its established usefulness, one thing remains unsolved. Should we have additional pulmonary flow after BDG?

It is a well-known fact that in the presence of a BDG shunt alone to secure pulmonary blood flow, the main pulmonary artery size decreases over time [Miyaji 1996]. Kobayashi et al emphasized the benefit of accessory antegrade pulsatile pulmonary flow (APBF) in preventing the late development of pulmonary arteriovenous malformations [Kobayashi 2001]. It leads to long-term preservation of the myocardium with the addition of pulsatile pulmonary blood flow. Thus, it simplifies an eventual total cavopulmonary connection [Berdat 2005].

The response of the pulmonary vasculature to this unique circulatory physiology is the determining question. There are concerns about pulsatile SVC syndrome, including increased pericardial and pleural effusions and increased incidence of chylothorax [Berdat 2005; Neema 2009].

Sources of additional antegrade pulmonary blood flow may be from (1) construction of a systemic pulmonary artery (PA) anastomosis (Blalock–Taussig [BT] shunt); (2) through a stenosed PA with a gradient across the valve; or (3) controlled banding of the native PA. In our series, we used the native stenosed pulmonary artery as the only additional antegrade pulmonary blood flow.

Here we report the results of BDG with APBF in our 20-patient series.

MATERIAL AND METHODS

We retrospectively reviewed the clinical and surgical records of 20 patients (11 girls and 9 boys) who underwent BDG with pulsatile pulmonary flow (APBF) between June 2007 and November 2011 in our institution. Informed consent was obtained in all cases.

Patient Selection

In every case scheduled for bidirectional Glenn cavopulmonary anastomosis, cardiac anatomy was considered unsuitable for biventricular repair. As for inclusion criteria, attention was paid to patients with mean PA pressure less than 15 mmHg and systolic pressure less than 20 mmHg, as suggested by Freedom et al [Freedom 1998]. PA and SVC sizes were also taken into consideration. It was confirmed that there was no mismatch between PA and the SVC. Two patients, who were not included in the study, were denied BDG operation because of SVC and PA size mismatch. They were palliated with modified BT shunts. Patients with severe atrioventricular valve regurgitation were not operated using BDG.

Postoperative follow-up ranged from 6 to 55 months (mean, 23.9 ± 15.7 months) and was complete for all patients. The patients were followed by general pediatricians, but they were also seen by the referring pediatric cardiologist every 3 months. Data obtained in serial follow-up visits at the referring cardiologist's office included chest radiography, systemic arterial oxygen saturation obtained by pulse oxymetry on room air, and echocardiographic study assessing ventricular function and atrioventricular valve regurgitation. Cardiac catheterization was performed in all patients before BDG. Only 1 postoperative cardiac catheterization was needed in the pulsatile Glenn patients.

Morbidity was defined as chest tube drainage of 10 days or more, hospital length of stay of 14 days or more, presence of chylothorax, need for hospital readmission, emergency cardiac catheterization, or reoperation.

Surgical Technique

All operations were carried out using the standard median sternotomy approach using cardiopulmonary bypass (CPB). The patients were premedicated after their parents' written consents were taken for anesthesiological interventions and surgical operation. After routine monitorization (electrocardiogram, noninvasive blood pressure, partial oxygen pressure),

induction of anesthesia was performed. Intubation with endotracheal tube was made. Invasive blood pressure monitorization via a radial artery catheter and central venous pressure monitorization via the left internal jugular vein (in order to prevent interfering with cannulation of the SVC) were established.

Aortic cross-clamping was not used. The SVC was anastomosed in an end-to-side fashion to the right PA. We used 7-0 polypropylene sutures for the anastomosis, and we tried to make the anastomoses as wide as possible. The main pulmonary artery (MPA) was left patent in all patients. The anastomoses were constructed paying attention to incise the right PA as wide as the SVC. We took care to make wide anastomoses and tried to leave no purse-string narrowness in order to avoid shear stress. The azygous vein was clipped or ligated in all patients except 1 who had azygous vein continuation. The MPA was left uninterrupted in all patients.

Statistical Analysis

Data are expressed as mean ± standard deviation for continuous variables and percentages for categorical variables. The Wilcoxon signed-ranks test was used to evaluate the degree of significance between preoperative and postoperative MPA dimensions and preoperative and postoperative partial oxygen pressures on room air. Statistical analyses were performed using a software program (SPSS version 11, SPSS, Chicago, IL, USA). Statistical significance was defined as a P value less than or equal to .05.

RESULTS

There were 11 female and 9 male patients. The average age of the patients was 36.7 months. Mean weight at operation was 12.37 ± 7.15 kilograms. Mean preoperative ambient oxygen pressure was 69.9 ± 11.9%. MPA dimension was 9.17 ± 3.21 mm. Mean PA pressure was 9.71 ± 3.90 mmHg (Table 1).

There were 8 patients with double outlet right ventricle (DORV), 7 patients with complex single ventricle, 5 patients with tricuspid atresia, and 1 patient with pulmonary atresia with malposition of the great arteries and double SVC (Table 2).

The previous surgical procedures were modified BT systemic-to-pulmonary artery shunts in 2 patients and PA banding in 6 patients (Table 3). The median time from the previous surgical procedure to the BDG operation was 10 months (mean, 12.4 ± 6.2 months).

Table 1. Demographic Features and Preoperative Data

Age, m	36.7 ± 39.4 (range, 6-180)
Sex	11 girls (55%), 9 boys (45%)
Weight at operation, g	12.376 ± 7.151 (range, 6.500-38.900)
Preoperative O$_2$ saturation, %	69.9 ± 11.9 (range, 42-88)
Preoperative right atrial pressure, mmHg	7.62 ± 3.70 (range, 2-13)
Main pulmonary artery dimension, mm	9.17 ± 3.21 (range, 5.4-15.4)
Mean pulmonary artery pressure, mmHg	9.71 ± 3.90 (range, 3-14)
Pulmonary artery gradient, mmHg	65.1 ± 24.2 (range, 10-109)

Table 2. Anatomical Lesions

Diagnosis	Number
Tricuspid atresia	5
Pulmonary atresia with malposition of the great arteries and double superior vena cava	1
Double outlet right ventricle	8
Complex single ventricle	6
n (total)	20

Table 3. Previous Surgical Procedures

Modified Blalock-Taussig shunt	2 patients (10%)
Pulmonary banding	5 patients (25%)

Nineteen patients had unilateral BDG with APBF (95%). One patient had bilateral BDG (Kawashima) with APBF. This was a 7-month-old male patient with pulmonary atresia with malposition of the great arteries and double SVC. CPB time was 53.85 ± 18.97 minutes (range, 27 to 94 minutes). There was 1 reoperation (5%). There were no reoperations for bleeding (Table 4).

Table 4. Operative Variables

Unilateral bidirectional Glenn cavopulmonary anastomosis (BDG)	19 patients (95%)
Bilateral BDG (Kawashima type)	1 patient (5%)
Cardiopulmonary bypass time, min	53.85 ± 18.97 (range, 27-94)
Reoperation	1 patient (5%)
Reoperation from bleeding	none

Mean duration of ventilatory support was 13.76 ± 5.1 hours. Length of intensive care unit (ICU) stay was 4.5 ± 5.3 days. Total length of hospital stay was 13.2 ± 8.9 days (Table 5).

No pulsatile SVC syndrome was observed. Two patients (10%) exibited prolonged pleural effusions. The only prominent morbidity was the number of prolonged hospital stays (>14 days), which was seen in 7 patients (35%). There was 1one incident of supraventricular tachycardia (SVT), which was successfully treated with beta blocker therapy. Long-term freedom from arrythmia was 95%. No pulmonary arteriovenous malformation was observed in the follow-up period. We observed no pericardial effusions or chylothoraces (Table 6).

All patients had > 80% systemic arterial oxygen saturation by pulse oxymetry on room air postoperatively. Improvement of partial oxygen pressure after pulsatile Glenn cavopulmonary shunt in comparison to preoperative levels was shown in all patients (P = .00). Postoperative MPA dimension (at a mean interval of 22.9 months after operation) became 14.19 ± 4.74 mm. This shows a statistically significant increase in size in comparison to preoperative MPA size (P = .028) (Table 5).

Two patients died in the early postoperative period (10%). One of them was a 15-month-old complex single ventricle patient who died of sepsis and right atrial thrombus in the pediatric ICU. The other patient was a 14-month-old single ventricle male patient who died 14 days after operation. He showed signs of pulmonary overflow. His MPA was ligated in a reoperation 3 days after BDG with APBF. He died of low cardiac output 11 days after reoperation. One patient died 6 months after the operation due to pneumonia. Therefore, early mortality was 10%, and overall mortality was 15% (Table 6).

Table 6. Postoperative Complications and Morbidities

Complication	Number of Patients
Reoperation	1 (5%)
Prolonged pleural effusion	2 (10%)
Pericardial effusion	0
Chylothorax	0
Supraventricular tachycardia	1 (5%)
Pulsatile superior vena cava syndrome	0
Pulmonary artery thrombosis	0
Right atrial thrombosis	1 (5%)
Arteriovenous malformations	0
Prolonged hospital stay (>14 days)	7 (35%)
Early mortality	2 (10%)
Overall mortality	3 (15%)

Only 1 patient with complex single ventricle physiology (5%) was converted to Fontan type circulation 51 months after BDG with APBF. Follow-up time was 23.9 ± 15.7 months (1.99 ± 1.31 years; range, 6 to 55 months).

Table 5. Hemodynamic Variables after Bidirectional Cavopulmonary Anastomosis

Duration of ventilatory support, h	13.76 ± 5.1 (range, 4.25-21.83)
Postextubation ambient O_2 saturation, %	87 ± 4.45 (range, 78-93)
Chest tube drainage, mL	138.5 ± 86.5 (range, 30-330)
Length of intensive care unit stay, d	4.5 ± 5.3 (range, 2-24)
Length of hospital stay, d	13.2 ± 8.9 (range, 4-33)
Postoperative main pulmonary artery dimension (at a mean interval of 22.9 months after operation), mm	14.19 ± 4.74 (range, 9-23)

DISCUSSION

BDG cavopulmonary anastomosis has several advantages, including relief of the volume load on a single functional ventricle [Kobayashi 1991; McElhinney 1998], reduced atrioventricular valve regurgitation, avoidance of PA distortion resulting from PA banding or a systemic-to-pulmonary artery shunt, reduction of ventricle size, and prevention of pulmonary vascular obstructive disease [Silvilairat 2008]. In 1991, Kobayashi et al first reported the use of BDG with an additional pulmonary blood flow in children not suitable for the Fontan procedure, which is the standard definitive palliation in such patients [Kobayashi 1991].

A number of disagreements exist regarding BDG, including timing of the procedure [Silvilairat 2008] and the interval to Fontan completion. Moreover, there is contention regarding the use or elimination of accessory pulsatile forward pulmonary blood flow [Silvilairat 2008].

Proponents for the provision of APBF cite many advantages and refer to more physiological levels of oxygen saturation, inhibition of pulmonary arteriovenous malformations, and the potential to decrease development of PA collateral vessel development [Silvilairat 2008]. Kobayashi et al also reported APBF benefit in preventing the development of pulmonary arteriovenous malformations because of the delivery of hepatic venous blood to the pulmonary capillaries [Kobayashi 1991]. Our series showed a significant improvement in postoperative ambient oxygen pressures in comparison to preoperative levels ($P = .00$) (Table 5). Our results also show a clear tendency in favor of abscence of arteriovenous malformations after pulsatile Glenn (Table 6).

Because BDG provides less pulmonary flow than the normal or eventual Fontan circulation, it may lead to limited PA before any Fontan completion [Mendelsohn 1994; Gray 2007]. Growth of the pulmonary bed has been shown to be strongly flow-dependent in patients who are Fontan candidates [Tatum 2006]. Therefore, since BDG is being performed as an interim solution before an eventual Fontan circulation can be constructed, a better form of pulmonary flow should be contemplated and devised. APBF is such a suitable option at this stage.

As Miyaji et al reported, it is a well-known fact that in the presence of BDG shunt alone (in the absence of antegrade pulsatile pulmonary flow), MPA size decreases over time [Miyaji 1996]. However, as Uemura et al reported, maintenance of forward flow from the ventricle may protect against regression of pulmonary arterial size [Uemura 1995]. This was the case in our series. As the results of this study confirmed, at least for the medium term, at a mean interval of 22.9 months, MPA size continued to increse after BDG with APBF ($P = .028$).

It has been suggested that the growth of pulmonary arteries does not match the increase in body size after a BDG anastomosis and after total cavopulmonary shunt [Reddy 1996; Tatum 2006]. Whether this is due to inadequate pulmonary blood flow and lack of pulsatility at a critical time in the growth and development of the pulmonary arteries or to some other cause remains to be fully elucidated. It has been speculated that this poor PA growth may be a contributing factor to late Fontan failure [Tatum 2006].

Despite potential advantages of leaving competitive forward flow, many centers routinely perform BDG with ligation of all alternative sources of pulmonary flow. This stems from the concern that leaving pulsatile flow may result in excessively high PA pressure and the development of SVC syndrome and chronic effusions [Webber 1995]. It has also been stated that APBF may elevate central venous pressure, increase ventricular volume load, and negatively impact Fontan candidacy. It has also been implicated in increased interstage morbidity on the way to Fontan operation, including prolonged chest tube drainage, increased pulmonary vascular resistance, and longer length of hospital stay [Gray 2007]. Data from our results may be interpreted as not supporting these concerns. As our results demonstrate, this was not the case with our group of 20 patients.

After bidirectional cavopulmonary shunt, pulmonary endothelial functional attenuation has been shown, and decreased pulsatility of cavopulmonary flow has been blamed for this endothelial abnormality [Kurotobi 2001]. Pulsatility may be a factor in better clinical results obtained from pulsatile BDG operations.

There were 5 single-ventricle patients who were not included in this study in whom we have made a conversion to total cavopulmonary circulation during the almost 5-year study period. All of these patients converted to the Fontan circulation were non-pulsatile BDG patients with no anterograde pulmonary artery flow. These patients had low oxygen saturations in comparison to the pulsatile BDG group. Only 1 patient with univentricular cardiac anatomy physiology who underwent BDG with APBF was converted into Fontan type circulation. This patient was included in the study because it was a pulsatile Glenn cavopulmanary shunt.

Postoperative oxygen saturations are high in our 20-patient series. They continue to have oxygen saturations greater than 80% on ambient air. All patients are free from heart failure. No medication other than acetyl salicilic acid are prescribed. All patients are asymptomatic. Quality of life is good. There has been only 1 patient who needed conversion to total cavopulmonary connection. This patient had an uneventful recovery after lateral tunnel-type Fontan repair. We have observed only one SVT in the postoperative follow-up period. Freedom from arrrythmia has been 95%.

Disadvantages of APBF after BDG are higher postoperative central venous pressures and a risk for development of chylothorax [Frommelt 1995]. Although some studies demonstrated increased rates of persistent pleural effusions and development of SVC syndrome [Neema 2009], we have found no SVC syndrome, no low cardiac output, and few arrhythmias after creation of the bidirectional cavopulmonary anastomosis in the presence of APBF through the main PA. Postoperative deterioration of atrioventricular valve regurgitation was not observed.

Frommelt et al underlined in their report the possibility that antegrade pulmonary flow may elevate systemic venous pressure resulting in an increased volume overload on the single ventricle and a higher incidence of persisitent pleural effusions [Frommelt 1995]. Our experience shows that this may not be the case because we encountered no SVC syndrome in any patient. Absence of pulsatile SVC syndrome shows prudent patient selection on behalf of the referring pediatric cardiologist [Neema 2011]. Leaving APBF has beneficial effects for carefully selected patients after BDG.

We observed 2 mortalities in the early postoperative period. One of them, the 15-month-old complex single ventricle patient, was due to sepsis and right atrial thrombus, and the patient died in the pediatric ICU 29 days after operation.

The other was a 14-month-old single ventricle male patient who died 14 days after operation. He showed signs of pulmonary overflow. His MPA was ligated in a reoperation 3 days after BDG with APBF. He died of low cardiac output 11 days after reoperation.

The follow-up period after the BDG operation is very important. Close follow-up is necessary to prevent late complications and to decrease cardiac and noncardiac mortality. A general pediatrician should follow the BDG patients because problems related to systems other than the cardiovascular system may occur. It is our institutional policy to endorse our BDG patients to have follow-ups carried out by general pediatricians.

Families should also be educated on possible symptoms of complications that may appear in the follow-up period in order to quickly recognize noncardiac and cardiac problems. If closer follow-up and well-timed medical management could have been possible, we might not have lost 1 patient due to pneumonia 6 months after BDG with APBF. We increased our educational talks with families after this unfortunate event.

CONCLUSION

The results of this analysis demonstrate beneficial effects of an additional source of pulsatile pulmonary blood flow on the outcome of bidirectional cavopulmonary anastomosis. The analysis showed a significant increase of partial oxygen saturation (P = .000) and continuing PA growth (P = .028) after BDG with APBF. It should surely be stated that it is highly unlikely that a single management strategy will be optimal in patients with single-ventricle physiology [Mainwaring 2003], yet BDG with APBF may be seen as a definitive (terminal) palliation in patients who may never attain candidacy for Fontan type repair as Miyaji, McElhinney, and others have proposed earlier [Miyaji 1996; McElhinney 1998].

Study Limitations

The power of our study is limited because it was not a controlled, randomized study. The number of patients is relatively low, and the follow-up time is as yet short. Despite these imperfections, our results seem to be generally applicable because they are in close concordance with those of recently published articles.

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