Paracorporeal lung assist devices as a bridge to recovery or lung transplantation in neonates and young children

David M. Hoganson, MD,[a] Avihu Z. Gazit, MD,[b,c] Umar S. Boston, MD,[a] Stuart C. Sweet, MD,[d] R. Mark Grady, MD,[c] Charles B. Huddleston, MD,[e] and Pirooz Eghtesady, MD, PhD[a]

Objective: To evaluate paracorporeal lung assist devices to treat neonates and children with decompensated respiratory failure as a bridge to recovery or lung transplantation.

Methods: One neonate (23 days old) and 3 young children (aged 2, 9, and 23 months) presented with primary lung disease with pulmonary hypertension, including alveolar capillary dysplasia in 2 and right pulmonary hypoplasia and primary pulmonary hypertension in 1. The patients were listed for lung transplantation but decompensated and required extracorporeal membrane oxygenation (ECMO). The patients were transitioned from ECMO to a pumpless paracorporeal lung assist device (Maquet Quadrox-iD oxygenator in 3, Novalung in 1) with inflow from the pulmonary artery and return to the left atrium.

Results: The patients were weaned from ECMO and supported by the device for 44 ± 29 days (range, 5-74). Three patients were extubated while supported by the device (after 9, 15, and 72 days). One patient was bridged to lung transplant (9 months old, with alveolar capillary dysplasia, supported 5 days). One patient was bridged to recovery with maximal medical therapy (23 months old, with primary pulmonary hypertension, supported 23 days). Two patients died while awaiting a suitable lung donor after a support time of 54 and 72 days.

Conclusions: Pediatric patients bridged from ECMO to lung transplantation have poor results. An alternative method for longer term respiratory support was necessary as a bridge for these patients. The use of a paracorporeal lung assist device successfully supported 4 patients to recovery, lung transplantation, or past the average wait time for pediatric donor lungs (27 days). This therapy has the potential to bridge children with decompensated respiratory failure to lung transplantation. (J Thorac Cardiovasc Surg 2014;147:420-7)

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Neonates or small children with end-stage lung disease who develop respiratory failure requiring extracorporeal membrane oxygenation (ECMO) have few clinical options. Some of these patients can be weaned from ECMO, especially if their condition can be managed with optimized medical therapy. This, however, is an uncommon scenario, and survival for these patients has been <50% and has often been accompanied by significant complications.[1] Although these children can be listed for lung transplantation (LT), the post-transplant results for patients receiving ECMO, particularly venoarterial, have been poor.[2] Given these poor outcomes, our philosophy has been to reconsider the candidacy of listed patients if their clinical deterioration has warranted ECMO support. This clinical conundrum led us to seek alternative options for support, as a bridge to lung transplantation or recovery, in listed patients with clinical decompensation.

Recently, adult patients with end-stage respiratory failure and pulmonary hypertension who have become decompensated and required ECMO have been successfully bridged to lung transplantation with the support of the Novalung oxygenator (Novalung GmbH, Heilbronn, Germany) using central cannulation with blood inflow from the pulmonary artery (PA) and blood return to the left atrium (LA).[3-5] Many of these patients have been extubated and participated in physical therapy during support.

The present report summarizes our experience with the first series of infants and children with severe respiratory failure who were supported with a centrally placed paracorporeal pumpless oxygenator in a PA to LA configuration. Each of these patients had pulmonary hypertension and preserved right ventricular function. These prerequisites were intentionally chosen, because of the presumption that the elevated pulmonary vascular resistance would result in shunting blood flow through the lower resistance paracorporeal oxygenator. All patients were initially treated with an intent of a bridge to lung transplantation.

From the Division of Cardiothoracic Surgery,[a] Department of Surgery, Division of Critical Care,[b] Division of Cardiology,[c] and Division of Allergy, Immunology, and Pulmonary Medicine,[d] Department of Pediatrics, St Louis Children's Hospital and Washington University; and Division of Pediatric Cardiothoracic Surgery,[e] Department of Surgery, St Louis University, St Louis, Mo.

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Address for reprints: Pirooz Eghtesady, MD, PhD, Section of Pediatric Cardiothoracic Surgery, Division of Cardiothoracic Surgery, Department of Surgery, Washington University School of Medicine, Campus Box 8234, 660 S Euclid Ave, St Louis, MO 63110 (E-mail: eghtesadyp@wudosis.wustl.edu).

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Abbreviations and Acronyms

ACD = alveolar capillary dysplasia
ATIII = antithrombin III
AV = atrioventricular
ECMO = extracorporeal membrane oxygenation
LA = left atrium
LT = lung transplantation
PA = pulmonary artery

METHODS

Patient Presentation

One neonate (aged 23 days) and 3 young children (aged 2, 9, and 23 months) presented with primary lung disease, including alveolar capillary dysplasia (ACD) in 2, horseshoe lung with right pulmonary hypoplasia, pulmonary interstitial glycogenosis, and an atrioventricular (AV) canal defect in 1, and primary pulmonary hypertension in 1. All these patients had pulmonary hypertension demonstrated by echocardiography. All patients had been evaluated and listed for LT at their clinical deterioration requiring venoarterial ECMO support despite maximal medical therapy. These patients were considered for paracorporeal oxygenator support with central cannulation. Each case was reviewed with the university human research protection office and our institutional multidisciplinary ethics team, and extensive and open discussions were had with each family, who agreed to proceed.

Technique of Implanting Paracorporeal Oxygenator With Central Cannulation

Each patient was in the intensive care unit receiving ECMO support with right carotid artery and right internal jugular venous cannulation before being brought to the operating room. Of the 4 patients, 3 were transitioned to traditional cardiopulmonary bypass by way of a median sternotomy. The 23-month-old patient was transitioned directly from ECMO to the paracorporeal Novalung support. For PA cannulation, an aortic Berlin Heart cannula (Berlin Heart AG, Berlin, Germany) was sewn to the main PA. The 6-mm version of the cannula was used in the 3 infants and the 9-mm version in the 23-month-old child. In 2 patients, an interposed short piece of 8-mm Gore-Tex shunt (W. L. Gore & Associates, Flagstaff, Ariz) was used between the 6-mm cannula and the PA (with a pericardial washer on the Gore-Tex graft) to allow for easier implantation and to improve the hemostasis of the cannula to PA anastomosis. For the LA shunt, in the first 3 patients, a metal tip right angle cannula (DLP Medtronics Inc, Grand Rapids, Mich) was inserted into the LA through a pursestring suture (16F in the 23 day old neonate and 2-month-old infant and 22F in the 23-month-old child). After observations of significant thrombus formation around and inside the metal cannula tip from the first few cases, 1 of us (P.E.) devised an alternative approach for the LA cannulation (Figure 1). This technique was used in the fourth patient, a 9-month-old infant with ACD. LA cannulation was performed using a 6-mm Berlin arterial cannula modified with a 10-mm-diameter Gore-Tex graft extension. The 10-mm graft attached to the Berlin cannula was anastomosed to a surgically created atrial septal defect (corresponding to the area of a Blalock-Hanlon incision) by way of a right atriotomy. The right atrial incision was then closed around the 10-mm shunt. In all patients, the cannulas were passed through the chest wall, and the oxygenator was positioned just below the patient's feet, supported by a custom holding device. The patient with the AV canal underwent complete repair of the AV canal during the same operation as the transition to paracorporeal oxygenator support.

For the 23-month-old child, who was the first to be treated,[1] the Novalung oxygenator was used to support the patient. However, the minimum recommended flow of the Novalung (500 mL/min) was greater than the expected blood flow through the device for the neonate and infants. Therefore, for the infants, the Quadrox iD oxygenator (Maquet, Wayne, NJ), with a minimum recommended flow of 200 mL/min, was used. Similar to the Novalung, the Quadrox iD was designed to have a low gradient across the oxygenator. A low-flow air-oxygen mixer (Sechrist Industries, Inc, Anaheim, Calif) was used to control the sweep and inspired oxygen percentage in the oxygenator. Blood flow through the oxygenator was monitored continuously at the bedside using a Transonic HT110 flowmeter (Transonic Systems, Inc, Ithaca, NY). Pressures proximal and distal to the oxygenator were continuously monitored in the postoperative period.

Anticoagulation Management of Paracorporeal Oxygenator

Anticoagulation was achieved using a heparin infusion with a targeted activated clotting time of 160 to 200 seconds in 3 patients, consistent with what has been reported for adults who have been treated with the paracorporeal Novalung with central cannulation.[5,6] In the neonatal patient, a target activated clotting time of 180 to 220 seconds was achieved, and aspirin was also given, as has been reported for adult Novalung patients.[7] The neonate and 2 infants also had their antithrombin III (ATIII) levels monitored. ATIII was replaced with recombinate ATIII (Atryn, ABO Pharmaceuticals, San Diego, Calif) to maintain levels >80%. The circuit, including cannulas, tubing, connectors, and oxygenator, was monitored for thrombus buildup by visual inspection and continuous measurement of the transmembrane gradient and postmembrane blood gases. An increase in the transmembrane gradient of the oxygenator greater than the baseline suggested potential thrombus buildup in the oxygenator. If that occurred, the oxygenator and connectors were changed out at the bedside, with a circuit clamp times of <1 minute.

RESULTS

These 4 patients were supported by ECMO for a period of 8 ± 7 days. During the operation to transition to oxygenator support, adequate flow through the oxygenator allowed prompt weaning of cardiopulmonary bypass or ECMO (in the Novalung patient). The duration of oxygenator support was 44 ± 29 days (range, 5-74). The patients and support times on the paracorporeal oxygenator are listed in Table 1. One patient (9 months old, with ACD, supported for 5 days) was bridged to lung transplantation and was doing well 10 months after transplantation. One patient (23 months old) had primary pulmonary hypertension and was supported on the device while the pulmonary vasodilators were escalated. After 22 days of oxygenator support, the patient developed an embolic stroke and was taken to the operating room, where the Novalung oxygenator was successfully weaned. The patient has continued to receive an intravenous pulmonary vasodilator and was doing well at home 34 months after weaning from the paracorporeal oxygenator support, with minimal neurologic sequelae from his stroke. Two patients died while awaiting a suitable lung donor after a paracorporeal oxygenator support time of 54 and 74 days. The neonatal patient with ACD was supported for 54 days and was extubated after 15 days of support.[8] However, that patient experienced a hemorrhagic stroke after 44 days of support that progressed during the next 10 days despite