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CASE REPORTS

# Pulmonary Artery Banding Before Norwood Procedure

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**Described here is the use of bilateral pulmonary artery banding as a means to achieve effective restoration of adequate systemic blood flow before a Norwood procedure in two newborns with hypoplastic left heart syndrome who presented after birth with a severe imbalance of Qp/Qs and multiorgan system dysfunction despite usual pharmacologic and ventilatory strategies.**

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An increasing understanding of the physiology exemplified by neonates with single ventricle and a ductus-dependent systemic circulation has led to significant progress in the perioperative management of patients with hypoplastic left heart syndrome (HLHS). Nevertheless, significant challenge still exists when these patients present after birth with significant disparity of flow to the pulmonary versus the systemic circulation, accompanied by inadequate end-organ perfusion that persists despite measures to decrease the high Qp/Qs. We describe here the use of bilateral pulmonary artery banding as a means of achieving increased systemic flow and consequential recovery of severe end-organ dysfunction before a Norwood procedure.

## Case Reports

### *Case 1*

A 2.9-kg newborn presented with grunting and mild cyanosis. The diagnosis of HLHS (aortic atresia, mitral hypoplasia) was made, and PGE1, infusion along with mechanical ventilation were initiated before transport. On admission signs of a high Qp/Qs and low systemic perfusion were evident. Initial arterial blood gas was pH 6.59, $Paco_2$ 15, $Pao_2$ 188, and BE –30. Laboratory findings included a serum creatinine of 2.9 mg/dL, AST 1369 IU, and ALT 300 IU. Nitrogen and $CO_2$ were added to the inspired gas admixture, intravascular volume was repleted, and a dopamine infusion was initiated. All measures were ineffective in balancing the Qp/Qs.

Therefore, through a midline sternotomy, the right and left pulmonary arteries were individually banded. This was readily accomplished by placing a 7F wire or right-angle clamp (Codman, Randolph, MA) adjacent to the outside of the artery proximally. A ligature was tied around the artery and wire combined (Fig 1). The size of the bands was based on approximating the cross-sectional area to a 4-mm systemic-to-pulmonary artery shunt. The combined cross sectional area of two 6F orifices is 3.82 mm and 4.4 mm for a 7F size.

Subsequently, the patient was continued on the same ventilation strategy. Shortly thereafter, signs of a Qp/Qs~ 1 with improved systemic perfusion became apparent. The arterial blood gas showed a pH of 7.37, $Paco_2$ 62, $Pao_2$ 37, and BE +11. Postoperative echocardiography revealed a peak gradient across the right and left pulmonary artery bands of 60 and 52 mm Hg, respectively (Fig 2). Renal, hepatic, and cardiac dysfunction resolved over the next few days. The patient underwent a Norwood procedure 10 days later. The postoperative course was unremarkable, and the patient went home on postoperative day 35.

### *Case 2*

A 2.8-kg newborn was transferred from overseas with diagnosis of HLHS (aortic atresia, mitral atresia). There was moderate atrioventricular valve regurgitation, and the ventricular shortening fraction was severely decreased on echocardiography. Before transport, the patient was intubated and a PGE1 infusion was instituted. Despite ventilation with 21% $FiO_2$ there was significant imbalance of ventricular output towards the pulmonary circulation with signs of poor systemic perfusion. On admission the patient was placed on 3% inspired $CO_2$, the $FiO_2$ was reduced to 17% and a dopamine infusion was begun. Poor peripheral perfusion and metabolic acidosis was unrelenting. The patient was anuric, with a distended abdomen and bloody stools. Arterial blood gas was pH 7.24, $Paco_2$ 17, $Pao_2$ 48, and BE –20. Laboratory values included serum creatinine of 2.8 mg/dL, AST 1097 IU, and ALT 200 IU. The patient underwent bilateral pulmonary artery banding. Soon afterward, there was resolution of the persistent metabolic acidemia and improvement of peripheral perfusion. However, blood cultures grew *Citrobacter Fruendii,* and serial abdominal films revealed extensive colonic pneumatosis. A total abdominal colectomy was performed the following day. Signs of well-balanced Qp/Qs and improved systemic perfusion were sustained, and renal and liver function test returned to normal. Subsequently, a Norwood procedure was performed 6 days after pulmonary artery banding. The remaining hospital course was uncomplicated, and the patient was discharged home on postoperative day 20.

## Comment

After considerable experience and a better understanding of the physiology present in newborns with HLHS, preoperative management of these patients has improved that generally achieves circulatory stability and good end-organ perfusion in preparation for surgical palliation. The critical role played by the balance be-

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tween systemic and pulmonary circulation in newborns with HLHS has long been recognized, and several strategies have been developed to achieve this goal. The usual maneuvers generally include the use of PGE1 infusion and measures to balance pulmonary to systemic resistance ratio including the use of inspired hypoxic admixture, carbon dioxide and judicious use of inotropic agents or vasodilators [1, 2]. In some cases, however, a severe imbalance of Qp/Qs and consequential multiorgan system dysfunction ensues before surgical intervention, raising concern of the added impairment from cardiopulmonary bypass and a period of circulatory arrest. Moreover, in this scenario, pharmacologic and ventilatory maneuvers often prove insufficient because of combined hypotension and markedly elevated systemic vascular resistance and mechanical measures are required to establish adequate systemic perfusion. In the cases presented here, bilateral branch pulmonary artery banding was performed to mechanically limit systolic pulmonary flow and diastolic runoff into the pulmonary circulation. In both cases, pharmacologic and ventilatory strategies failed to restore effective systemic flow. Shortly after pulmonary artery banding there was a significant improvement in systemic perfusion, evidenced by physical signs as well as laboratory data. In addition, this beneficial effect persisted over time, providing the necessary conditions for the recovery of organ dysfunction, and in one case allowed for a major intrabdominal procedure to be performed without significant disturbance of appropriate circulatory balance.

Placement of a tourniquet around the systemic-to-pulmonary artery shunt after the Norwood procedure has been reported to be effective in achieving a balanced Qp/Qs when other measures have failed [3]. Reduction of pulmonary blood flow by pulmonary artery banding was reported by Gibbs and colleagues [4] in a group of patients with HLHS using bilateral pulmonary artery banding, stenting of the PDA and atrial septectomy as an alternative to a Norwood procedure in newborns. However, with a similar approach we have observed intimal hyperplasia through the stent mesh, resulting in obstruction to systemic flow with insidious development of pressure load as well as volume load. In the current era, the use of extracorporeal circulatory support may seem an attractive option to resuscitate these critically ill patients. However, in addition to the deleterious effects of extracorporeal support, the excessive runoff into the pulmonary bed at the expense of systemic perfusion remains a significant problem [5].

With these considerations in mind, we elected to reduce the excessive runoff into the pulmonary vascular bed by performing a bilateral pulmonary artery banding

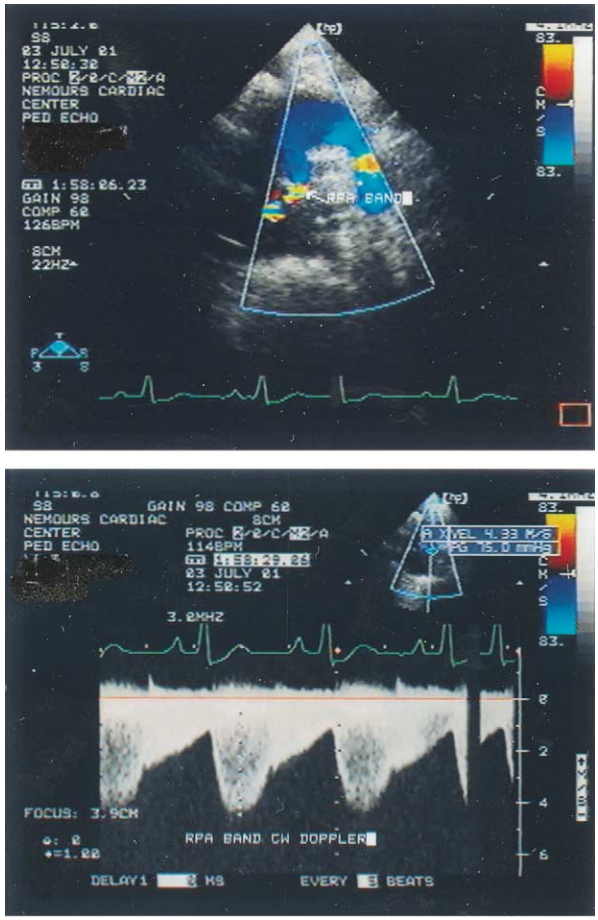


*Fig 2. Postoperative echocardiogram with color (A) and continuous wave Doppler (B) showing narrowing and increased velocity across the right pulmonary artery* (RPA) *band.*

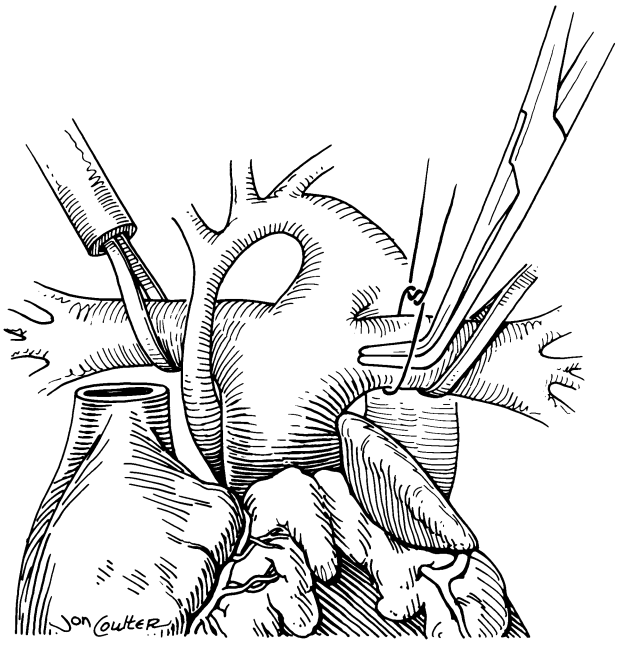


*Fig 1. Schematic drawing of the branch pulmonary artery banding. A tourniquet has been placed around the right pulmonary artery to allow partial control of the pulmonary blood flow while the banding is performed on the left pulmonary artery.*

in preparation for a Norwood procedure. This approach proved to be a simple, quick, and remarkably effective means of restoring a satisfactory systemic perfusion, providing the appropriate circulatory conditions for the recovery of multiple organ dysfunction in these 2 critically ill neonates before a Norwood procedure in the newborn period.

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CASE REPORTS

# Pulmonary-to-Systemic Blood Flow Ratio Oriented Management After Repair of Obstructive Total Anomalous Pulmonary Venous Connection in Neonates With Single Ventricle

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**Caval oxygen saturation was monitored to estimate pulmonary-to-systemic blood flow ratio after relief of obstructive total anomalous pulmonary venous connection in two neonates with single ventricle. Distribution between systemic and pulmonary blood flow was manipulated by pharmacologic, ventilatory, and surgical interventions aimed at achieving pulmonary-to-systemic blood flow ratio of 0.5 to 1.0. Monitoring of pulmonary-to-systemic blood flow ratio facilitates appropriate balancing between tissue perfusion and oxygenation, and detects redundant ventricular volume-load.**

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Recent articles indicate the usefulness of mixed venous oxygen saturation ($SvO_2$) monitoring to estimate pulmonary-to-systemic blood flow ratio (Qp/Qs) in perioperative management of the Norwood procedure [1,2]. We monitored Qp/Qs after repair of pulmonary venous obstruction in two neonates with right isomerism, single ventricle (SV), and supracardiac total anomalous pulmonary venous connection (TAPVC).

Patient 1, a previously asymptomatic female infant, exhibited dyspnea at 20 days of age. She was taken to a community hospital in an ambulance. Because of profound cyanosis, she was intubated, given alprostadil (PGE1), and transferred to our hospital. On admission, arterial blood gas analysis revealed arterial oxygen saturation of 0.47 and acid-base balance of −4.9. Chest radiograph revealed dextrocardia, normal heart size, bilaterally right-sided bronchial arrangement, ground-glass like lung fields, and central liver. Echocardiography disclosed left-sided aortocaval juxtaposition, bilateral superior vena cava (SVC), obstructive total anomalous pulmonary venous connection to the left-sided SVC, single atrium, unbalanced complete atrioventricular septal defect with dominant right ventricle, ventricular l-loop, d-malposition of the great arteries, and pulmonary stenosis. After resuscitation and stabilization, operation was performed the next morning. Intraoperative inspection revealed isomeric right atrial appendages and vertical vein obstruction at its junction with the left-sided SVC. She underwent common pulmonary vein-to-common atrium anastomosis. The vertical vein was left patent. After surgery, the sternum was left open. Qp/Qs was calculated from arterial oxygen saturation ($SaO_2$) and right-sided SVC oxygen saturation as a surrogate of $SvO_2$, assuming pulmonary venous oxygen saturation to be 0.96 (Fig 1). Qp/Qs gradually increased from 1.33 before skin closure to 2.9 at 55th postoperative hour despite pharmacologic and ventilatory manipulations to decrease Qp/Qs. Therefore, pulmonary artery banding was performed concomitantly with sternal closure. Qp/Qs after pulmonary artery banding ranged between 0.51 and 1.29. Endotracheal tube was removed at 110th postoperative hour. Staged total cavopulmonary connection was completed at 3 years old. At 4 years old, although she suffers from neurologic disorder, her cardiopulmonary condition is stable.

Patient 2, a 1-day-old male infant exhibiting cyanosis and tachypnea, was transferred from an obstetrician. Arterial blood gas analysis in room air revealed oxygen saturation of 0.6 and normal acid-base balance. Chest radiograph revealed levocardia, normal heart size, bilaterally right-sided bronchial arrangement, subtly hazy lung field, central liver, and left-sided gastric bubbles. Echocardiography revealed right-sided aortocaval juxtaposition, total anomalous pulmonary venous connection to the left innominate vein, unbalanced complete atrioventricular septal defect with dominant right ventricle, ventricular d-loop, d-malposition of the great arteries, pulmonary atresia, and patent ductus arteriosus. Pulsed


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