

Measurements of Recirculation during Neonatal Venovenous Extracorporeal Membrane Oxygenation: Clinical Application of the Ultrasound Dilution Technique

David Clements, AS, RN,* Johanna Primmer, BS;† Pamela Ryman, RRT,* Bonnie Marr, MD,* Bruce Searles, BS, CCP,* Edward Darling, MS, CCP*

*State University of New York, Upstate Medical University and Crouse Hospital, Syracuse, New York; and †Transonic Systems, Ithaca, New York

Abstract: Recirculation during dual lumen venovenous (DLVV) extracorporeal membrane oxygenation (ECMO) is a dynamic event that results in a fraction of the oxygenated blood exiting the arterial lumen and immediately shunting back into the venous lumen. Excessive recirculation will result in suboptimal oxygen delivery to the patient. Ultrasound dilution is a technology that has been shown to rapidly quantify recirculation in venovenous (VV) ECMO animal models. This manuscript reports the first clinical application of ultrasound dilution in quantifying recirculation during neonatal VV ECMO. A 2.8-kg neonate with congenital diaphragmatic hernia was placed on VV ECMO using a single DLVV cannula inserted into the right atrium through the internal jugular vein. Ultrasound sensors were clamped to the arterial and venous lines near the dual lumen cannula and 3- to 5-mL bolus injections of isotonic saline were used proximal to the circuit heat exchanger to make

the recirculation measurements. Recirculation measurements were made after initiation and periodically thereafter. During the 12-day ECMO period, 86 recirculation measurements were performed. The average recirculation was 34.3% (range, 15–57%). Reproducibility of paired measurements was 5.6%. Changes in patient positioning resulted in significant changes in recirculation. Measurements using platelet injections were compared with those made with saline. The two were found to closely correlate (mean difference, $.25\% \pm 2.8\%$). Ultrasound dilution measurements of recirculation provided rapid monitoring data during a clinical VV ECMO procedure. Application of this technique could provide early data that will assist the clinician in guiding interventions to minimize recirculation. **Keywords:** extracorporeal membrane oxygenation, venovenous, recirculation, shunt fraction, ultrasound. *JECT. 2008;40:184-187*

Recirculation is the fraction of oxygenated blood infused into the right atrium that is immediately pulled back into the venous line of the extracorporeal membrane oxygenation (ECMO) circuit during venovenous (VV) ECMO and is a well-known limitation of the therapy (1). Although there have been various techniques developed to measure and minimize recirculation, none of these has proved to be a practical bedside method (2,3).

Ultrasound dilution (UD) technology uses a saline bolus and clamp-on ultrasound sensors (similar to what are commonly used to measure blood flow through extracorporeal tubing) to generate a dilution curve. Applying this principle to VV ECMO, a methodology has been developed that has been effective in measuring recirculation in animal models (4,5). Using two clamp-on ultrasonic

sensors attached to the dual lumen venovenous (DLVV) cannula arterial inlet and venous outlet, a small bolus of saline is injected into the VV ECMO arterial line. As the saline passes the arterial line sensor, a dilution curve is generated. Another dilution curve is generated when the recirculated fraction passes the venous line sensor. These two dilution curves are analyzed, and a percent recirculation is calculated. This describes the first known clinical application of UD recirculation measurements during DLVV ECMO in a neonate.

CASE REPORT

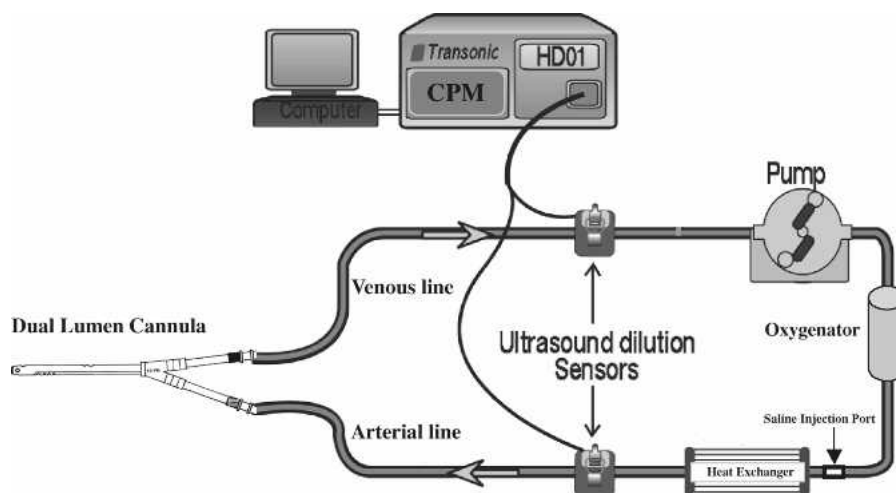
This study was approved by the Medical Ethics Committee at Crouse Hospital, Syracuse, NY (institutional review board approval). Informed consent was obtained from the parents of the neonate.

A 2.8-kg male born with congenital diaphragmatic hernia (CDH) was placed on VV ECMO using a 12-F dual lumen cannula (OriGen Biomedical, Austin, TX). The

Address correspondence to: Edward Darling, MS, CCP, Cardiovascular Perfusion, SUNY-Upstate Medical University, 750 East Adams Street, Syracuse, NY 13027. E-mail: darlinge@upstate.edu

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Figure 1. Schematic of the VV ECMO circuit interfaced with ultrasound dilution technology.



standard VV ECMO circuit consisted of the use of .25-inch tubing, a mechanical bladder box (Seabrook Medical Systems, Cincinnati, OH), a roller pump (Cobe Cardiovascular, Arvada, CO), a silicon membrane oxygenator (Medtronic, Minneapolis, MN), and a heat exchanger (Gish Biomedical, Irvine, CA).

Calibrated ultrasound flow sensors (Transonic Systems, Ithaca, NY) were placed on the arterial and venous lines near the DLVV cannula. These sensors were interfaced with a HD02 meter (Transonic Systems) and a laptop computer loaded with software developed to analyze the dilution curve and automatically calculate and display the percent recirculation (Figure 1).

To make recirculation measurements, bolus injections (3–5 mL) were made with room temperature normal saline through a stopcock proximal to the heat exchanger. Within 45 seconds of the saline bolus, the recirculation measurement was calculated and displayed (Figure 2).

During the 12-day VV ECMO period, 86 recirculation measurements using UD were performed. The average recirculation was 34.3% (range, 15–57%). Reproducibility of paired measurements was 5.6%. Changes in patient positioning resulted in significant changes in recirculation (Figure 3). When platelet infusions were indicated, measurements made with 3-mL bolus injections of platelets were compared with those of saline. It was found that a platelet bolus correlated with saline and therefore could be used as a substitute indicator (mean difference, $.25\% \pm 2.8\%$). No complications were experienced when recirculation measurements were made.

DISCUSSION

Several aspects of using UD to quantify recirculation were studied during this case including (i) reproducibility, (ii) safety of the procedure, (iii) influence of the saline

bolus volume, and (iv) the effects of patient/pump changes on recirculation.

This study showed that measurements performed within 5 minutes of each other resulted in reproducibility of 5.6%. This closely agrees with a reported 6% reproducibility in a previous animal study also using UD to measure recirculation (5). The reproducibility of ultrasound dilution also compares with other published alternative techniques to quantify recirculation such as thermodilution and lithium indicator methods (2,3).

Safety issues associated with saline bolus injections into a site after the oxygenator on the arterial line were considered. Although VV ECMO is inherently safer than

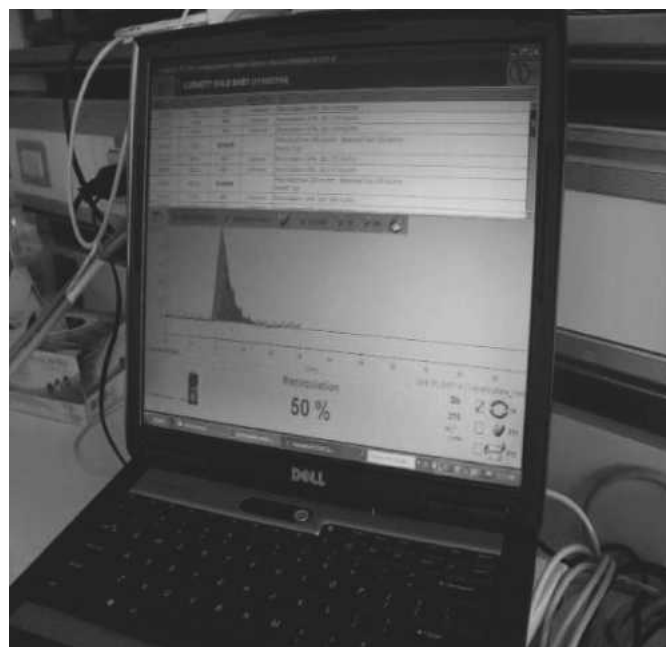


Figure 2. Photograph of the laptop display showing recirculation calculations.

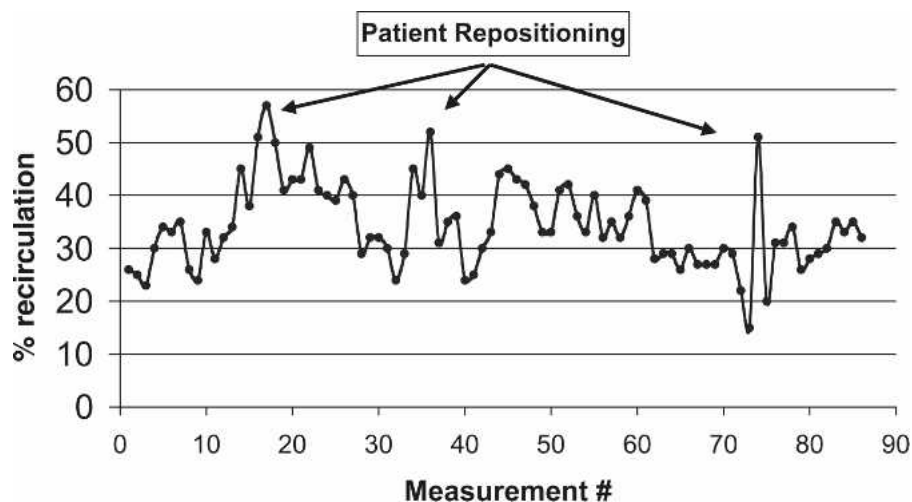


Figure 3. Chronological measurements of recirculation. Arrows denote changes in recirculation associated with patient positioning.

veno-arterial (VA) ECMO with respect to systemic arterial embolization, prevention of air entrainment into the ECMO circuit was of paramount importance. In addition to meticulous de-airing of the bolus syringe, stopcock, and pigtail, the injection was performed at a site proximal to the heat exchanger and bubble detector providing trapping and detection defense against air bubbles. No air was visualized in the heat exchanger nor was there ever a detection of air by the bubble detector after any injections.

In earlier work in an animal model, the volume of saline needed to produce a clear signal in UD was 1–2 mL/kg (5). Because minimizing the amount of saline indicator used in UD is important to prevent volume overload and fluid shifts in patients on VV ECMO, our initial measurements compared recirculation values obtained with bolus injections of 3 and 5 mL of saline. These values were within 1% and, therefore, 3-mL bolus injections were used for the remainder of the study. It seems that a bolus of ~1 mL/kg will provide an adequate signal to accurately determine recirculation in neonatal VV ECMO.

During the course of VV ECMO, it is common for platelet counts to drop, requiring periodic platelet concentrate infusion. We compared the injection of saline vs. platelet concentrate boluses and found that they were interchangeable. Opportunistically, using scheduled infusions to make UD recirculation measurements can also minimize added volume associated with this technique.

Before having the ability to actually measure recirculation, experts have suggested that recirculation rates range from 20% to 50% using the DLVV cannula (6). Our measured data in a single patient showed an even greater range of recirculation (15–57%), confirming just how dynamic the recirculation events can be. Measurements before and after patient positioning often showed very

different recirculation fractions (Figure 3) that could be corrected with cannula manipulation.

Direct measurements of recirculation may have an important role as VV ECMO aggressively expands to more challenging patients, including congenital diaphragmatic hernia patients and babies requiring inotropic support (7,8). In these patients, monitoring actual recirculation could help identify changes and direct interventions to minimize recirculation and fully optimize the therapy. Additionally, quantifying recirculation may allow for accurate monitoring of patient mixed venous oxygen saturation and provide an additional index of perfusion adequacy (9).

In summary, in this initial case experience, the UD technique provided rapid, reproducible bedside results that clearly show changes in recirculation associated with ECMO therapy. The intention of this manuscript is to report the first clinical use of this technique in the neonate. Future clinical applications will allow data to be collected that could correlate flow rates, volume status, patient positioning, and blood gases to recirculation. With further experiences, the use of the UD technique to guide ECMO management will be more clearly understood.

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