Bilateral pulmonary artery banding for resuscitation in high-risk, single-ventricle neonates and infants: A single-center experience

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Objectives: Bilateral pulmonary artery banding with or without ductal stenting has been performed as a resuscitative intervention for patients considered at too high risk for conventional single ventricle palliation. The purpose of the present study was to determine the outcomes using this strategy.

Methods: We performed a retrospective review of 24 patients with single ventricle anatomy who were younger than 3 months who had undergone bilateral pulmonary artery banding and ductal stenting or maintenance of prostaglandin E_1 from January 2007 to October 2011 at our institution. The echocardiographic, angiographic, operative, and clinical data were reviewed. Follow-up data were available for 100% of the patients.

Results: All 24 patients (13 male patients) underwent bilateral pulmonary artery banding at a median age of 8 days (range, 2-44 days). Their gestational age was 38 weeks (range, 27-41 weeks), and their weight was 3.01 kg (range, 1.5-4.4 kg). The cardiac diagnoses included hypoplastic left heart syndrome/variant hypoplastic left heart syndrome in 18, unbalanced atrioventricular canal in 4, and tricuspid atresia in 2. In the hypoplastic left heart syndrome group, 9 (50%) had an intact or a highly restrictive atrial septum requiring open (n = 1) or transcatheter (n = 8) atrial septostomy with or without atrial stent placement (n = 4). Ductal stenting was performed in 14 patients, and 10 patients were continued with prostaglandin E_1. Fifteen patients (62.5%) survived to undergo a Norwood procedure (n = 7), comprehensive stage 2 (n = 1), or primary cardiac transplantation (n = 7). Of the 9 who died, support was withdrawn in 5 because of a contraindication to transplantation, 1 because of sepsis and/or multiorgan system failure, and 1 for whom palliative care was desired. Two died awaiting transplantation. All 7 patients who underwent a conventional Norwood operation survived to discharge, and 6 of the 7 (85.7%) underwent bidirectional Glenn shunt placement. Of the 7 patients who underwent transplantation, 6 (85.7%) were alive at a median follow-up of 33.6 months.

Conclusions: Bilateral pulmonary artery banding with or without ductal stenting is an effective method of resuscitation for high-risk neonates and infants with a single ventricle, allowing for reasonable survival to conventional first-stage palliation or primary transplantation. (J Thorac Cardiovasc Surg 2013;145:206-14)

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Patients with hypoplastic left heart syndrome (HLHS), including variant HLHS and other complex congenital cardiac defects with functional single ventricle (SV) physiology and systemic outflow tract obstruction continue to be a challenge to even the most experienced congenital heart surgeon. Although operative mortality has steadily decreased from the time Norwood performed and reported his first successful procedure in 1981,[1] ‘‘high-risk’’ neonates undergoing first-stage Norwood palliation still face mortality rates of 20% to 50%.[2,3]

Hybrid palliation consisting of bilateral pulmonary artery (PA) banding (bPAB) and ductal stenting (DS) or a ‘‘modified’’ hybrid approach consisting of bPAB and continuation of prostaglandin E_1 (PGE_1) are strategies that have been used for the initial palliation of HLHS until second-stage palliation is undertaken.[4-6]

Early success with the hybrid approach has prompted the increasing use of this strategy for ‘‘high-risk’’ patients with HLHS and other SV anatomy as a less-invasive initial procedure to optimize preoperative hemodynamics and, in turn, improve surgical outcomes.[7-9] Ongoing controversy exists regarding what constitutes ‘‘high-risk’’ criteria, but these have included an intact atrial septum (IAS) or a restrictive atrial septum (RAS), profound metabolic acidosis or pH less than 7, renal insufficiency/failure, moderate or greater atrioventricular valve regurgitation (AVVR), a diminutive aorta, severe ventricular dysfunction, low birth weight, prematurity, preoperative cerebrovascular accident, and/or the presence of an extracardiac syndrome.[2,3] Controversy

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Abbreviations and Acronyms

AVVR	= atrioventricular valve regurgitation
bPAB	= bilateral pulmonary artery banding
CS2	= comprehensive stage 2
DS	= ductal stent/ductal stenting
ECMO	= extracorporeal membrane oxygenation
HAA	= hypoplastic aortic arch
HLHS	= hypoplastic left heart syndrome
IAS	= intact atrial septum
NIRS	= near-infrared spectroscopy
PA	= pulmonary artery
PaO_2	= partial pressure of oxygen
PDA	= patent ductus arteriosus
PGE_1	= prostaglandin E_1
POD	= postoperative day
RAS	= restrictive atrial septum
SaO_2	= oxygen saturation
SV	= single ventricle

continues regarding the optimal timing and appropriate choice for the second-stage procedure.

At Children's Medical Center (Dallas, Tex), we have performed bPAB and DS or continuation of PGE_1 in our ''high-risk'' neonates and infants with HLHS or other SV physiology with systemic outflow tract obstruction for resuscitation and stabilization of these challenging patients as a bridge to conventional Norwood palliation or primary cardiac transplantation when absolute contraindications to Norwood palliation are present.

METHODS

Study Design

We performed a retrospective review of all patients with anatomic or functional SV anatomy who were younger than 3 months and who underwent bPAB and DS or maintenance of PGE_1 from January 2007 to October 2011 at Children's Medical Center. All clinical, echocardiographic, angiographic, and operative data were reviewed. The heart rate, systolic, diastolic, and mean blood pressure, oxygen saturation (SaO_2), partial pressure of oxygen (PaO_2), head and flank near-infrared spectroscopy (NIRS), arteriovenous oxygen difference (using the NIRS data as a surrogate for mixed venous saturation), hemoglobin, lactate, net fluid balance, urine output, serum creatinine, and base deficit recorded immediately before bPAB, 24 hours after bPAB, and 4 days after bPAB. Patients receiving extracorporeal membrane oxygenation (ECMO) support ($n = 4$; 2 before bPAB and 2 after bPAB) were excluded from the analysis of the hemodynamic, laboratory, and fluid balance data. The risk factors for hospital death were assessed. Follow-up was complete for all 24 patients (100%).

Definitions

Patients who died before hospital discharge (including those awaiting transplantation) or within 30 days of bPAB were designated as hospital deaths according to the Society of Thoracic Surgeons National Database criteria. Patients listed for cardiac transplantation who were inactivated (United Network for Organ Allocation status 7) and died within 6 months of listing were considered ''wait list mortalities'' and also designated as hospital deaths.

A restrictive atrial septum (RAS) was defined as a color flow jet width of 3 mm or less across the interatrial septum on the echocardiogram.[10] Ventricular dysfunction and AVVR were graded as mild, moderate, or severe according to the echocardiographic data. Renal failure was defined as anuria or the need for dialysis. Renal insufficiency was defined as oliguria with an increasing creatinine.

Management of IAS or RAS

For neonates with an IAS or RAS diagnosed prenatally, rapid planned transfer from the delivery room to the cardiac catheterization laboratory for emergent radiofrequency perforation or transseptal puncture, balloon atrial septostomy, and atrial stent placement (premounted Genesis stent), in appropriate patients, was undertaken. For those with a postnatal diagnosis of IAS or RAS, similar procedures were performed immediately after the echocardiographic diagnosis.

Operative Technique for bPAB

bPAB procedures were performed in the operating room or cardiac catheterization laboratory (when DS performed simultaneously) with the patient under general anesthesia. After standard median sternotomy and minimal branch PA mobilization, 3.5-mm Gore-Tex grafts were sectioned and secured around the left and right branch PAs to achieve a 10- to 15-mm Hg increase in blood pressure, 10% to 15% decrease in oxygen SaO_2, and 10- to 15-mm Hg decrease in PaO_2. The right PA band was positioned laterally to the ascending aorta. The bands were affixed to the adventitia of the respective branch PAs to prevent migration. Small hemoclips clips were applied for radiographic identification of the banding sites. Intracardiac lines, pacing wires, and an abdominal drain were placed. The sternum was closed, unless the patients had significant intraoperative dysrhythmias or anasarca.

Catheterization Technique for DS Placement

The DS procedures were performed in the cardiac catheterization laboratory with the patient under general anesthesia. After obtaining percutaneous femoral access, the patent ductus arteriosus (PDA) was crossed antegrade with a guidewire over which either a self-expanding or premounted stent was advanced and deployed to position the stent within the full length of the PDA. For patients who underwent simultaneous bPAB and DS placement, direct transpulmonary DS placement was performed using a 6F sheath inserted through a 5-0 Prolene purse-string suture.

Aortic Arch Reconstruction, DS Removal, and PA Debanding During Surgical Palliation and Transplantation

At the Norwood procedure or comprehensive stage 2 (CS2) palliation, after beginning cardiopulmonary bypass, the DS was divided between the hemoclips. The proximal stent was removed from the main PA, and the distal main PA was either oversewn primarily or closed with a patch of autologous pericardium, if necessary. Using selective cerebral perfusion and after cardioplegic arrest, the distal stent was removed from the proximal descending aorta and the area s debrided to normal tissue to prevent aortic dissection. Standard neoaortic arch reconstruction was undertaken using a pulmonary homograft.

For patients undergoing primary transplantation, an end-to-end donor descending thoracic aortic to recipient descending thoracic aortic anastomosis was performed. A recipient brachiocephalic button or ''island''-to-donor transverse arch anastomosis using selective cerebral perfusion was performed, as previously described.[11]

The PA bands were removed, and all adventitial scar tissue was sharply excised. The branch PAs were assessed by both visual inspection and calibrated vascular dilators. When indicated, branch pulmonary arterioplasty was performed using pulmonary homograft, donor PA, or donor pericardium.

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