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## Original Article

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# Two hundred and twenty-nine cases of bidirectional cavopulmonary anastomosis with and without antegrade pulmonary blood flow, a single-center experience

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**Abstract**

Bidirectional cavopulmonary anastomosis is palliative surgical procedure for stepwise adaptation of the ventricle by time-phased relief of blood volume from the single functional ventricle. There still exists a controversial question regarding maintaining additional antegrade pulmonary blood flow. We retrospectively reviewed the surgical cases of 261 patients who underwent bidirectional cavopulmonary anastomosis in our institution from 2012 to 2022 with special regard to antegrade pulmonary blood flow as our preferred strategy. The mean age at the time of surgery was 33.1 months (range 2.9–192 months), and the mean weight was – 7.6 kg (range 3.9–38 kg). Furthermore, we divided all the patients into two groups: in group 1 ($n = 182$) – patients who underwent bidirectional cavopulmonary anastomosis with antegrade pulmonary blood flow, and in group 2 ($n = 47$) – patients without antegrade pulmonary blood flow. The mean follow-up time was 56 months (range 24–120 months). Mortality rate was 4.8 % ($n = 11$) in the past 10 years. Statistical difference between groups was in the following positions: group 2 had less ICU stay ($p < 0.000125$) and hospital stay ($p < 0.017110$); group 1 had a longer duration of pleural effusion ($p < 0.000003$) and amount of drainage output ($p < 0.007$), also demonstrated higher oxygen saturation ($p < 0.000264$) and Glenn shunt pressure ($p < 0.002$) after the surgery; but there was no difference in oxygen saturation after 6, 12, and 24 months; mortality in both groups has no statistic difference. Considering our experience, we take a stand on the controlled to antegrade pulmonary blood flow strategy during bidirectional cavopulmonary anastomosis.

## Introduction

In patients with functional single ventricle physiology, bidirectional cavopulmonary anastomosis is a palliative staged surgical procedure before total cavopulmonary connection. It allows stepwise adaptation for the ventricle by time-phased relief of blood volume from the single functional ventricle and prevents complications that can occur.[1–4]

There still exists a controversial question regarding maintaining additional antegrade pulmonary blood flow. Some research centres[5,6] claim that persistent antegrade pulmonary blood flow enhances the growth of pulmonary veins (PAs) (because of pulsatile blood flow), prevents pulmonary arteriovenous malformations, and improves arterial oxygen saturation. Other research centres[7] insist that antegrade pulmonary blood flow potentially raises central venous pressure exposing the venous system to ventricular pressure, resulting in a higher prevalence of superior caval vein syndrome and persistent pleural effusions or late development of chylothorax.

## Materials and methods

### Patients

We retrospectively reviewed the surgical cases of 261 patients who underwent bidirectional cavopulmonary anastomosis in our institution from 2012 to 2022. The 32 patients were excluded from the study, due to a lack of information needed for statistical analysis. As a result, we analyzed 229 patients: the mean age at the time of surgery was 53.1 months (range 2.9–192 months), and the mean weight was – 7.6 kg (range 3.9–38 kg). The variety of congenital heart anomalies in this cohort is shown in Table 1, most of the patients had an association of heart defects. Furthermore, we divided all the patients into two groups: in group 1 ($n = 182$) – patients who underwent bidirectional cavopulmonary anastomosis with antegrade pulmonary blood flow, and in group 2 ($n = 47$) – patients who underwent bidirectional cavopulmonary

**Table 1.** Patients characteristics

| Variables | | | All patients $n = 229$ | Group 1 ($n = 182$) | Group 2 ($n = 47$) |
|---|---|---|---|---|---|
| Age at BCPA (m) mean (Range) | | | 33.1 (2.9–192) | 36.7 (2.9–176) | 25.4 (2.9–204) |
| Weight (kg) mean (Range) | | | 7.6 (3.8 –38) | 13.3 (3.8 –40) | 11 (3.9–36) |
| Diagnosis | Tricuspid atresia, % | | 48 (20.9%) | 35 (15.2%) | 13 (5.6%) |
| | Mitral atresia, % | | 8 (3.4%) | 6 (2.6%) | 2 (0.8%) |
| | Hypoplastic left heart syndrome, % | | 2 (0.8%) | 1 (0.4%) | 1 (0.4%) |
| | CAVSD, % | | 26 (11.3%) | 14 (6.1%) | 12 (5.2%) |
| | TAPVC, % | | 4 (1.7%) | 1 (0.4%) | 3 (1.3%) |
| | Double-outlet right ventricle, % | | 47 (20.5%) | 35 (15.2%) | 13 (5.6%) |
| | Ebstein anomaly, % | | 7 (3.0%) | 7 (3%) | 0 (0%) |
| | Pulmonary atresia, % | | 44 (19.2%) | 25 (10.9%) | 19 (8.2%) |
| | TGA, % | | 32 (13.9%) | 9 (3.9%) | 23 (10%) |
| | ccTGA, % | | 22 (9.6%) | 6 (2.6%) | 16 (6.9%) |
| | LVOTO, % | | 5 (2.1%) | 1 (0.4%) | 4 (1.7%) |
| | ASD, % | | 24 (10.4%) | 15 (6.5%) | 9 (3.9%) |
| | VSD, % | | 154 (67.2%) | 104 (45.4%) | 50 (21.8%) |
| | RV-CorA fistula, % | | 5 (2.1%) | 2 (0.8%) | 3 (1.3%) |
| | Pulmonary stenosis | Valvar pulmonary stenosis | 12 | 11 (4.8%) | 1 (0.4%) |
| | | Supravalvar pulmonary stenosis | 3 | 3 (1.3%) | 0 (0%) |
| | | Subvalvar (infundibular) pulmonary stenosis | 12 | 12 (5.2%) | 0 (0%) |
| | | Mixt | 49 | 46 (20%) | 3 (1.3%) |
| | | Pulmonary artery banded | 74 | 66 (28.8%) | 8 (3.4%) |
| Ventricular dominance | | Left, % | 99 (43.2%) | 84 (36.6%) | 15 (6.5%) |
| | | Right, % | 21 (9.1%) | 19 (8.2%) | 2 (0.8%) |

BDCPA = bidirectional cavopulmonary anastomosis; CAVSD = complete atrioventricular septal defect; TAPVC = total anomalous pulmonary venous connection; TGA = transposition of the great arteries; ccTGA = congenitally corrected transposition of the great arteries; LVOTO = left ventricular outflow tract obstruction; ASD = atrial septal defect; VSD = ventricular septal defect; RV-CorA fistula = right ventricle – coronary artery fistula.

anastomosis without antegrade pulmonary blood flow. The cohort in both groups was statistically homogeneous. The mean follow-up time was 56 months (range 24–120 months) after bidirectional cavopulmonary anastomosis, (11) 4.8 % were lost to follow-up. The final result was determined as either bidirectional cavopulmonary anastomosis as a definitive procedure, Fontan completion, or death. Information in the patient's database was obtained after follow-up visits where the following examinations were performed: systemic arterial oxygen saturation on room air gained by pulse oximetry and echocardiographic study, cardiac catheterization, if needed.

Each patient undergoes cardiac catheterisation before bidirectional cavopulmonary anastomosis or bidirectional cavopulmonary anastomosis. Another indication for cardiac catheterisation included: evidence of excessive aortopulmonary or intrapulmonary collaterals and worsening cyanosis.

## Surgical technique

All procedures were performed through a median sternotomy using aortic and bicaval cannulation with moderate hypothermic cardiopulmonary bypass. Previously created systemic-to-pulmonary shunts were removed. Albeit there is no need for aortic cross-clamping for bidirectional cavopulmonary anastomosis alone, in some patients aortic cross-clamping with cardiac arrest, or artificial fibrillation was induced for intracardiac repair or revision. Cavopulmonary connection was performed by anastomosing the superior caval vein to the right pulmonary artery in an end-to-side fashion with some technical modification to prevent anastomotic stenosis. In cases with additional left superior vina cava (LSVC), bilateral bidirectional cavopulmonary anastomosis was performed in all cases. Azygos vein was ligated, except for patients with azygos continuation of interrupted inferior caval vein.

Bidirectional cavopulmonary anastomosis with antegrade pulmonary blood flow is our preferred institutional strategy. If antegrade pulmonary blood flow was present, PA (pulmonaty artery) banding is established, and the circumference of the band is determined by saturation (75–85% on FiO2 21%) and central venous pressure (15 mm Hg).

## Statistical analysis

Retrospective records of pre-and post-operation patients who underwent bidirectional cavopulmonary anastomosis (BDCPA) in our institution from 2012 to 2022 were analysed. The SPSS

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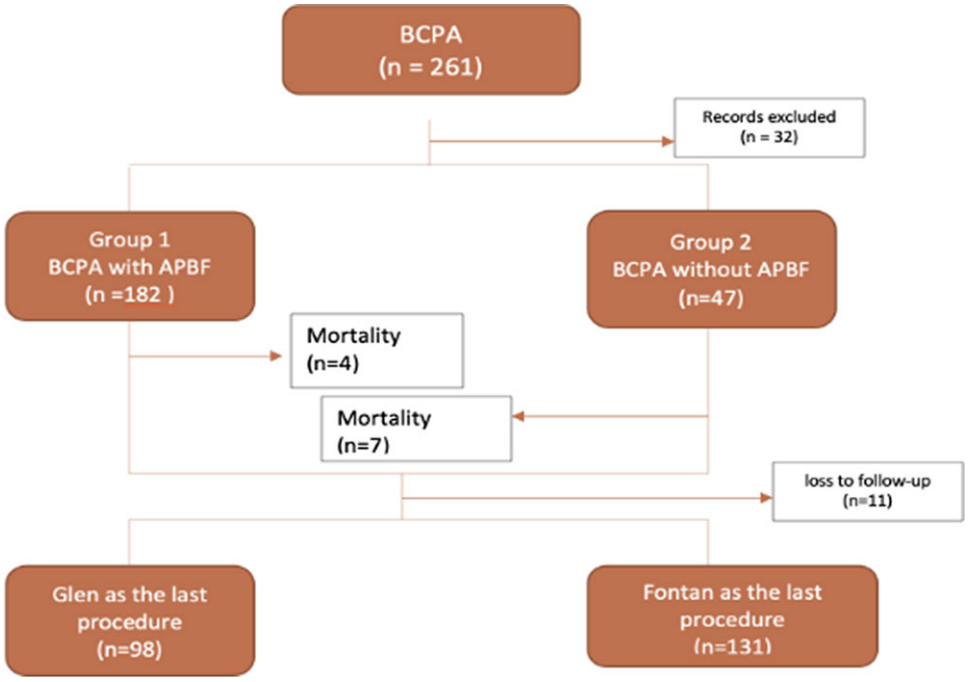


**Figure 1.** Overview of the study cohort.

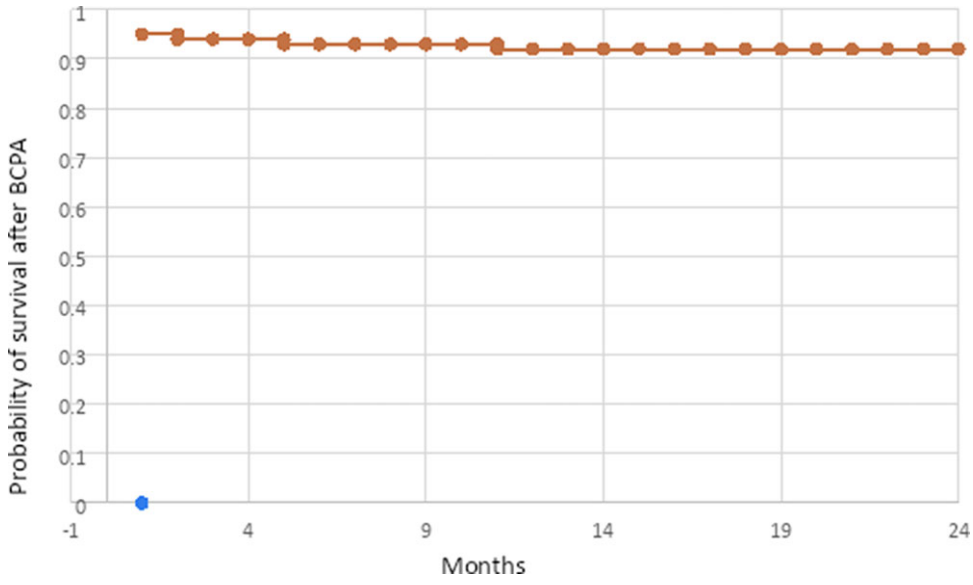


**Figure 2.** Kaplan–Meier survival (includes hospital mortality).

statistical program for Windows version 10 (SPSS Inc., Chicago, Ill) was used for data analysis. The results of this study are presented as median with the range. For group comparison, we used a Mann–Whitney test. A Kaplan–Meier test was used for survival analysis. A $p$-value of less than 0.05 was considered statistically significant.

## Results

In our centre, BDCPA is routinely performed at age 33.1 months (range 2.9–192) with an average weight of 7.6 kg (range 3.9 –38) in patients with single ventricle anatomy. The final result was determined as either BDCPA as a definitive procedure, Fontan completion, or death (Figure 1). Each patient undergoes catheterization before the surgical procedure.

Mortality rate was 4.8 % ($n = 11$) in the last 10 years. A Kaplan–Meier curve demonstrates the probability of survival at 24 months after BDCPA - 0.92 (Figure 2).

In Table 2 we demonstrate postoperatively results in patients who underwent BDCPA and in Table 3 we compared two groups of study: group 1 ($n = 182$) - patients who underwent BDCPA with antegrade pulmonary blood flow and group 2 ($n = 47$) - patients who underwent BDCPA without antegrade pulmonary blood flow. Our research has shown that the statistical difference between the two groups was in the following positions: group 2 had less ICU stay ($p < 0.000125$) and hospital stay ($p < 0.004910$) than group 1; group 1 had a longer duration of pleural effusion ($p < 0.000003$) and amount of drainage output ($p < 0.007$) in comparison with the group 2; group 1 demonstrated higher oxygen saturation ($p < 0.000264$) and Glenn shunt pressure ($p < 0.002$) after the

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**Table 2.** Postoperative results

| Variables | All patients $n = 229$ | Group 1 ($n = 182$) | Group 2 ($n = 47$) | $p$-value |
|---|---|---|---|---|
| Hospital stays (days), mean | 17.3 | 17 | 12.9 | 0.004910 |
| Intensive care stay (days), mean (Range) | 5.8 (0–78) | 7.02 | 5.1 | 0.000125 |
| Post-operative drainage (days), mean (Range) | 3 (3.1–25) | 5.1 | 3.4 | 0.000003 |
| Pleural effusion ml/kg, mean (Range) | 25.6 (2.7–285.4) | 28.9 | 13.1 | 0.007640 |
| Glenn shunt pressure during the surgery (mmHg), mean (Range) | 14.3 (4–23) | 16.8 | 14.2 | 0.000013 |
| Glenn shunt pressure after extubation (mmHg), mean (Range) | 13.3 (8–27.2) | 13 | 11.8 | 0.002235 |
| Systemic infection | 25 | 20 | 5 | 0.478820 |
| Mean oxygen saturation at ICU, % | 84.1 (60–95) | 86.3 | 79 | 0.000264 |
| Mean oxygen saturation (at the time of discharge from hospital), % | 85.1 (71–96) | 85.5 | 82 | 0.000815 |
| Mean oxygen saturation after 6 months, % | 85.3 (66–96) | 85.9 | 83.5 | 0.167970 |
| Mean oxygen saturation after 12 months, % | 85.3 (72–96) | 85.9 | 83.9 | 0.103233 |
| Mean oxygen saturation after 24 months, % | 86.8 (67–96) | 85 | 85.2 | 0.100020 |
| Mortality, (%) | 11 (4,8) | 4 (1,7) | 7 (3) | 0,070103 |

Groupe 1 – Bidirectional cavopulmonary anastomosis with antegrade pulmonary blood flow; Groupe 2 – Bidirectional cavopulmonary anastomosis without antegrade pulmonary blood flow.

surgery; but there was no difference between the groups in oxygen saturation after 6, 12, 24 months; mortality in both groups has no statistic difference.

## Discussion

Patients with functional single ventricle physiology must undergo BDCPA as an intermediate step before the Fontan procedure, which allows stepwise adaptation for the ventricle by time-phased relief of blood volume from the single functional ventricle.[1–4]

In our center, BDCPA is routinely performed from 3 to 6 months in patients with single ventricle anatomy. However, the exact time is still controversial because early BDCPA is a high risk of postoperative complications. Still, on the other hand – it's positively induced on the body growth and long-term outcomes in the next stage – Fontane procedure.[8,9] Each patient undergoes catheterization before the surgical procedure. Other palliative interventions, depending on how well pulmonary and systemic blood flow is balanced, may be needed in the neonatal period.

The literature review demonstrates that in most institutions mortality rate is between 1 to 13% in cohorts with different anatomic conditions and ages.[10–12] Our center achieved a mortality rate of 4.8 % ($n = 11$) in the last 10 years, which demonstrates good technique and postoperative patient care in the ICU.

Risk factors for mortality and morbidity included: age less than 3 months, high transpulmonary gradient, low weight, pulmonary branch stenoses, and severe preoperative cyanosis, which were also shown by other institutional studies.[13,14]

Furthermore, in this study, we analyzed our center strategy concerning antegrade pulmonary blood flow in patients who underwent BCPA, as it is still a controversial question in most institutions. Antegrade pulmonary blood flow is provided through the native pulmonary artery that can be banded if needed and determined by saturation (75–85% on FiO2 21%) and central venous pressure (15 mmHg).

Our study has shown that there is no difference between the two groups of study (group 1 - patients who underwent BDCPA with antegrade pulmonary blood flow and group 2 - patients who underwent BDCPA with no APBF) in aspects of survival, but the patients with antegrade pulmonary blood flow have higher saturation in the first 6 months that positive induced on body growth and long-term outcomes on the next stage – Fontane procedure, prevents pulmonary arteriovenous malformations and enhances the growth of PAs. But on the other hand, antegrade pulmonary blood flow is a trigger for a longer duration of pleural effusion which as a consequence leads to longer ICU and hospital stays.

In summary, considering our experience and foreign institutions' experience, we recommended the controlled antegrade pulmonary blood flow strategy during the BCPA. However, we have been analyzing the further condition of patients with antegrade pulmonary blood flow to improve their long-term outlook.

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**Competing interests.** None.

**Ethical standards.** This manuscript does not involve human or animal experimentation.

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