Bilateral Pulmonary Artery Banding as Rescue Intervention in High-Risk Neonates

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Background. Presentation in shock and preoperative infection remain risk factors for neonatal cardiac surgery. This report describes bilateral pulmonary artery banding (bPAB) in ductal-dependent lesions with systemic outflow obstruction as rescue intervention before surgery with cardiopulmonary bypass in these high-risk neonates.

Methods. A retrospective chart review was conducted for 10 patients who underwent bPAB before conventional surgery with cardiopulmonary bypass. Patient characteristics including birth weight, gestational age, cardiac and noncardiac diagnoses, preoperative and postoperative markers of organ function, and outcome measures were examined.

Results. The majority of patients (8 of 10) were considered high-risk owing to multiorgan dysfunction syndrome. The median age at bPAB was 12 days (range, 5 to 26 days), and the median interval between bPAB and second surgery was 10.5 days (range, 5 to 79 days). Organ function improved after admission and continued to improve after bPAB in 9 of 10 patients. No patient experienced new complications between bPAB and subsequent operation. Of 8 patients who had stage I palliation, 5 have undergone or are awaiting completion Fontan, 1 underwent Kawashima procedure, 1 underwent orthotopic heart transplant, and 1 with hypoplastic left heart syndrome and intact atrial septum died at 44 days old. Both patients who underwent biventricular repair are alive and well. Median follow-up for survivors was 2.9 years (range, 0.25 to 6.25 years).

Conclusions. Bilateral pulmonary artery banding is safe in ductal-dependent lesions with systemic outflow obstruction. High-risk patients with preoperative organ dysfunction or infection can recover within a short period and become lower risk candidates for complex congenital heart surgery using cardiopulmonary bypass.

For patients with complex congenital heart lesions dependent on a patent ductus arteriosus for systemic blood flow, such as hypoplastic left heart syndrome or interrupted aortic arch, conventional treatment is neonatal repair using deep hypothermic cardiopulmonary bypass (CPB). These patients can present with shock and end-organ dysfunction as well as preoperative infection, greatly increasing the risk of surgery [1–3].

Bilateral pulmonary artery banding (bPAB) as a means of controlling pulmonary blood flow while awaiting a more definitive surgical procedure avoids exposure to CPB and may improve systemic perfusion. Maintenance of ductal patency can be achieved by means of either a ductal stent or continuous prostaglandin E1 (PGE1) infusion. Although some centers have reported success with bPAB and ductal stenting [4, 5], other outcomes have not been as favorable [6, 7], and a steep learning curve has been documented [8]. This report describes use of bPAB with a preferred method of PGE1 infusion for ductal patency as rescue intervention before surgery with CPB in high-risk neonates with preoperative organ dysfunction or infection.

Patients and Methods

Ten patients with ductal-dependent congenital heart disease owing to systemic outflow obstruction who underwent bPAB as rescue intervention before conventional surgery with CPB between 2003 and 2011 were identified, and a retrospective chart review was conducted. Approval for the study was obtained from the Children’s Hospital of Wisconsin Institutional Review Board.

The technique for branch pulmonary artery banding in this series of patients included a median sternotomy incision, followed by dissection of the branch pulmonary arteries. From a 3.0- or 3.5- mm Gore-Tex graft (W.L. Gore & Assoc, Flagstaff, AZ), segments 2 to 3 mm in length were cut and incised longitudinally. These small...
segments of graft were passed around the proximal branch pulmonary arteries and reapproximated using 6-0 polypropylene sutures. Because retraction on the main pulmonary artery is required to expose the left pulmonary artery and because this can compromise pulmonary blood flow, the left pulmonary artery was banded first. Indications of adequate banding included a reduction in arterial saturation to 85% to 90% on 50% inspired oxygen and an increase in systemic arterial pressure. Neither echocardiography nor angiography was used to assess the adequacy of banding.

Ductal patency was maintained with PGE1 infusion at 0.01 µg·kg⁻¹·min⁻¹ with the exception of 1 patient who required ductal stenting for ductal constriction refractory to PGE1. Unless otherwise specified, routine intensive care unit monitoring included continuous recording of heart rate, blood pressure, systemic arterial oxygen saturation (Sao₂), end-tidal carbon dioxide, central venous pressure, and cerebral and somatic tissue oxyhemoglobin saturation measured using near infrared spectroscopy. Medical management was aimed at optimizing systemic oxygen delivery, targeting Sao₂ greater than 80%, cerebral tissue oxyhemoglobin saturation greater than 50%, and Sao₂ minus somatic tissue oxyhemoglobin saturation difference less than 20%.

Patient characteristics including birth weight, gestational age, cardiac and noncardiac diagnoses, and patient outcomes were collected. Hemodynamic and oximetry data including mean arterial pressure, diastolic blood pressure, coronary perfusion pressure, Sao₂, cerebral tissue oxyhemoglobin saturation, and somatic tissue oxyhemoglobin saturation during the 48 hours preceding bPAB and after bPAB were compared. Preoperative and postoperative markers of organ function were also compared.

Results
The study group is described in Table 1. Each patient had a ductal-dependent lesion with systemic outflow obstruction and preoperative organ dysfunction or infection. Eight of 10 patients had single-ventricle anatomy, including 6 patients with hypoplastic left heart syndrome, 1 of which had an intact atrial septum. Three of 10 patients had extracardiac congenital abnormalities or genetic syndromes. The majority of patients (8 of 10) were considered high risk for surgery with CPB owing to preoperative multiorgan dysfunction syndrome, whereas the remaining 2 patients required treatment for bacteremia. In 2 patients (of 4 diagnosed with congenital heart disease in the postnatal period), organ dysfunction was associated with presentation in cardiogenic shock. One patient with intact atrial septum had low cardiac output after atrial septectomy on day 1 of life. Three patients exhibited abdominal distention, with concern for evolving sepsis on the day before scheduled complex surgery with CPB. One patient born at 30 weeks’ gestation experienced necrotizing enterocolitis on the day of scheduled complex surgery, and 1 patient had multiorgan dysfunction syndrome after a complication during heart catheterization. Average birth weight was 2.93 kg (±0.69 kg). The median age at bPAB was 12 days (range, 5 to 26 days), and the median interval between bPAB and the second surgery was 10.5 days (range, 5 to 79 days), with a median age at the time of the second surgery of 22 days (range, 10 to 81 days). Timing of the second surgery, either biventricular repair or stage I palliation (S1P), was dependent on the patient’s clinical course with particular attention to recovery of organ function.

Hemodynamic data for the 48 hours before bPAB and the 48 hours after bPAB were examined for each patient. Table 2 summarizes these observations. Eight of 10 patients demonstrated higher average mean arterial pressure in the 48 hours after bPAB compared with the 48 hours before the intervention (Fig 1). The average coronary perfusion pressure (calculated as the difference between diastolic blood pressure and central venous pressure) and organ perfusion pressure (calculated as the difference between mean arterial pressure and central venous pressure) increased after bPAB in 6 patients.

Table 1. Patient Characteristics and Current Status

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Diagnosis</th>
<th>Preoperative Risk Factors</th>
<th>Second Surgery</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HLHS, AA, MA</td>
<td>Cardiogenic shock, MODS</td>
<td>SIP-RVPAC</td>
<td>Completion Fontan</td>
</tr>
<tr>
<td>2</td>
<td>HLHS, AS, MS</td>
<td>MODS</td>
<td>SIP-RVPAC</td>
<td>Completion Fontan</td>
</tr>
<tr>
<td>3</td>
<td>HLHS, AA, IAS</td>
<td>MODS</td>
<td>SIP-RVPAC</td>
<td>Deceased</td>
</tr>
<tr>
<td>4</td>
<td>HLHS, AA, MS</td>
<td>Preoperative ex-laparotomy, portal vein thrombosis</td>
<td>SIP-RVPAC</td>
<td>Awaiting Fontan</td>
</tr>
<tr>
<td>5</td>
<td>HLHS, AS, MS</td>
<td>Sepsis</td>
<td>SIP-MBTS</td>
<td>Awaiting Fontan</td>
</tr>
<tr>
<td>6</td>
<td>TA/TGA/coarctation</td>
<td>Sepsis</td>
<td>SIP-MBTS</td>
<td>Awaiting Fontan</td>
</tr>
<tr>
<td>7</td>
<td>TA/TGA/arch hypoplasia, Williams syndrome</td>
<td>MODS</td>
<td>SIP-MBTS</td>
<td>Awaiting Fontan</td>
</tr>
<tr>
<td>8</td>
<td>HLHS, AA, MA, heterotaxy</td>
<td>Congenital junctional rhythm, MODS</td>
<td>SIP-MBTS</td>
<td>Kawashima</td>
</tr>
<tr>
<td>9</td>
<td>IAA type B, ASD, VSD</td>
<td>Low birth weight, prematurity, MODS, necrotizing enterocolitis</td>
<td>Biventricular repair</td>
<td>Alive</td>
</tr>
<tr>
<td>10</td>
<td>IAA type B, ASD, MS, DiGeorge</td>
<td>Cardiogenic shock, MODS</td>
<td>Biventricular repair</td>
<td>Alive</td>
</tr>
</tbody>
</table>

AA = aortic atresia; AS = aortic stenosis; ASD = atrial septal defect; BDG = bidirectional Glenn; HLHS = hypoplastic left heart syndrome; IAA = interrupted aortic arch; IAS = intact atrial septum; MA = mitral atresia; MBTS = modified Blalock-Taussig shunt; MODS = multiorgan dysfunction syndrome; MS = mitral stenosis; OHT = orthotopic heart transplant; RVPAC = right ventricle to pulmonary artery conduit; S1P = stage I palliation; TA = tricuspid atresia; TGA = transposition of the great arteries; VSD = ventricular septal defect.
Perfusion pressures could not be calculated in 2 patients in whom a catheter capable of central venous pressure measurement was not present. The average SaO2 and partial pressure of arterial oxygen decreased in the majority of patients (7 of 10), and the SaO2 minus somatic tissue oxyhemoglobin saturation difference narrowed after bPAB for 8 of 10 patients.

Organ function improved after admission, with continued recovery of creatinine after bPAB in 9 of 10 patients (Fig 3). Patient 2 experienced multiorgan injury when intraatrial stent placement was complicated by hemopericardium and tamponade, necessitating 6 minutes of cardiopulmonary resuscitation on the day before bPAB. Mean airway pressure decreased by 2 to 5 cm of H2O in 7 of 10 patients after bPAB. Two patients were extubated before the second surgery, and 50% of patients achieved enteral nutrition between bPAB and the second surgery. No patient experienced a new complication between bPAB and the subsequent operation.

Nine of 10 patients are still alive, with follow-up data available for all surviving patients to a median length of 2.9 years (range, 0.25 to 6.25 years) from the date of bPAB. The single death occurred in a patient who had an emergent atrial septectomy for hypoxia and low cardiac output after delivery by cesarean section for prenatal diagnosis of hypoplastic left heart syndrome with intact atrial septum. Four days later he had bPAB with subsequent S1P with Sano at 15 days of age. He required cannulation for extracorporeal membrane oxygenation on day 34 of life owing to a persistent low cardiac output state. Support was discontinued on day 44 of life after the patient had an intracranial hemorrhage. Of the remaining 7 patients who had S1P, 5 have undergone or are awaiting

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**Table 2. Changes in Hemodynamics and Laboratory Values After Bilateral Pulmonary Artery Banding**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average During 48 Hours Before bPAB (mean ± SD)</th>
<th>Average During 48 Hours After bPAB (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP (mm Hg)</td>
<td>44 ± 4</td>
<td>48 ± 6</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>33 ± 4</td>
<td>35 ± 4</td>
</tr>
<tr>
<td>CPP (mm Hg)</td>
<td>22 ± 4</td>
<td>26 ± 4</td>
</tr>
<tr>
<td>OPP (mm Hg)</td>
<td>33 ± 3</td>
<td>38 ± 5</td>
</tr>
<tr>
<td>SaO2 (%)</td>
<td>91 ± 4</td>
<td>85 ± 5</td>
</tr>
<tr>
<td>Pao2 (mm Hg)</td>
<td>57 ± 14</td>
<td>48 ± 7</td>
</tr>
<tr>
<td>SaO2 – rS02S difference</td>
<td>26 ± 10</td>
<td>18 ± 12</td>
</tr>
<tr>
<td>SaO2 – rS02C difference</td>
<td>25 ± 11</td>
<td>19 ± 13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laboratory Value</th>
<th>Peak Value Before bPAB (mean ± SD)</th>
<th>Value Day Before Second Surgery (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatinine (mg/dL)</td>
<td>1.3 ± 0.7</td>
<td>0.5 ± 0.6</td>
</tr>
<tr>
<td>Albumin (g/dL)</td>
<td>2 ± 0.3</td>
<td>2.6 ± 0.8</td>
</tr>
</tbody>
</table>

bPAB = bilateral pulmonary artery banding; CPP = coronary perfusion pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; OPP = organ perfusion pressure; Pao2 = partial pressure of arterial oxygen; rS02C = cerebral tissue oxyhemoglobin saturation; rS02S = somatic (renal) tissue oxyhemoglobin saturation; SaO2 = systemic arterial saturation; SD = standard deviation.

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completion Fontan, 1 underwent Kawashima procedure, and 1 patient who underwent bidirectional Glenn at 5 months of age had an orthotopic heart transplantation at 13 months of age. Both patients who underwent biventricular repair are alive and well.

Comment

Despite improvement in survival rates for patients undergoing surgery for congenital heart disease, patients with functional single-ventricle physiology and systemic outflow tract obstruction remain a high-risk group. Rather than a Norwood procedure, some centers have opted for an alternative hybrid approach with bPAB and ductal stenting as described by Gibbs and colleagues in 1993 [9]. Some centers have used the technique selectively [10, 11], targeting use in high-risk patients, whereas others have applied the strategy to a broader group of patients such as those with systemic outflow tract obstruction as a bridge to biventricular repair [4, 12].

In our series, bPAB was performed in 10 neonates with ductal-dependent systemic outflow tract obstruction and preoperative organ dysfunction or infection. The preferred method for ductal patency was PGE₁ infusion, which was used in 9 of the 10 patients; 1 patient had a ductal stent in place for 7 days secondary to ductal constriction refractory to PGE₁. Use of bPAB with PGE₁ infusion as a rescue intervention before a conventional S1P has been described previously. Ishizaka and associates [13] and Pizarro and Norwood [14] published reports in 2003 describing dramatic improvement in patient condition after bPAB and survival to discharge in all 3 patients after a Norwood procedure.
procedure. Sasaki and colleagues [15] reported their experience in 12 patients, similar to our study group in regard to diagnoses and risk factors. They also used a strategy of initial palliation with bPAB, maintenance of ductal patency with PGE1 infusion, and choice of conventional S1P with Norwood or biventricular repair for the second surgery (aside from 1 patient who underwent comprehensive stage II procedure). However, patients in their cohort were much older at the time of second surgery (1 to 5 months) versus a median age of 22 days (range, 10 to 81 days) in ours. Although they report high interstage morbidity including ductal constriction and development of branch pulmonary artery stenosis, no patient in our series required pulmonary artery intervention at the time of second surgery. Guleserian and coworkers [16] recently described their experience with bPAB and use of either ductal stenting or PGE1 infusion as a resuscitative intervention in 24 patients who subsequently underwent conventional S1P or primary orthotopic heart transplant. The study included analysis of preoperative and postoperative hemodynamics and laboratory values. Trends in laboratory values and hemodynamics in our series were generally in agreement with those observed by Guleserian and colleagues, with most patients demonstrating increase in mean and diastolic blood pressures, decrease in SaO2 and partial pressure of arterial oxygen, and decrease in the difference between SaO2 and regional tissue oxyhemoglobin saturation difference, as measured by near infrared spectroscopy, after bPAB. Trends in coronary perfusion pressure were not described in the paper by Guleserian and associates [16] for comparison, whereas we report an increase in this variable. Although we report results on a smaller group of patients, overall survival in our series was favorable at 90% compared with 58.3%. Finally, 9 of 10 patients in our series had organ recovery. Of the 9 hospital deaths in the series reported by Guleserian and colleagues [16], 3 patients had support withdrawn owing to renal failure or uncontrollable sepsis.

Optimal timing and choice of the next procedure in patients initially palliated with the hybrid approach is unknown. We opted to proceed with definitive surgery as soon as end-organ function had improved. Planned conventional S1P or biventricular repair rather than comprehensive stage II procedure or primary heart transplantation likely contributes to the relatively short time to second surgery in our series. Although control of heart failure with improved perfusion is desirable, commitment to a prolonged period of branch pulmonary artery banding and ductal stenting requires an operation that will necessarily include management of the incorporated stent and pulmonary artery reconstruction to relieve branch stenosis as a consequence of the branch pulmonary artery banding. In contrast, with our approach the bands can be removed without the need for additional patch arterioplasty, and a standard approach to the aortic arch can be used. No new management strategies need to be learned by the team caring for the patients, and no new procedures are required. We believe this is a reasonable alternative for patients with ducral-dependent systemic blood flow presenting in shock or sepsis.

This study is limited by a nonrandomized, retrospective design. In addition, the cohort was a small and heterogeneous group of patients without a control group for comparative outcomes of organ function and recovery. Patients were managed at a single center and are subject to institutional bias regarding operative and medical management strategies.

In conclusion, we found bPAB with PGE1 infusion to be safe and effective in patients with ductal-dependent systemic outflow obstruction. We believe this is a reasonable alternative for patients with ductal-dependent systemic blood flow presenting in shock or sepsis. High-risk patients with preoperative organ function or infection can recover within a short period and become lower risk candidates for complex congenital heart surgery using CPB.

Financial support for data collection was provided from Wings of Angels.

References

12. Michel-Behnke I, Akintuerk H, Marquardt I, et al. Stenting of the ductus arteriosus and banding of the pulmonary arteries:

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The Thoracic Surgery Foundation for Research and Education (TSFRE) was established in 1988 as a 501(c)(3) not-for-profit charitable organization. Representatives from the four leading thoracic surgery societies - the American Association for Thoracic Surgery (AATS), The Society of Thoracic Surgeons (STS), the Southern Thoracic Surgical Association (STSA), and the Western Thoracic Surgical Association (WTSA) serve on the TSFRE Board of Directors. The Foundation represents all of thoracic surgery in the United States and its research and educational initiatives support the broad spectrum of thoracic surgery.

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