Turk Gogus Kalp Dama 2015;23(3):441-447
doi: 10.5606/tgkdc.dergisi.2015.10351

Original Article / Özgün Makale

The effects of leaving additional pulmonary blood flow in combination with bidirectional cavopulmonary anastomosis on early outcomes

Bidireksiyonel kavopulmoner anastomoz sırasında ilave pulmoner kan akımının bırakılmasının erken dönem sonuçlara etkisi

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ABSTRACT

Background: This study aims to assess the effects of additional pulmonary blood flow on the early outcomes of patients who underwent bidirectional cavopulmonary anastomosis due to single ventricle physiology.

Methods: A total of 121 patients (62 males, 59 females; mean age 45.2±41.1 months; median age 31 months; range 4-252 months) who underwent bidirectional cavopulmonary anastomosis between January 2004 and July 2010 were retrospectively analyzed. Patients were divided into two groups as having (group 1) or not having (group 2) additional pulmonary blood flow accompanied by bidirectional cavopulmonary anastomosis. There was no demographic difference between the groups.

Results: While mortality was seen in three patients (3.4%) in group 1, there was none (0%) in group 2 (p=0.55). Mean postoperative oxygen saturation value was 87.1±5.8 in group 1 and 83.4±6.1 in group 2 (p=0.01). Mean duration of intensive care stay was 3±5.4 days (median 2.0 days) in group 1 and 3.3±2.2 days (median 3.0 days) in group 2 (p=0.02). Mean duration of hospital stay was 9.2±7.3 days (median 7.0 days) in group 1 and 11.6±7.8 days (median 8.0 days) in group 2, with a statistically significant difference between the groups (p=0.03).

Conclusion: Oxygen saturation values are higher and durations of intensive care and hospital stay are shorter in patients with additional pulmonary blood flow in early postoperative period. Maintenance of antegrade pulmonary blood flow in patients with pulmonary arterial pressure at ≤16 mmHg who underwent bidirectional cavopulmonary anastomosis provides an improved postoperative clinical course.

Keywords: Bidirectional cavopulmonary anastomosis; palliation; pulmonary blood flow; single ventricle physiology.

ÖZ

Amaç: Bu çalışmada tek ventrikül fizyolojisi nedeniyle bidireksiyonel kavopulmoner anastomoz yapılan hastalarda ilave pulmoner kan akımının erken dönem sonuçlara etkileri değerlendirildi.

Çalışma planı: Ocak 2004 - Temmuz 2010 tarihleri arasında bidireksiyonel kavopulmoner anastomoz yapılan 121 hasta (62 erkek ve 59 kız; ort. yaş 45.2±41.1 ay; medyan yaş 31 ay; dağılım 4-252 ay) retrospektif olarak incelendi. Hastalar, bidireksiyonel kavopulmoner anastomoz ile birlikte ilave pulmoner kan akımı olan (grup 1) ve olmayan (grup 2) olarak iki gruba ayrıldı. Gruplar arasında demografik farklılık yoktu.

Bulgular: Mortalite grup 1'de üç hastada (%3.4) görülürken, grup 2'de yoktu (%0) (p=0.55). Ameliyat sonrası ortalama oksijen satürasyonu değeri grup 1'de 87.1±5.8, grup 2'de 83.4±6.1 idi (p=0.01). Yoğun bakımda ortalama yatış süresi grup 1'de 3±5.4 gün (medyan 2.0 gün), grup 2'de 3.3±2.2 gün (medyan 3.0 gün) idi (p=0.02). Hastanede ortalama yatış süresi gruplar arasında istatistiksel olarak anlamlı bir farklılıkla grup 1'de 9.2±7.3 gün (medyan 7.0 gün), grup 2'de 11.6±7.8 gün (medyan 8.0 gün) idi (p=0.03).

Sonuç: Ameliyat sonrası erken dönemde ilave pulmoner kan akımı olan hastalarda oksijen satürasyon değerleri daha yüksek, yoğun bakımda ve hastanede kalış süreleri daha kısadır. Pulmoner arter basıncının ≤16 mmHg olduğu bidireksiyonel kavopulmoner anastomoz yapılan hastalarda antegrad pulmoner kan akımının korunması daha iyi bir ameliyat sonrası klinik seyri sağlar.

Anahtar sözcükler: Bidireksiyonel kavopulmoner anastomoz; palyasyon; pulmoner kan akımı; tek ventrikül fizyolojisi.

Available online at
www.tgkdc.dergisi.org
doi: 10.5606/tgkdc.dergisi.2015.10351
QR (Quick Response) Code

Received: May 18, 2014 *Accepted*: November 22, 2014

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Bidirectional cavopulmonary (BDCP) anastomosis is important in palliative surgery for patients with a single ventricle[1,2] because it has several advantages, including reducing the functional volume load of the single ventricle, decreasing pulmonary artery (PA) distortion caused by modified Blalock-Taussig (mBT) shunts, and lowering the risk of pulmonary vascular disease resulting from long-term left-to-right shunting, which eventually facilitates Fontan circulation.[3,4] However, this procedure also runs the risk of causing arteriovenous fistula (AVF) formation as well as reduced PA development.[5] Furthermore, leaving an additional source of pulmonary blood flow (PBF) in place during BDCP anastomosis is still controversial.[3,6-8] In this study, we aimed to assess how the additional PBF affected the early outcomes of patients who underwent BDCP anastomosis.

PATIENTS AND METHODS

This study was conducted in accordance with the principles of the Helsinki Declaration using a study protocol that was approved by the hospital ethics committee. Between January 2004 and July 2010, the clinical and surgical records of 121 patients (59 females, 62 males; mean age: 45.2±41.1 months; median age 31 months; range 4-252 months) who underwent BDCP anastomosis at Dr. Siyami Ersek Hospital were retrospectively analyzed. Those with a history of prior surgery in another healthcare institution were excluded from the study. Echocardiography was performed on all of the patients prior to the procedure, and catheterization was also carried out. However, the catheterization efforts failed in seven patients due to either pulmonary stenosis (PS) or a lack of antegrade blood flow. In these patients, because of the decrease in blood flow to the PA, we accepted that the PAP was on the lower side of the limits set for this study.

The patients were divided into two groups. Group 1 underwent BDCP anastomosis with additional PBF while group 2 had the same procedure without the additional PBF. The baseline characteristics of the patients are shown in Table 1.

Additional sources of PBF were an antegrade flow from a native pulmonary valve in 76 patients, an adjusted antegrade PBF via pulmonary banding (PAB) in eight patients, previous aortopulmonary shunts in four others, or some combination of these three items.

Fifty-four patients (44%) had received previous palliative interventions, and all prior surgical procedures are shown in Table 2 by patient groups. We also recorded the age, gender, weight, pre- and postoperative PAP, arterial oxygen saturation rates, systemic arterial pressure, hemoglobin levels, extubation times, length of intensive care unit (ICU) and hospital stays, mortality rates, and the presence of arrhythmia and pleural effusion for each patient.

A median sternotomy was performed on each of the study participants. Thirty-four patients in group 1 and 15 in group 2 were operated on under normothermic cardiopulmonary bypass. Moderate hypothermia (32 °C), if needed, was maintained, and blood cardioplegia was used to achieve cardiac arrest. A temporary passive shunt was then inserted between the superior vena cava (SVC) and the right/systemic venous atrium in 72 patients who underwent an off-pump procedure, and

Table 1. Baseline characteristics of the patient groups

	Group 1 (n=87)				Group 2 (n=34)				
	n	Mean±SD	Median	Range	n	Mean±SD	Median	Range	*p*
Age (months)		49.4±49.6	32.5	4-252		33.9±29.7	28.0	6-156	0.10
Gender									0.32
Males	47				15				
Females	40				19				
Weight (kg)		15.8±11.8	12			11.7±8.2	9.7		0.16
Preoperative oxygen saturation		77.6±7.2				76.7±7.1			0.63
Hemoglobin (g/dL)		15.7±2.8				14.7±2.9			0.19
Pulmonary artery pressure (mmHg)		11±2.9				11.5±3.2			0.57
Right atrial pressure (mmHg)		9.1±4.4				7±1.6			0.02
McGoon index		1.9±0.1				2.3±1.6			0.35
Qp/Qs		0.9±0.3	0.9			1.4±1.10	0.9		0.57
Pulmonary vascular resistance (Wood)		1.4±1.2	1.1			2.3±0.9	2.4		0.09

SD: Standard deviation; Qp/Qs: Pulmonary-systemic flow ratio.

Table 2. Previous procedures performed prior to bidirectional cavopulmonary anastomosis

	Group 1 (n=87)		Group 2 (n=34)	
	n	%	n	%
Modified Blalock-Taussig shunt	17		12	
Pulmonary artery banding	2		4	
Bilateral pulmonary artery banding	1		–	
Multiple shunts	2		–	
Aortopulmonary central shunt	–		1	
Ductus arteriosus stenting + modified Blalock-Taussig shunt	–		2	
Ductus arteriosus stenting	4		4	
Balloon pulmonary valvuloplasty	2		–	
Balloon atrial septostomy	3		–	
Total	31	37	23	67

standard end-to-side anastomosis was also performed using a 7/0 prolene suture.

The PAP was monitored via a jugular vein catheter in all of the patients, and all measurements were performed under normothermic conditions while the patients were in sinus rhythm and on 50% inspired oxygen. Any previous mBT shunts were left open until the BDCP anastomosis was completed, and no repairs were made for patent ductus arteriosus. When the Glenn pressure was 16 mmHg, the mBT shunt was ligated, and either PAB was performed or the band was tightened based on the need for an arterial OS rate of between 70 and 85%.

In two of the three patients in group 1 who had previously undergone PAB, PBF was restored by tightening the band, and in four patients in group 2 who had also undergone the PAB procedure, the antegrade blood flow was completely blocked by tightening the band. Moreover, PBF was restored using PAB in six patients in group 1, and the blood flow was completely blocked by ligating the band to the main PA in four patients in group 2. In addition, we closed the mBT shunt in 16 of the 19 patients in group 1 who had previously undergone this procedure in order to regulate the antegrade blood flow.

Table 3. Additional procedures performed during bidirectional cavopulmonary anastomosis

	Group 1 (n=87)		Group 2 (n=34)	
	n	%	n	%
mBT shunt division	15		10	
Patent ductus arteriosus division	5		4	
Pulmonary artery reconstruction	5		3	
Pulmonary banding	7		4	
mBT shunt division + pulmonary banding	1		1	
mBT shunt division + pulmonary artery reconstruction	–		1	
Patent ductus arteriosus ligation + mBT shunt division + pulmonary banding	–		1	
Patent ductus arteriosus ligation + pulmonary banding	–		2	
Patent ductus arteriosus ligation + pulmonary artery reconstruction	1		1	
Patent ductus arteriosus ligation + atrial septectomy	2			
Patent ductus arteriosus ligation + mBT shunt division + pulmonary artery reconstruction	–		2	
Atrial septectomy	1		–	
TAPVR correction	1		–	
TAPVR correction + pulmonary artery reconstruction + mBT shunt	1		–	
Pulmonary artery reconstruction + pulmonary valvulotomy	1		–	
Annuloplasty + atrial septectomy	2		–	
Total	42	48	29	85.2

mBT: Modified Blalock-Taussig; TAPVR: Total anomalous pulmonary venous return.

The persistent left SVC was anastomosed to the left PA in 11 patients in group 1 and three patients in group 2. Patients with azygos continuation of the vena cava had already been excluded from the study. A total of 42 patients in group 1 and 29 in group 2 underwent additional intervention with BDCP anastomosis. All additional procedures are shown in Table 3. The patients were weaned from mechanical ventilation under mild sedation, and the Glenn pressure and systemic arterial pressure were continuously monitored while they were in the ICU.

Statistical analysis

Statistical analysis was performed using the 2007 version of the Number Cruncher Statistical System (NCSS) software program (NCSS, LLC, Kaysville, Utah, USA) and the 2008 version of the Power Analysis and Sample Size (PASS) Statistical Software 2008 (NCSS, LLC, Kaysville, Utah, USA). In addition to descriptive statistical methods [mean, standard deviation (SD), and frequency), Student's t-test was used to evaluate statistically significant differences in the normally distributed variables between the groups, and a paired sample t-test was used to perform intragroup comparisons. In addition, we utilized the Mann-Whitney U test to evaluate statistically significant differences in the abnormally distributed variables between the groups and used the Wilcoxon signed-rank test for intragroup comparisons. Furthermore, a chi-square test and Fisher's exact test were used to compare the qualitative data between the two groups. We also used a 95% confidence interval (CI), and a *p* value of <0.05 was considered to be statistically significant.

RESULTS

Mortality was seen in three patients (3.4%) in group 1, but all of the patients in group 2 survived (p=0.55).

Exitus 1: Bilateral BDCP anastomosis and total anomalous pulmonary venous return (TAPVR) correction were performed on a 17-month-old patient with dextrocardia, right atrial isomerism, double outlet right ventricle (DORV), an AV canal defect, supracardiac-type TAPVR, PS, and bilateral SVC pathology (postoperative PAP of 10 mmHg). However, the patient died due to acute abdominal syndrome on the postoperative third day.

Exitus 2: A seven-and-a-half-year-old patient had an unguarded tricuspid valve, atrial septal defect (ASD), and right ventricular hypoplasia. The patient had also developed cardiac cachexia. An atrial septectomy, annuloplasty, and BDCP anastomosis were performed, but the patient died on the postoperative first day due to sudden cardiac arrest.

Exitus 3: Off-pump bilateral BDCP anastomosis was performed on a six-and-a-half-year-old patient with a hypoplastic left ventricle, right atrial isomerism, DORV, TAPVR, and PS, and the surgery was performed using a temporary passive shunt. Perioperatively, a complication occurred that was related to the endotracheal entubation tube. Treatment via hypoxic encephalopathy was considered, but the patient developed cardiopulmonary arrest and died on the ninth postoperative day.

The postoperative characteristics of all of the patients are summarized in Table 4. The mean postoperative OS rate was 87.1±5.8 in group 1 and 83.4±6.1 in group 2 (p=0.01). Furthermore, the ICU and hospital stays were significantly shorter in group 1. Moreover, there were no statistically significant differences in the Glenn pressure between the two groups, but a statistically significant pre- and postoperative increases in the PAP were observed in group 1 (p=0.02). However, the same did not occur in group 2 (p=0.08).

Table 4. Postoperative characteristics of the patient groups

	Group 1 (n=87)				Group 2 (n=34)				
	n	%	Mean±SD	Median	n	%	Mean±SD	Median	*p*
Extubation time (hours)			21.2±39.8	7.0			14.7±18.4	9.50	0.60
Length of intensive care unit stay (days)			3±5.4	2.0			3.3±2.2	3.0	0.02*
Length of hospital stay (days)			9.2±7.3	7.0			11.6±7.8	8.0	0.03*
Postoperative oxygen saturation (%)			87.1±5.8				83.4±6.1		0.01*
Postoperative hemoglobin (g/dL)			12.3±1.8				12.5±1.8		0.77
Postoperative Glenn pressure (mmHg)			12.1±2.6				11.7±3.8		0.67
Mortality	3	3.4			0	0			0.55

SD: Standard deviation; * p<0.05.

During the postoperative period, six patients had prolonged pleural effusion (>7 days), two had supraventricular tachycardia (SVT), and two had convulsions. In addition, one patient in group 1 was revised due to excessive chest drainage.

The six patients in group 1 with prolonged pleural effusion had a Glenn pressure of <15 mmHg, and they were treated and followed up with medical therapy. Three had chylothorax, and one also had SVT. One of the two patients with convulsions underwent PAB due to a Glenn pressure of 22 mmHg, and this dropped to 14 mmHg after the procedure. The other patient with convulsions became agitated and had a Glenn pressure of 19 mmHg after being weaned from mechanical ventilation. He was closely monitored, and the agitation resolved with medical therapy.

One patient in group 2 with blocked PBF (PAB) had a Glenn pressure of >20 mmHg, and a 2-3 mm antegrade blood flow was seen on control echocardiography. The tape on the PA, which had been previously compressed with clips, was removed, and new tape was applied to block the antegrade PBF. Afterwards, the Glenn pressure decreased to 14 mmHg. Additionally, three of the five patients in group 2 with prolonged pleural effusion developed chylothorax. These patients were administered medical treatment, and no increases in the Glenn pressure were observed.

DISCUSSION

In single-ventricle pathologies, the ventricle has to maintain both the systemic and pulmonary blood circulation since they are parallel circuits. This presents the dual problems of arterial desaturation, both at rest and at increased rates during exercise, and chronic volume overload of the single ventricle, which can impair ventricular function over time.[9] The major merit of BDCP anastomosis is that it increases the systemic arterial OS rate without loading on the functional ventricular volume.[1] In addition, this procedure enables pulmonary perfusion without increasing the PAP.[10]

Bidirectional cavopulmonary anastomosis in combination with PBF is still controversial[11] because the added PBF may adversely affect the reduction of the single ventricular volume load, an advantage of the BDCP anastomosis physiology. Thus, pulmonary vascular complications may occur as a result.[5] However, the additional PBF may also offer some advantages such as raising the basal cyanotic levels and providing increased exercise tolerance because of the elevated OS values.[5]

Some authors have reported increased postoperative OS values in patients who undergo BDPC anastomosis with additional PBF versus those who undergo only the anastomosis.[12] Although we observed higher postoperative OS values in our patients who underwent BDPC anastomosis with additional PBF, there were no statistically significant differences in the mortality rates between the groups. Moreover, the high OS values, which can be attributed to the higher PBF, were actually anticipated.

Various authors have also reported that a higher incidence of prolonged pleural effusion in patients who receive additional PBF, which can lead to increased morbidity and longer hospital stays.[13,14] However, other studies have suggested that there are no differences between the prolonged pleural effusion rates and the SVC syndrome in these patients.[11] Similarly, we observed no differences in the prolonged pleural effusion rates between the two groups in our study. Furthermore, there were no differences in the Glenn pressure, which can be attributed to the similar pleural effusion rates. In addition, no differences in the PAP (<16 mmHg) were noted among the patients with chylothorax, which might have been caused by a lymphatic injury during the dissection.

Regulating the antegrade blood flow is another matter up for debate. Low-level antegrade blood flow cannot maintain an effective increase in the OS rate. Likewise, the increased blood flow may result in a higher PAP or even heart failure. Recently, some have suggested that all sources of antegrade blood flow be blocked,[15] but others have recommended the preservation of these sources.[12] Furthermore, many surgeons prefer to maintain an antegrade blood flow when the PA pressure falls below 16 mmHg during BDCP anastomosis.[11] In the study by Chang et al.,[15] they maintained an antegrade blood flow in patients with an arterial OS rate of below 70%; however, our clinical experience indicates that this flow should be maintained in patients with a PAP of 16 mmHg and an arterial OS rate of below 85%.

Several studies have also reported higher PAP values in patients who underwent BDCP anastomosis with additional PBF compared with those who underwent only the anastomosis procedure,[15,16] but the PAP values in our two groups were similar.

Furthermore, Caspi et al.,[11] found that previous aortopulmonary shunts caused PA distortion. In our study, we observed the same thing, and eight patients (10%) in group 1 and seven (20.5%) in group 2 had to undergo PA reconstruction. In the majority of these

patients, mBT shunting or patent ductus arteriosus stenting was performed. Furthermore, we believe that the mBT shunt may be left in place if it is unlikely to cause PA distortion and if it does not lead to an increase the PAP in patients who are scheduled for BDCP anastomosis.

Another controversial issue is PA development following BDCP anastomosis. Previous reports of PA growth after BDCP anastomosis have described either an increase in the PA diameter, no change in the diameter,[17,18] or a decrease in the diameter of the PA contralateral to the cavopulmonary anastomosis.[19] Reddy et al.[20] also showed that all PA indices decrease on average, but the changes did not reach statistical significance in their study. Therefore, when taking into consideration PA development, we suggest that an additional source of PBF should be maintained via an antegrade pathway.

Furthermore, not only do OS values decrease as children get older, but the contribution of SVC blood flow to the systemic venous circulation tends to be reduced.[21] Therefore, patients with antegrade PBF may survive with a high OS value for a longer period of time.

In our study, we observed statistically significant differences in the length of the ICU and hospital as well as the postoperative OS values between the two groups. Therefore, we believe that an additional source of PBF should be present in patients who undergo BDCP anastomosis, a procedure which can provide beneficial short-term outcomes such as higher OS values and shorter ICU and hospital stays. Furthermore, an adjusted antegrade PBF is likely to develop in a well-balanced setting in the right-to-left PAs and pulmonary vascular bed. Moreover, in the absence of proximal stenosis, well-balanced PAs indicate an improved distal bed. As a result, it can be hypothesized that improvement in the PAs can be achieved via antegrade blood flow in patients with a single-ventricle physiology, especially in those who are candidates for Fontan circulation. However, it is also possible to perform BDCP anastomosis with antegrade blood flow as the final surgery. As a case in point, Yurlov et al.[22] found no significant differences in the 15-year survival rates among patients who underwent BDCP anastomosis with antegrade blood flow and those who required a Fontan operation.

One of the limitations of this study was that it was a single-center experience; thus, further studies are needed that involve patients at multiple facilities to verify our findings. Furthermore, the study was retrospective in nature, and it was not randomized. Moreover, there was an unbalanced distribution of the antegrade blood supply in the patients with an antegrade blood flow.

Conclusion

In this study, the early postoperative results showed higher arterial OS values and shorter ICU and hospital stays for those patients who had additional PBF along with the BDCP. Antegrade PBF can be achieved in patients who undergo this type of anastomosis with an improved postoperative clinical course if the PAP is maintained at ≤16 mmHg. In addition, due to the potential long-term positive results, antegrade PBF in patients with BDCP must be protected as much as possible.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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