Extracorporeal membrane oxygenator support in infants with systemic-pulmonary shunts

Phil Botha, PhD, FRCS, Shriprasad R. Deshpande, MBBS, MS, Michael Wolf, MD, Micheal Heard, RRT, Bahaaldin Alsoufi, MD, Brian Kogon, MD, and Kirk Kanter, MD

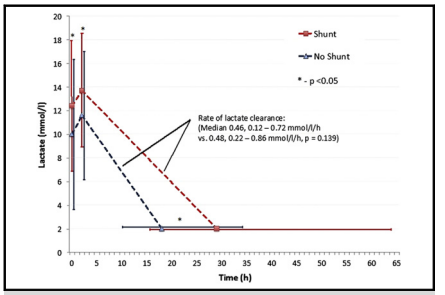
ABSTRACT

Background: Management of a patent systemic-pulmonary (SP) shunt and the resulting runoff during extracorporeal membrane oxygenation (ECMO) varies among institutions. We have used a strategy of increased flow without surgical reduction of the shunt diameter, and here report our results with this strategy.

Methods: In this database review of 169 successive veno-arterial ECMO runs performed between 2002 and 2013 in infants and neonates, ECMO flow, time to achieve lactate clearance, normal pH, and negative fluid balance were compared in patients with shunts and those without shunts.

Results: Fifty-one of 169 infants (30.2%) had a shunt in situ when ECMO was initiated. Significantly higher ECMO flows were maintained in the shunt group compared with the nonshunt group (161 ± 43 mL/kg/minute vs 134 ± 41 mL/kg/minute; $P < .001$). Infants with shunts had significantly higher pre-ECMO and peak lactate levels (12.4 ± 5.6 mmol/L vs 10.0 ± 6.3 mmol/L; $P < .05$ and 13.7 ± 4.9 mmol/L vs 11.6 ± 5.5 mmol/L; $P < .02$, respectively) and required a longer period of support for clearance (median, 28.8 hours [16.1-63.3 hours] vs 17.5 hours [10.8-34.5 hours]; $P < .001$). Although the absolute rate of lactate clearance was not significantly different between the 2 groups (median, 0.46 mmol/L/hour [0.12-0.72 mmol/L/hour] vs 0.48 mmol/L/hour [0.22-0.86 mmol/L/hour]; $P = .139$) the presence of a shunt, neonatal age, peak lactate, extracorporeal cardiopulmonary resuscitation, and the use of hemofiltration on ECMO significantly predicted the rate of clearance. Survival to hospital discharge was similar in the shunt and nonshunt groups (49.0% vs 48.3%; $P = .932$).

Conclusions: A strategy of increased ECMO flow without surgically restricting shunt diameter appears to be successful in providing circulatory support in the majority of patients with an SP shunt. Equivalent survival suggests that routine surgical reduction of shunt diameter is not indicated. (J Thorac Cardiovasc Surg 2016;152:912-8)



Variable clearance of lactic acid in shunt versus Sano patients on ECMO.

Central Message

A strategy of increased flow without restricting shunt flow may be adequate to achieve equivalent survival irrespective of the method of pulmonary blood flow (shunt vs Sano).

Perspective

Survival in single ventricle patients requiring ECMO support is poor. Strategies to maximize flow during ECMO successfully compensate without surgical restriction of shunt flow. There are subtle differences between the Blalock–Taussig shunt and the Sano shunt; however, survival appears to be similar with the 2 types. Perioperative management and timing of escalation to ECMO warrant systematic investigation to improve overall outcomes.

See Editorial Commentary page 919.

Circulation in the presence of a surgical systemic-pulmonary (SP) shunt is inherently unstable, particularly in the setting of single-ventricle physiology. Fluctuations in either systemic or pulmonary vascular tone can result in a profound and rapid alteration of systemic perfusion. In the presence of systemic diastolic runoff into the low-resistance pulmonary bed, any reduction in the systemic perfusion pressure can lead to a rapid decompensation of myocardial perfusion and resulting impaired cardiac output. In addition to a tendency toward periods of pulmonary overcirculation, acute thrombosis of the shunt will similarly precipitate a profound collapse of the

From Children's Healthcare of Atlanta, Emory University, Atlanta, Ga.

Received for publication July 15, 2015; revisions received March 26, 2016; accepted for publication March 30, 2016.

Address for reprints: Shriprasad R. Deshpande, MBBS, MS, Division of Pediatric Cardiology, Department of Pediatrics, Emory University School of Medicine, Children's Healthcare of Atlanta, 1405 Clifton Rd, Atlanta, GA 30322-1101 (E-mail: deshpandes@kidsheart.com).

0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2016.03.075

Scanning this QR code will take you to the article title page.

Abbreviations and Acronyms
BT = Blalock–Taussig
CVVH = continuous veno-venous hemofiltration
ECMO = extracorporeal membrane oxygenation
SP = systemic-pulmonary

cardiovascular system. For these reasons, the clinician caring for patients with shunts is not infrequently faced with a need to support the collapsed circulation using extracorporeal membrane oxygenation (ECMO).

Initial reports of ECMO for postcardiotomy circulatory support considered patients with a systemic-pulmonary (SP) shunt unsuitable. The resultant runoff, increased pulmonary flow, and thus pulmonary venous return were thought to preclude successful support using this modality.[1,2] Complete occlusion of the shunt by means of a surgical clip at the time of ECMO was shown to lead to unacceptable mortality rates, and thus many centers have adopted a strategy of increased flow to compensate for shunt runoff.[3] It has been suggested that partial occlusion of the shunt during ECMO may reduce runoff into the pulmonary bed, resulting in improved perfusion pressure and hastening resolution of the malperfusion state.[4] Our institution has pursued a strategy of liberal flow on ECMO without applying any limitation on shunt runoff. Here we review our results using this strategy in terms of resolution of the malperfusion state and other outcomes.

METHODS

We interrogated our prospectively collected ECMO database to identify all patients who underwent ECMO for cardiac indications in our institution between January 2002 and October 2013. These data were supplemented by chart review and examination of the electronic record of laboratory investigations. Neonates and infants who underwent veno-arterial ECMO with an SP shunt in situ (shunt group) were compared with infants and neonates who underwent veno-arterial ECMO without an SP shunt (nonshunt group) during the same period. Patients who underwent a first-stage Norwood procedure with a Sano right ventricle–pulmonary artery conduit were not included in the shunt group. In patients who underwent both precardiotomy and postcardiotomy ECMO, only the postoperative ECMO was analyzed.

The site of ECMO cannulation was dictated by the clinical situation. Cannulation was performed via central cannulation (reopening of the sternotomy incision) in the early postoperative period and via a neck incision (jugular and carotid vessels) in those requiring ECMO after 2 weeks postsurgery.

With cannulation via the right carotid artery, we aim to place the tip of the arterial cannula at the junction of the innominate artery and the aortic arch. This produces the possibility of occlusion of the systemic end of the shunt by the cannula, however. Nonetheless, we routinely continue ventilation in this setting, and a loss of end-tidal CO_2 demonstrates shunt occlusion by the cannula. We have not observed this phenomenon, however. We further confirm the patency with routine echocardiography during ECMO, as well as during the weaning trials. Again, if there is any concern about cannula placement or shunt occlusion, the cannula is repositioned.

Similarly, for patients with an open chest poststernotomy, direct central cannulation was performed which involved cannulation of the right atrium (venous) and the aorta (arterial). ECMO was delivered using a standard circuit (S-97-E Tygon tubing; Medtronic, Minneapolis, Minn), oxygenator (pediatric Quadrox D; Maquet, Rastatt, Germany), and roller pump (Century, Mesa, Ariz) during this period. ECMO flows were increased to ~100 mL/kg/minute in the nonshunt group and up to 200 mL/kg/minute in the shunt group. Flow rate was adjusted according to premembrane oxygen saturation and blood pressure.

Serum lactic acid level was measured using a regularly calibrated point-of-care analyzer (iSTAT, Abbott). The serum lactate level measured before the start of ECMO and the peak serum lactate measured during ECMO support were documented. Typically, serum lactate levels were measured initially approximately 2 hours in the early phase after institution of ECMO and according to clinical need thereafter. The time to lactate clearance was defined as the interval between the institution of ECMO and measurement of a serum lactate value <2.0 mmol/L (the upper limit of normal in our laboratory). The rate of lactate clearance was calculated as peak lactate – 2.0, divided by the time elapsed between the start of ECMO and the first lactate measurement <2.0 mmol/L recorded. For analysis of variables affecting the rate of lactate clearance, the range of clearance rates was divided into equal quartiles and entered into univariate and multivariate logistic regression models. For multivariate analysis, all variables with a P value <.10 in univariate analysis were entered into the multinomial logistic regression model in a stepwise fashion. This analysis considered the highest quartile of lactate clearance as the reference category, and parameter estimates for the contrast with the lowest quartile are reported.

Arterial blood gas analysis was performed at hourly intervals initially after institution of ECMO using the same point-of-care analyzer as used for lactic acid measurements. The fluid balance was recorded in the electronic record throughout and analyzed in 12-hour intervals from 07:00 to 19:00 and from 19:00 to 07:00. The time at conclusion of the first 12-hour interval after the initiation of ECMO during which a negative fluid balance was achieved for that 12-hour period was taken as the time at which a negative fluid balance was attained for the analysis. Total fluid balance was calculated as total measured intake minus total measured fluid loss, not accounting for insensible losses.

Statistical analyses were performed using SPSS version 21 (IBM, Armonk, NY). Parametric continuous variables are presented as mean ± standard deviation and analyzed using the Student t test. Nonparametric variables are presented as median (interquartile range [IQR]) and analyzed using the Wilcoxon rank-sum test or the Mann–Whitney U test as indicated. In all analyses, a P value <.05 was considered statistically significant. Our Institutional Review Board reviewed the study protocol and waived the requirement for individual informed consent. All coauthors have had full access to the data and have read and approved this final version of the manuscript.

RESULTS

During the period of January 2002 to October 2013, 218 patients underwent a total of 224 ECMO runs for cardiac indications. Of these, 169 patients were neonates or infants at the time of ECMO, including 51 with an SP shunt and 118 without a shunt. One patient with a diagnosis of pulmonary atresia/ventricular septal defect with a modified Blalock–Taussig (BT) shunt placed during a previous admission underwent veno-venous ECMO for a suspected occluded shunt and thus was not included in the present analysis. Demographic data for the shunt and nonshunt groups are