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Case Report

Ventricular Function Determination During Extracorporeal Membrane Oxygenation (ECMO) Following Norwood Operation: A Case Report

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Abstract: Extracorporeal membrane oxygenation has been used successfully to support both cardiac and pulmonary function following Stage I Norwood operation. Determination of the return of native cardiac function and pulmonary function can be easily accomplished because of the single ventricle physiology. The pulmonary function can be assessed while on full flow ECMO by isolating the membrane oxygenator gas compartment, allowing evaluation of native pulmonary gas exchange through the modified Blalock–Taussig shunt. Cardiac output can be calculated by using the following oxygen delivery equation: Total O_2 delivery = ECMO oxygen delivery + ventricular oxygen delivery. The ventricular O_2 saturation used in the formula for oxygen delivery is same as the mixed venous O_2 saturation returning to the ECMO pump because of the large atrial communication following the Norwood operation.

A 3.2 kilogram patient was placed on a pediatric ECMO circuit utilizing a heparin-coated centrifugal pump and a microporous membrane oxygenate after failure to wean from bypass because of a low oxygen saturation and poor ventricular function. On day 1 of support, the systemic arterial oxygen saturation was 100% and matched the ECMO arterial saturation. On day 2 of the support, the patient's arterial saturation decreased to 96%, and the ECMO mixed venous saturation was 87%. Using the oxygen delivery formula, the ventricular cardiac output was calculated to be 175 mL/min, with an ECMO flow of 400 mL/min for a total cardiac output of 575 mL/min. The native ventricular contribution was, therefore, 30% of total cardiac output. Calculation of cardiac output would normally require a left ventricular sample in a patient with biventricular physiology. The single ventricle physiology in the post-operative Norwood patient makes this calculation a useful tool for assessing return of ventricular function in these patients. **Keywords:** ECMO, postcardiotomy support, Norwood Operation, hypoplastic left heart syndrome. *JECT. 2002;34:148–150*

Extracorporeal membrane oxygenation (ECMO) has been used successfully for post-cardiotomy support in the pediatric population (1–9). An exceptionally challenging group of patients requiring ECMO are those with hypoplastic left heart syndrome following a Stage I Norwood operation (10). Because of the small size of these patients and the univentricular physiology requiring a systemic to pulmonary artery shunt, postoperative support may be required for both cardiac and/or pulmonary failure (11).

In a recent article by Jaggers (10), the success rate with ECMO was significantly greater when the modified Blalock–Taussig shunt was kept open during ECMO support. A higher blood flow is, therefore, required for both the systemic and pulmonary circulation. Because of the benefits of continued pulmonary blood flow (12), the options for support include either ventricular assist (13) or ECMO. Options for ECMO include either a solid silicone membrane lung with a roller pump or a heparin-coated hollow fiber membrane and centrifugal pump.

One advantage of the ECMO option over ventricular assist is the incorporation of a heat exchanger in the ECMO circuit, important for thermal regulation in this small infant population. The use of a heparin-coated circuit may also be advantageous in the early post-operative period when bleeding complications are a major concern.

Return of native cardiac function and pulmonary function during the support period can be determined by cardiac output calculations using the Fick Principle because of the single ventricle physiology. Cardiac output can be computed by summing the total oxygen delivery: Total O_2 delivery = ECMO oxygen delivery + ventricular oxygen

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delivery (14). Because of the large atrial septal communication following the Norwood operation, the ventricular O_2 saturation used in the formula for oxygen delivery is same as the mixed venous O_2 saturation returning to the ECMO pump.

The pulmonary function may be assessed while on full flow ECMO by isolating the membrane oxygenator gas pathway, allowing evaluation of native pulmonary gas exchange through the modified Blalock–Taussig shunt.

CASE REPORT

The patient was a 5-day-old male (3.2 kg) with hypoplastic left heart syndrome with severe hypoplasia of the ascending aorta (2 mm) and transverse aortic arch. Preoperative coagulation studies revealed a prothrombin time of 17.9 sec, a partial thromboplastin time of 56.2 sec, and a platelet count of 141,000/mm^3. CPB time was 369 min, and after weaning from cardiopulmonary bypass, circulating heparin was neutralized with protamine sulfate. The patient's hemodynamic status continued to deteriorate over the next 45 min with hypotension and decreasing arterial saturation into the low 50s. A pediatric emergency bypass circuit consisting of a heparin-coated oxygenator and centrifugal pump was primed with crystalloid fluid. The patient was emergently placed on the heparin-coated ECMO circuit. Because of the rapid onset of bypass with a crystalloid prime, aggressive hemoconcentration and transfusion were carried out until a hematocrit of 40% was achieved.

Approximately 20 hours later, when coagulation studies and platelet count returned to near normal levels, and chest tube bleeding decreased, systemic heparin was begun. No further significant chest tube bleeding occurred.

Following 41 hours of support, the oxygenator gas compartment was isolated to evaluate pulmonary function, which was satisfactory. After another 24 hours of cardiac support only (no oxygenator gas exchange), the patient was successfully weaned.

Ventricular function determination was done at both 24 and 48 hours based on the oxygen delivery calculations. This correlated with improvements seen with surface echocardiography. The trend in improvement in cardiac output from the native ventricle was demonstrated by the calculations, which was borne out by the successful wean from ECMO. On day 1 of support, the systemic arterial oxygen saturation was 100% and matched the ECMO arterial saturation, and there was a calculated native ventricular output of 0 mL/min. On day 2 of the support, the patient's arterial saturation decreased to 96%, and the ECMO mixed venous saturation was 87%. Using the oxygen delivery formula (15), the ventricular cardiac output was 175 mL/min, with an ECMO flow of 400 mL/min for a total cardiac output of 575 mL/min. The native ventricular contribution was, therefore, estimated to be 30% of total cardiac output (see Table 1).

Table 1. Calculation of Cardiac Output (x).

Hemoglobin	11.7 g/dL
Patient arterial saturation	96.1%
RV sat (ECMO venous sat)	87%
ECMO arterial sat	100%
ECMO flow	400 mL/min

Total oxygen delivery = 1.34 *11.7 *0.961 *(.400 + x) = **6.02 + 15.06x**
ECMO oxygen delivery = (1.34* 11.7* 1.0)* .400 = **6.27**
Ventricular oxygen delivery = (1.34* 11.7* 0.87)* x = **13.64x**

Total oxygen delivery = ECMO oxygen delivery + Ventricular oxygen delivery
6.02 + 15.06x = 6.27 + 13.64x
1506x–13.64x = 6.27 – 6.02
1.42x = 0.25
x = 0.175

	Cardiac Output	ECMO Flow	Total Effective Flow	% Cardiac Output of Total Flow
Day 1	0 mL	600 mL	600 mL	0%
Day 2	175 mL	400 mL	575 mL	30%

DISCUSSION

Computation of cardiac output during ECMO support in a patient with biventricular physiology requires a left ventricular blood sample (14). Because of the single ventricle physiology, the ECMO venous saturation can be used to calculate native ventricular cardiac output. This may be an important predictor in the determination of whether there is adequate ventricular function before weaning from ECMO.

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