CARDIOPULMONARY SUPPORT AND PHYSIOLOGY

A PROSPECTIVE COMPARISON OF ATRIO-FEMORAL AND FEMORO-ATRIAL FLOW IN ADULT VENOVENOUS EXTRACORPOREAL LIFE SUPPORT

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Introduction: In the United States, venovenous extracorporeal life support has traditionally been performed with atrial drainage and femoral reinfusion (atrio-femoral flow). Although flow reversal (femoro-atrial flow) may alter recirculation and extracorporeal flow, no direct comparison of these 2 modes has been undertaken. **Objective:** Our goal was to prospectively compare atrio-femoral and femoro-atrial flow in adult venovenous extracorporeal life support for respiratory failure. **Methods:** A modified bridge enabling conversion between atrio-femoral and femoro-atrial flow was incorporated in the extracorporeal circuit. Bypass was initiated in the direction that provided the highest pulmonary arterial mixed venous oxygen saturation, and the following measurements were taken: (1) maximum extracorporeal flow, (2) highest achievable pulmonary arterial mixed venous oxygen saturation, and (3) flow required to maintain the same pulmonary arterial mixed venous oxygen saturation in both directions. Flow direction was then reversed, and the measurements were repeated. Data were compared with paired *t* tests and are presented as mean $\pm$ standard deviation. **Results:** Ten patients were studied, and 9 were included in the data analysis. Femoro-atrial bypass provided (1) higher maximal extracorporeal flow (femoro-atrial flow = 55.6 ± 9.8 mL/kg per minute, atrio-femoral flow = 51.1 ± 11.1 mL/kg per minute; $P = .04$) and (2) higher pulmonary arterial mixed venous oxygen saturation (femoro-atrial flow = $89.9\% \pm 6.6\%$, atrio-femoral flow = $83.2\% \pm 4.2\%$; $P = .006$); (3) furthermore, it required less flow to maintain an equivalent pulmonary arterial mixed venous oxygen saturation (femoro-atrial flow = 37.0 ± 12.2 mL/kg per minute, atrio-femoral flow = 46.4 ± 8.8 mL/kg per minute; $P = .04$). **Conclusions:** During venovenous extracorporeal life support, femoro-atrial bypass provided higher maximal extracorporeal flow, higher pulmonary arterial mixed venous oxygen saturation, and required comparatively less flow to maintain an equivalent mixed venous oxygen saturation than did atrio-femoral bypass. (J Thorac Cardiovasc Surg 1998;116:628-32)

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Extracorporeal life support (ECLS) supplements the failing cardiorespiratory system.¹ In the absence of significant cardiac failure, venovenous bypass has been an effective means of delivering supplemental oxygen to the circulation and has gradually replaced venoarterial support in this setting.^{2,3}

Because of the high extracorporeal flows frequently required during venovenous ECLS (50-100 mL/kg per minute), currently cannulation of the venous system involves conduits of large caliber. Such adequate sites include the right atrium and the common femoral/common iliac system. These areas can be readily accessed

Fig 1. The modified ECLS bridge. This bridge was placed in the ECLS circuits of all patients studied. Flow was redirected from AF to FA by changing position of the tubing clamps as indicated. *Arrows* indicate the path of blood flow with the 2 modes of support.

via the right internal jugular and right common femoral veins.

Oxygen supplementation during ECLS depends on extracorporeal flow rate and the amount of oxygen available for systemic distribution. In contrast to venoarterial bypass, venovenous ECLS requires both drainage and infusion from prepulmonary capacitance veins. Because of this, a fraction of highly oxygenated ECLS blood is returned to the circuit and is not available for systemic use. Several factors govern extracorporeal flow and recirculation, including cannula position, venous diameter, thoracoabdominal pressure differential, and flow direction.

The cumulative effects of these variables may significantly differ when atrial drainage and femoral reinfusion (AF ECLS) is compared with femoral drainage with atrial reinfusion (FA ECLS) and may result in distinctly different levels of support achieved during venovenous ECLS. Despite the routine use of opposite flow directions in the United States³ and Europe (using FA access and a long atrial reinfusion catheter^{4,5}), no direct comparison between these 2 ECLS modes has been performed. This study was undertaken to prospectively compare the amount of extracorporeal support

provided by FA and AF flow during venovenous ECLS using our standard access.

Methods

Adult patients subjected to venovenous ECLS for the treatment of severe respiratory failure were prospectively studied. In all patients, consent for ECLS and its related procedures was obtained before institution of bypass. A modified bridge was designed that allowed conversion between AF and FA bypass without the need for circuit modifications (Fig 1). With the exception of this bridge, the conduct of ECLS was routine and as previously described.³

In all patients, access for cannulation was attempted percutaneously, via a modified dilatational Seldinger technique. This was possible in all but 1 patient who required a cervical incision for atrial catheter placement. The right internal jugular vein was instrumented for atrial access and the right common femoral vein for iliac vein–inferior vena cava access. When possible, two 25 cm (tip to flare) 23F Bio-Medicus catheters (Medtronic Bio-Medicus, Eden Prairie, Minn) were placed. Tips were positioned in the right atrium and right common iliac vein–inferior vena cava confluence. This was confirmed with radiography.

After initiation of ECLS, standard pressure-controlled rest ventilator settings were instituted.³ These included pressure-

Table I. FA and AF comparative data

Patient	Weight (kg)	Maximum flow (L/min)		Maximum flow (mL/kg/min)		Flow required to reach same Svo ₂ (L/min)		Flow required to reach same Svo ₂ (mL/kg/min)		Maximum Svo ₂	
		AF	FA	AF	FA	AF	FA	AF	FA	AF	FA
1	98.0	3.9	5.0	39.8	51.0	3.9	2.7	39.8	27.6	77	86
2	88.0	5.0	5.2	56.8	59.1	4.2	3.1	47.7	35.2	89	91
3	81.0	5.2	5.4	64.2	66.7	4.0	5.4	49.4	66.7	80	75
4	95.0	4.4	5.0	46.3	52.6	4.0	3.4	42.1	35.8	83	92
5	110.0	4.3	4.3	39.1	39.1	4.3	3.3	39.1	30.0	80	87
6	116.1	5.3	5.3	45.7	45.7	5.3	3.1	45.7	26.7	88	97
7	86.1	3.5	4.8	40.7	55.7	3.6	2.8	41.8	32.5	81	93
8	75.1	5.1	5.3	67.9	70.6	5.1	3.2	67.9	42.6	83	95
9	77.2	4.6	4.6	59.6	59.6	3.4	2.8	44.0	36.3	88	93
10*	109.0	4.4	3.6	40.4	33.0	4.4	2.4	40.4	22.0	79	96
Average		4.6	5.0	51.1	55.6	4.2	3.3	46.4	37.0	83.2	89.9
Standard deviation		0.6	0.4	11.1	9.8	0.6	0.8	8.8	12.2	4.2	6.6
P value			.04		.04		.03		.04		.006

Individual patient data comparing atrio-femoral (AF) and femoro-atrial (FA) flow during venovenous ECLS. Each paired set of measurements was obtained within 24 hours of initiating ECLS by changing clamp position on a modified bridge. *P* values represent FA and AF comparisons between individual patients by paired *t* tests.

*Patient 10 was not included in data analysis because of 2 different cannula sizes.

controlled inverse-ratio ventilation at a respiratory rate of 6 breaths/min with peak inspiratory pressures of 30 cm H₂O at an end-expiratory pressure of 10 cm H₂O ($\Delta P = 20$ cm H₂O). Patients were pharmacologically paralyzed. Fiberoptic pulmonary artery (PA) catheters (Oximetrix, Abbott Critical Care Systems, North Chicago, Ill) were placed in all patients to allow continuous Svo₂ monitoring during the study. An ultrasonic flow probe (Transonic Systems Inc, Ithaca, NY) was placed on the infusion limb of the ECLS circuit to obtain continuous flow measurements.

Immediately after cannulation, bypass was conducted in an AF direction. Flow direction was briefly reversed to FA by changing clamp position. Patients were initially maintained on the form of bypass that provided the highest PA saturation during this preliminary comparison. Regardless of initial flow direction, formal measurements were not performed until stable venovenous bypass was attained; this was defined as no change in PA Svo₂ for 15 minutes. The following three measurements were collected on the direction of bypass originally selected.

Highest ECLS flow. Extracorporeal flow was gradually advanced by increasing the speed of the roller pump until the compliance chamber on the drainage limb of the circuit intermittently collapsed. Speed was then reduced to allow continuous uninterrupted flow. Flow, measured ultrasonically from the infusion limb of the circuit, was recorded in liters per minute as the maximal flow and corrected for body weight (milliliters per kilogram per minute).

Highest PA Svo₂. ECLS flow was increased until the highest obtainable PA Svo₂ was reached. This point occurred invariably at the maximum ECLS flow.

Amount of extracorporeal flow required to maintain equivalent PA saturation. ECLS flow was adjusted to attain a patient-specific PA oxygen saturation (based on the level of

PA Svo₂ achieved with initial bypass) obtainable with both modes of bypass.

Circuit flow was then reversed by changing clamp position on the modified bridge (Fig 1). After stable bypass was achieved in the opposite direction, a similar set of data was collected.

The patient continued to receive the form of bypass that provided the higher PA Svo₂. This procedure was performed once in each patient, within the first 24 hours of ECLS. Two-tailed paired *t* tests compared data from the 2 bypass directions. Data are expressed as mean $\pm$ standard deviation.

Results

Ten adult patients with severe respiratory failure unresponsive to conventional ventilation were treated with an ECLS circuit containing a modified bridge. Comparative AF and FA data are presented in Table I. Two 23F Bio-Medicus catheters of equal length (25 cm from tip to cannula flare) were inserted in 9 patients. Two cannulas of different calibers were inserted in another patient, and this patient was therefore excluded from the data analysis. Flow was maintained in the FA direction in 9 patients and in the AF direction in 1 patient because of the initial flow comparison. In all patients, the initial comparison based on PA Svo₂ was consistent with subsequent formal measurements.

For each set of formal paired measurements, FA bypass provided the same or higher maximal flow (Fig 2). Overall, when corrected for body weight, FA bypass provided significantly higher extracorporeal flow (FA = 55.6 ± 9.8 mL/kg per minute, AF = 51.1 ± 11.1 mL/kg per minute; *P* = .04).

Fig 2. Maximum ECLS flow. When corrected for body weight, FA bypass provided significantly higher extracorporeal flow (FA = 55.6 ± 9.8 mL/kg per minute, AF = 51.1 ± 11.1 mL/kg per minute; $P = .04$).

Eight of 9 patients had higher maximal PA oxygen saturations while in the FA mode (Fig 3). Overall, FA ECLS provided statistically higher levels of SvO_2 (FA = $89.9\% \pm 6.6\%$, AF = $83.2\% \pm 4.2\%$; $P = .006$).

FA bypass provided similar levels of PA SvO_2 at lower ECLS flows in 8 of 9 patients (Fig 4). Overall, significantly less flow (adjusted for patient weight) was required during FA ECLS to achieve comparatively similar levels of SvO_2 (FA = 37.0 ± 12.2 mL/kg per minute, AF = 46.4 ± 8.8 mL/kg per minute; $P = .04$).

Discussion

This study demonstrated that FA flow during venovenous ECLS is safe and can adequately support gas exchange. When compared directly with atriovenous flow in patients serving as their own controls, higher absolute levels of SvO_2 were achieved, and significantly less flow was required to maintain equivalent levels of extracorporeal support for the group. Contrary to our former belief, FA bypass provided comparably higher maximum flow for the group.

Historically, our practice has been to direct ECLS flow in an AF direction, draining deoxygenated blood from the atrium and reinfusing it into the femoral vein. This is predicated on the notion that the large caliber of the atrial chamber may afford greater drainage and therefore translate into higher flows when compared with drainage from the smaller femoral vein. When AF ECLS was initially chosen as the primary direction to conduct flow, ventilator rest settings included low-volume ventilation with pressure limits and short inspiratory times.

Current ECLS rest settings routinely use pressure-controlled inverse-ratio ventilation in an effort to maintain pulmonary recruitment. The increased intratho-

Fig 3. Maximum SvO_2 . FA ECLS provided statistically higher levels of SvO_2 (FA = $89.9\% \pm 6.6\%$, AF = $83.2\% \pm 4.2\%$, $P = .006$).

Fig 4. Flow required to maintain equivalent SvO_2 . Significantly less flow (adjusted for patient weight) was required during FA ECLS to achieve comparatively similar levels of SvO_2 (FA = 37.0 ± 12.2 mL/kg per minute, AF = 46.4 ± 8.8 mL/kg per minute; $P = .04$).

racic pressures that accompany this technique may significantly reduce atrial drainage and, by reciprocally shunting blood toward the lower extremities, thereby increase femoral drainage. These pressure relationships may account for our finding FA ECLS to provide significantly higher flows than AF ECLS.

We used changes in PA SvO_2 as an approximation of ECLS support. PA SvO_2 reflects the mixing of oxygen saturations that occurs from returning systemic blood combining with that of the ECLS circuit. Additionally, PA SvO_2 is not directly affected by contributions from the native lungs, as is arterial saturation. Although this value does not represent true native SvO_2 because of extracorporeal augmentation, we believe it does accu-

rately reflect relative changes in ECLS support. PA Svo_2 is routinely relied on at our institution to assess adequacy of support during venovenous ECLS.

During venovenous ECLS, both drainage and infusion occur via the same prepulmonary vasculature, and therefore a certain fraction of ECLS affluent unavoidably consists of recently delivered extracorporeally oxygenated blood. The magnitude of this recirculation directly affects peripheral oxygen delivery. During traditional AF ECLS, flow is directed from the infusion cannula directly toward the drainage cannula, and the systemic distribution of ECLS effluent necessitates passage of oxygenated blood past the orifice of the drainage cannula. Femoral drainage with atrial infusion (FA bypass) may reduce recirculation by directing oxygenated blood through the tricuspid valve for subsequent systemic distribution. Although not directly measured, reduced recirculation likely accounted for the significantly higher PA Svo_2 observed with FA bypass, as well as the provision of similar levels of support at lower circuit flow rates.

Although for a given paired comparison FA bypass usually provided higher PA Svo_2 , higher maximal flow, and required less flow to maintain similar support, this was not universal. As governed by Poiseuille's law, flow is greatly influenced by cannula diameter and length. All patients with equivalent cannulas in both access sites demonstrated higher flows in the FA direction. The 1 patient dropped from analysis because of cannula size discrepancy (atrial 23F, femoral 21F) had predictably higher flows with AF bypass. However, even with lower flows, PA Svo_2 s in this patient were significantly higher in the FA direction. Another patient (included in data analysis) demonstrated higher PA Svo_2 and required less flow to maintain Svo_2 with AF bypass, while having lower maximal flow in this direction. Radiography revealed appropriate cannula placement in this patient. Despite this isolated exception, FA bypass provided significantly higher Svo_2 , higher flow, and required less flow to maintain an equivalent Svo_2 in the group as a whole.

Although ECLS may be required for weeks in patients with respiratory failure, we compared differences in flow direction only on the first day of bypass. It is unclear how flow and recirculation relationships will change over time. Although not tested in this study, it is possible that FA flow may be compromised to a greater degree than AF flow by intravascular volume depletion, thereby limiting the application of the current findings.

To our knowledge, no complication resulted from the conduct of FA bypass. Routine circuit examinations did reveal a higher incidence of thrombus formation adjacent to Y connectors. Inasmuch as the modified bridge contains 2 more of these connectors than the standard bridge, it may increase the potential for embolic events. In routine ECLS any clot that dislodged during stable flow in either direction would be directed at the oxygenators. However, flow reversal under these circumstances could have resulted in free intravascular clot being directed toward the native pulmonary circulation. It is for this reason that flow reversals were not routinely performed after the first day of bypass. The modified bridge is more complex than the standard one and requires the manipulation of 2 tubing clamps rather than 1. Because of the added tubing, the bridge is larger and can be more difficult to transport without kinking. Regardless, after adequate staff training we found the device to be manageable and to require little additional care.

In summary, FA support during adult venovenous ECLS provided higher maximum flow, higher PA Svo_2 , and required less flow to maintain a given Svo_2 than did traditional AF bypass. Although we no longer routinely use the modified bridge, it permitted safe conversion between the 2 modes of support and allowed for direct comparisons within individual patients. On the basis of this study, it has become our practice to initiate flow in the FA direction in adult venovenous ECLS.

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