Monograph:

ECMO Publication Briefs That Cite Use of Transonic Technology

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Theory: Ultrasound Dilution (UDT)

Krivitski NM, Gregory Galyanov G,Gehron JM, Dirk Bandorski D, Boning A, **"New noninvasive methodology to measure cardiac output in veno-venous extracorporeal membrane oxygenation patients,"** Perfusion 2020; 35(15): 73-80. (Transonic Reference # ELS 11795T) *" The mathematical model and clinical retrospective analysis demonstrate that this new methodology has the potential to accurately measure CO in VV ECMO patients."*

Krivitski N, Galyanov G, Cooper D, Said MM, Rivera O, Mikesell GT, Rais-Bahrami K, **"*In vitro* and *in vivo* assessment of oxygenator blood volume for the prediction of clot formation in an ECMO circuit (theory and validation),"** Perfusion 2018; 33(IS): 51-56. (Transonic Reference #ELS11317) *"Dilution technology has the ability to accurately and reproducibly assess the clotting process in the oxygenator."*

ELSA UDT (REC & OxBV)

Said MM, Mikesell GT, Rivera O, Khodayar Rais-Bahrami K, **"Precision and Accuracy of the New Transonic ELSA Monitor to Quantify Oxygenator Blood Volume (*in-vivo* and *in-vitro* studies),"** 2015 PAS Annual Meeting and Eastern SPR Annual Meeting. (Transonic Reference #ELS10230V) *" The ELSA monitor would be a valuable tool to identify early clot formation in ECMO circuits and allow device change outs before they become a clinically emergent."*

Ruß M, Weber-Carstens S, Skrypnikov V, Taher M, Francis RCE, BoemkeW, Pickerodt PA, **"Optimization of V-V ECMO circuit determined by blood recirculation measurements improved systemic oxygenation in a 10-year-old patient,"** 5th Annual Symposium on ARDS, Berlin, Germany, June 2019 (Transonic Reference: #ELS10569A) *" When initiation of high flow V-V ECMO did not sufficiently support systemic oxygenation in the child, measurements of recirculation, imaging techniques and applied ECMO physiology led to optimization of systemic oxygenation and lung protective ventilation."*

Said MM, Mikesell GT, Rivera O, Khodayar Rais-Bahrami K, **"Influence of central hemodynamics and dual-lumen catheter positioning on recirculation in neonatal veno-venous ECMO,"** 2015 PAS Annual Meeting and Eastern SPR Annual Meeting. (Transonic Reference #ELS10231V) *"Using the injection of a small volume of saline, the ELSA monitor provides a non-invasive method to measure recirculation and optimize catheter performance in an ECMO circuit."*

UDT Clinical ECMO Studies

Badheka A, Stucker SE, Turek JW, Raghavan ML. **"Efficacy of Flow Monitoring During ECMO,"** ASAIO J. 2017; 63(4): 496-500. (Transonic Reference: EC11216AH) *"The results support the hypothesis that elevations in shunt flow can serve as an indicator of distal obstruction in the ECMO circuit."*

Palmér O, Palmér K, Hultman J, Broman M, **"Cannula Design and Recirculation During Venovenous Extracorporeal Membrane Oxygenation,"** ASAIO J. 2016; 62(6): 737-742. (Transonic Reference #EC11034AH) *"By utilizing the ultrasound dilution technique to measure Rf before and after repositioning, effective ECMO flow can be improved for a more effective ECMO treatment."*

Mosier JM, Kelsey M, Raz Y *et al,* **"Extracorporeal membrane oxygenation (ECMO) for critically ill adults in the emergency department: history, current applications, and future directions**," Crit Care. 2015;19:431. (Transonic Reference #EC11787AH) *"Flow, hemoglobin, hematocrit and venous saturation can be continuously monitored by ultrasonic meters attached to the circuit."*

Körver EP, Ganushchak YM, Simons AP, Donker DW, Maessen JG, Weerwind PW, **"Quantification of recirculation as an adjuvant to transthoracic echocardiography for optimization of dual-lumen extracorporeal life support,"** Intensive Care Med. 2012 38(5): 906-909. (Transonic Reference #ELS9679AH) *"We present an ultrasound dilution technique allowing quantification of recirculation for optimizing vv-ELS. ...Conclusion: We suggest quantification of recirculation in addition to image guidance to provide optimal vv-ELS."*

Clements D, Primmer J, Ryman P, Marr B, Searles B, Darling E, **"Measurements of recirculation during neonatal veno-venous extracorporeal membrane oxygenation: clinical application of the ultrasound dilution technique,"** J Extra Corpor Technol. 2008;40(3):184-7. (Transonic Reference: ELS9680AH) *"In this initial case experience, ultrasound dilution technique provided quick, reproducible beside results that showed changes in recirculation associated with VV ECMO therapy...This paper shows that ultrasound dilution technology can be used to quantify recirculation in neonates on VV ECMO."*

van Heijst AF, van der Staak FH, de Haan AF, Liem KD, Festen C, Geven WB, van de Bor M, **"Recirculation in double lumen catheter veno-venous extracorporeal membrane oxygenation measured by an ultrasound dilution technique,"** ASAIO J, 2001; 47(4): 372-6. (Transonic Reference #HD49V) *"The ultrasound dilution method is a useful method for measurement of the recirculation fraction in DLVV-ECMO and is easier to use than the other methods."*

Walker JL, Gelfond J, Zarzabal LA, Darling E, **"Calculating mixed venous saturation during veno-venous extracorporeal membrane oxygenation,"** Perfusion. 2009; 24(5): 333-9. (Transonic Reference #7904A) *" Recirculation (R), the shunting of arterial blood back into to the venous lumen, commonly occurs during veno-venous extracorporeal membrane oxygenation (VV-ECMO) and renders the monitoring of the venous line oxygen saturation no longer reflective of patient mixed venous oxygen saturation (S(V)O(2)."*

UDT Animal Studies

Darling EM, Crowell T, Searles BE, **"Use of dilutional ultrasound monitoring to detect changes in recirculation during venovenous extracorporeal membrane oxygenation in swine,"** ASAIO J 2006; 52(5): 522-4. (Transonic Reference #7309A) *"Dilutional ultrasound provides a clinically practical method to quantify and monitor recirculation in VV ECMO applications and may aid in assessing interventions to improve oxygen delivery."*

Melchior R, Darling E, Terry B, Gunst G, Searles B, **"A novel method of measuring cardiac output in infants following extracorporeal procedures: preliminary validation in a swine model,"** Perfusion 2005; 20(6): 323-7. (Transonic Reference #10234A) *This pilot study demonstrated that the CO UD technique correlates to other benchmarks of CO measurements.*

Publication Brief: (Krivitski ELS11795T)

New noninvasive methodology to measure cardiac output in veno-venous extra-corporeal membrane oxygenation patients

Krivitski *et al*, Transonic Systems Inc.

BACKGROUND:

Cardiac output (CO) measurement is vital during veno-venous extracorporeal membrane oxygenation (VV ECMO) to evaluate oxygen delivery and to identify early right heart failure. Standard clinical methods (pulmonary artery thermodilution, transpulmonary thermodilution) are known to be inaccurate in the VV ECMO setting, especially when recirculation is high.

OBJECTIVE:

To develop a simple noninvasive method to measure CO in patients during VV ECMO.

METHODS:

- A mathematical model was developed where CO was analyzed as a combination of two flows: oxygenated blood from ECMO and less oxygenated mixed venous blood.
- Two mass balance equations for oxygen saturations was introduced to calculate CO.
- Recirculation (ELSA Monitor) and arterial saturation at two extracorporeal membrane oxygenation flows after temporary pump flow decrease were measured.
- Mathematic modeling with a crude Monte Carlo method was used to analyze theoretical errors in CO calculations from unknown behavior of venous saturation.
- The developed concept was retrospectively applied to a clinical data archive of 17 adult patients (52 measurement sessions) on VV ECMO.

RESULTS:

- Mathematical modeling suggests that proportion of results with error ≤10% was between 86% and 100% if preoxygenated saturation was available; it was between 78% and 86% if pre-oxygenated saturation was not available.
- Application of two mass balance equation concept to clinical data suggests that as the decrease of the arterial saturation reaches 6% due to flow decrease, then CO calculations becomes highly reliable as 96% (2 standard deviations) of the results has a reproducibility within 6.4%.

CONCLUSION:

- The mathematical model and clinical retrospective analysis demonstrate that this new methodology has the potential to accurately measure CO in VV ECMO patients.
- Validation of the methodology in animal and clinical settings is the next step.

REFERENCE

Krivitski NM, Gregory Galyanov G,Gehron JM, Dirk Bandorski D, Boning A, "New noninvasive methodology to measure cardiac output in veno-venous extracorporeal membrane oxygenation patients," Perfusion 2020; 35(15): 73-80. (Transonic Reference # ELS 11795T)

Publication Brief: (ELS11317V Krivitski)

In Vitro and *In Vivo* Assessment of Oxygenator Blood Volume for the Prediction of Clot Formation in an ECMO Circuit (Theory and Validation)

Children's National Medical Center & George Washington University School of Medicine, Washington, DC

INTRODUCTION

Clotting and bleeding are major causes of mortality and morbidity during extracorporeal membrane oxygenation (ECMO). Oxygenator blood volume (OXBV) is the total amount of blood that flows through the oxygenator. As a clot develops, OXBV decreases. As clots form in the oxygenator, as an oxygenator blood volume (OXBV) decreases over time, OXBV becomes a direct measure of the volume of clots formed in the oxygenator. A pressure gradient, currently used to predict clot formation, is unreliable because its relative changes are not always proportional to a clot's size. An uneven clotting pattern leaves some areas of the fibers open which allows the pressure gradient to remain deceptively small.

OBJECTIVE

The objective of this study was to develop and validate measurements of OXBV by ultrasound dilution technology as a quantitative assessment of oxygenator clotting.

METHOD

Bench Test: Validation of the accuracy of OXBV was measured using the ELSA Monitor (Transonic Systems Inc., Ithaca, NY, USA) by measuring the transit time of a bolus of saline passing through the oxygenator recorded by a Flow/Dilution Sensor placed on the ECMO circuit after the oxygenator.

In Vivo Animal Experiment: The accuracy and reproducibility (coefficient of variation [CV]) of OXBV measurement and its independence from ECMO flow, was assessed *in vivo* by a total of 88 ultrasound dilution measurements in 6 newborn lambs undergoing ECMO. A bolus of 3-5 mL of isotonic saline into the ECMO circuit was used to measure OXBV and recirculation. Ultrasound dilution results were compared with actual volume changes from the injection of fixed known volumes (from 5 to 40 mL) of petroleum jelly (Vaseline) into oxygenators to mimic the formation of clots of varying sizes. To assess the reproducibility of the data, archived clinical data were analyzed to calculate the coefficient of variation (CV) of consecutive measurements.

RESULTS

In vitro accuracy compared with volumetric measurements of OXBV of 22-134 mL at flows of 300-700 mL/min was -0.8±6.6%. OXBV measured at different pump flows showed a variation of 0.11±2.86% from the mean flow of 400 mL/min. The *in vivo* animal experiment demonstrated a strong relationship (R^2= 0.85) between the volume of petroleum jelly injected into the oxygenators and the percentage decrease of the oxygenator blood volume measured by ultrasound dilution. OXBV ranged from 42- 387 mL; ECMO flow ranged from 210-5960 mL/min; the coefficient of variation was 3.20±2.44 %. For an OXBV of 355 mL at flows of 1020-7000 mL/min, accuracy was -0.4±1.6%.

CONCLUSION

Ultrasound dilution technology can accurately and reproducibly assess the clotting process in an oxygenator. Larger studies are needed to establish guidelines for the prediction of imminent clotting to help to avoid unnecessary ECMO circuit changes.

Krivitski N, Galyanov G, Cooper D, Said MM, Rivera O, Mikesell GT, Rais-Bahrami K, "*In vitro* and *in vivo* assessment of oxygenator blood volume for the prediction of clot formation in an ECMO circuit (theory and validation)," Perfusion. 2018 May; 33(1 suppl): 51-56. (Transonic Reference # ELS11317V)

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Publication Brief: (Said ELS10230A)

Precision and Accuracy of the New Transonic ELSA Monitor to Quantify Oxygenator Blood Volume (*in-vivo* and *in-vitro* studies)

Children's National Med Ctr, George Washington Univ School of Medicine, Washington, DC

BACKGROUND

Major complications of ECMO are bleeding and clotting in the circuit. The challenge of heparin therapy during ECMO is to keep the ECMO circuits (mostly the oxygenator) from clotting while preventing patient bleeding. Recently, the ELSA monitor (Transonic Systems Inc. Ithaca NY) was introduced that measures clot formation in the oxygenator by recording oxygenator blood volume (OXBV) using a dilution method.

OBJECTIVE

The purpose of the study was to evaluate the reproducibility *(in-vivo)* and absolute accuracy *(in-vitro)* of ELSA Monitor OXBV measurements.

METHOD

- During VV ECMO, OXBV was measured in seven newborn lambs (1- 5 days old, wgts. 4.2+0.5 kg).
- The ECMO circuit included a Jostra Rotoflow centrifugal pump and Quadrox-iD pediatric oxygenator with the circuits primed with heparinized ovine blood.
- ELSA flow-dilution sensors were attached to the blood lines.
- Isotonic saline was injected to measure OXBV.
- After completion of the animal experiments of each ECMO run, the lamb was removed from circuit.
- The circuit was transitioned to a recirculating loop and fixed volumes of Vaseline were injected into the oxygenators to mimic clot formation of varying size.

RESULTS

- A total of 88 OXBV measurements were taken.
- The coefficient of variation(1.49±1.12%) demonstrated high precision.
- OXBV measured at different pump flows (200-600 mL/min) showed a variation of 0.11±2.86% from the mean flow of 400mL/min.
- The *in vitro* arm of the study showed a strong inverse relationship (R^2= 0.85) between the volume of Vaseline injected into the oxygenators, and the percent decrease in oxygenator blood volume (Figure 1).

CONCLUSION

- The ELSA Monitor demonstrated high precision in measuring decrease in oxygenator volume in the ECMO circuit using the injection of a small volume of saline.
- The ELSA monitor would be a valuable tool to identify early clot formation in ECMO circuits and allow device change outs before they become a clinically emergent.

REFERENCE

Said MM, Mikesell GT, Rivera O, Khodayar Rais-Bahrami K, "Precision and Accuracy of the New Transonic ELSA Monitor to Quantify Oxygenator Blood Volume (in-vivo and in-vitro studies)." 2015 PAS Annual Meeting and Eastern SPR Annual Meeting (Transonic Reference: ELS10230V)

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Publication Brief: (Ruß ELS10569A)

Optimization of V-V ECMO circuit determined by blood recirculation measurements improved systemic oxygenation in a 10-year-old patient

Berlin University of Medicine, & Institute of Health, Germany

BACKGROUND

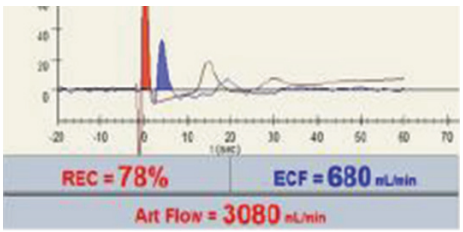
During veno-venous extracorporeal membrane oxygenation (V-V ECMO) used to treat life threatening acute respiratory distress syndrome (ARDS), the fraction of ECMO blood flow (Q_{EC}) that recirculates directly into the drainage cannula does not support systemic oxygenation. Therefore, measurement of recirculation is critical in identifying effective ECMO blood flow (Q_{EFF}).

CASE REPORT

- A 10-year-old patient weighing 44 kg and 132 cm tall suffering from extra-pulmonary ARDS caused by postoperative sepsis and massive transfusion was placed on V-V ECMO in the hospital's pediatric ICU.
- After femoro-jugular cannulas were inserted and ECMO was initiated, pulmonary arterial oxygen levels only increased from 44 mmHg to only 66 mmHg.
- The child was then transferred to Charité's intensive care unit. There, recirculation was measured with the Extracorporeal Life Support Assurance (ELSA) Monitor using saline dilution ultrasound technique.
- The position of the two cannulas was also visualized by CT-scans.
- Together, the high recirculation fraction (Rf = 78%, 65%) with corresponding low effective ECMO blood flows (Q_{EFF} = 680 mL/min, 1260 mL/min) results with the visualization of the cannulas, lead the clinicians to postulate that the depth of the drainage cannula's insertion caused direct jetting of blood towards the inferior vena cava which cause high recirculation.
- In response, they pulled the cannula back approximately 2 cm in an attempt to reduce recirculation.
- Recirculation dropped dramatically to 25% and effective ECMO blood flow increased to 1800 mL/min.

CONCLUSION

From this experience, the team concluded that, when initiation of high flow V-V ECMO did not sufficiently support systemic oxygenation in the child, measurements of recirculation, imaging techniques and applied ECMO physiology did lead to optimization of systemic oxygenation and lung protective ventilation.



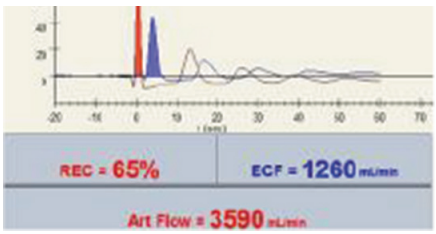
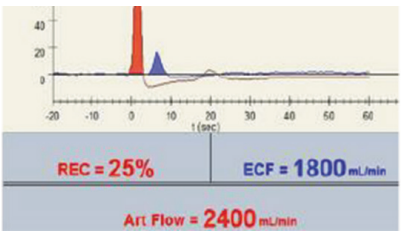


Fig. 1a, 1b: Two recirculation measurements after ECMO was initiated. Recirculation was 78% and 65% respectively. Effective flow was 680 mL/min and 1260/min.



After the outflow cannula was repositioned recirculation dropped to 25% and effective flow increased to 1800 mL/min.

TAKE HOME:

This poster demonstrates how recirculation measurements with the ELSA informs clinicians and is used to optimize ECMO flow.

REFERENCE

Russ M, Weber-Carstens S, Skrypnikov V, Taher M, Francis RCE, BoemkeW, Pickerodt PA, "Optimization of V-V ECMO circuit determined by blood recirculation measurements improved systemic oxygenation in a 10-year-old patient," 5th Annual Symposium on ARDS, Berlin, Germany, June 2019 (Transonic Reference: ELS10569A)

Russ(ELS10569A-pb)RevA2019USltr

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Publication Brief: (Said ELS10231A)

Influence of central hemodynamics and dual-lumen catheter positioning on recirculation in neonatal veno-venous ECMO

Children's National Med Ctr, George Washington Univ School of Medicine, Washington, DC

BACKGROUND

The gold standard for ECMO therapy has been venoarterial (VA) ECMO. During the last decade, a dual-lumen catheter been introduced for venovenous (VV) ECMO in neonates with respiratory failure. The catheter is inserted into the right atrium with return of oxygenated blood, directed toward the tricuspid valve. While the dual-lumen catheter enables single site cannulation (internal jugular vein), its major limitation during VV-ECMO is recirculation of the oxygenated blood, limiting the efficiency of the bypass system.

OBJECTIVE

To investigate the effectiveness of VV ECMO support via a dual lumen venovenous catheter (VV15, OriGen Biomedical, Austin, TX) as a function of catheter positioning and hemodynamic status in neonatal lamb model using an ELSA monitor (Transonic Systems Inc. Ithaca, NY) that measures flow and utilizes dilution principle to measure percent of recirculation.

METHOD

- During VV ECMO central hemodynamic assessment was performed prior to and during VV ECMO by measuring cardiac index (CI) in seven newborn lambs (1 - 5 days old, wgts. 4.2+0.5kg).
- The ELSA Monitor was used during catheter insertion to find the optimal positioning with minimal recirculation.
- ECMO flows were increased from 200 to 600mL/min. Recirculation was measured by ultrasound dilution with the ELSA Monitor and was calculated by measuring oxygen saturations from the SVC, IVC, pre and post- membrane.

RESULTS

- A Cardiac Index (CI) prior to VV-ECMO ranged from 120–310ml/min/kg.
- Two lambs with the lowest CI, of 120 and 130ml/min/kg, required intensive therapy and one died prior to initiating ECMO.
- During VV-ECMO, lambs with higher CI (>160ml/min/kg), had a tendency to have lower recirculation (7-34%, from 200 to 600ml/min) while lambs with low CI (<120 ml/min/kg), tended to have higher levels of recirculation (42-47%, from 200 to 600ml/min).
- Recirculation values calculated by blood sampling overestimate recirculation measured by dilution methods (bias 10%) but the two methods correlated well (R2 = 0.8).

CONCLUSION

- Central Hemodynamic status during VV-ECMO and catheter positioning plays an important role in optimal ECMO delivery. High recirculation may suggest cardiac output failure.
- Using the injection of a small volume of saline, the ELSA monitor provides a non-invasive method to measure recirculation and optimize catheter performance in an ECMO circuit.

REFERENCE

Said MM, Mikesell GT, Rivera O, Khodayar Rais-Bahrami K, "Influence of central hemodynamics and dual-lumen catheter positioning on recirculation in neonatal veno-venous ECMO." 2015 PAS Annual Meeting and Eastern SPR Annual Meeting (Transonic Reference: ELS10230V)

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Publication Brief: (Badheka EC11216AH)

Efficacy of Flow Monitoring During ECMO

Divisions of Pediatric Intensive Care and Pediatric Cardiac Surgery, University of Iowa Children's Hospital, Iowa City, Iowa; and Department of Biomedical Engineering, University of Iowa, Iowa City, Iowa.

BACKGROUND

Eighteen-percent of extracorporeal membrane oxygenation (ECMO) therapy across all age groups experience oxygenator-related complications resulting in 40 to 80% mortality for those patients. Clinical researchers found that pediatric ECMO patients at the University of Iowa over the last decade had a greater incidence of and higher mortality associated with oxygenator clotting (22.4%) compared with adult ECMO patients (7.5%). An effective strategy to identify oxygenator-specific problems in an ECMO circuit is to monitor, hourly, the pressure drop across the oxygenator. However, pressure monitoring does decipher other sources of distal circuit obstructions.

OBJECTIVE

The clinical researchers sought to test the hypothesis that blood flow monitoring with Transonic clamp-on tubing flowsensors could serve as an effective early indicator of distal obstructions in the ECMO circuit.

METHOD

- An ECMO circuit, adapted with a resistance chamber that simulated controlled and varying levels of distal obstructions, was used to test the hypothesis that distal circuit obstructions would result in an increased diversion of flow from the distal line to the shunt thus elevating flow through the shunt. This increase in shunt flow would then serve as a marker for a distal circuit obstruction.
- Experiments were conducted for conditions simulating varying-sized patients from infants to adults. Measurements at 500, 1000, 1500, 2000, 3000, 4000 and 5000 mL/min pump target flow rates simulated different levels of distal obstructions in the different size patients.
- At all flow rates, shunt flows and pressure drops across the obstruction were documented.

RESULTS

There was measurable and statistically significant elevation in the shunt flow at all flow rates from baseline values due to different levels of obstructions.

CONCLUSION

- The results support the hypothesis that elevations in shunt flow can serve as an indicator of distal obstruction in the ECMO circuit.
- Transonic flow monitoring is non-invasive, maintains sterility of the circuit, and is easy to implement. It is continuous and operator-free while pressure monitoring is not.
- Flow monitoring can serve as an early nonspecific warning of elevated distal resistance anywhere in the ECMO circuit. This in turn can trigger other measurements such as pressure drop across the oxygenator for a more specific assessment of the source for distal resistance.

TAKE HOME

Study uses Transonic flowmeter to test the efficacy of flow monitoring during ECMO to detect obstructions anywhere in the ECMO circuit and how flow measurements can complement hourly pressure monitoring to identify oxygenator complications.

REFERENCE

Badheka A, Stucker SE, Turek JW, Raghavan ML. "Efficacy of Flow Monitoring During ECMO," ASAIO J. 2017; 63(4): 496-500. (Transonic Reference: EC11216AH)

Badheka(EC11216AH-pb)RevA2017USltr

Publication Brief: (Palmér EC11034AH)

Cannula Design and Recirculation During Venovenous Extracorporeal Membrane Oxygenation.

Palmér O *et al,* ECMO Centre Karolinska, Karolinska University Hospital, Stockholm, Sweden.

BACKGROUND

Extracorporeal membrane oxygenation (ECMO) is a lifesaving respiratory or cardiac failure treatment. During venovenous (VV) ECMO, recirculation occurs, but how much is not known and actions to minimize recirculation after measurement are not routine.

OBJECTIVE

To investigate the effect of draining cannula design on recirculation fraction (Rf) during VV ECMO using the ELSA Monitor and ultrasound dilution technology (UDT).

STUDY

- Fourteen patients admitted to ECMO Centre Karolinska between October 2014 and July 2015 who were catheterized by the atrio-femoral single lumen method were included in the study.
- A total of 108 measurements were conducted to compare a conventional mesh cannula (n = 31) with a multistage cannula (n = 77).
- The effect of adjusting cannula position was also studied.
- Ultrasound dilution technique was used to measure recirculation at different ECMO flows and after cannula repositioning.

RESULTS

- The multistage cannula showed significantly less recirculation (19.0 ± 12.2%) compared with the conventional design cannula (38.0 ± 13.7).
- Adjustment of cannulas reduced Rf by 7%.

CONCLUSION

- The choice of cannula matters.
- Adjustment of the draining cannula position during atrio-femoral VV ECMO also matters.
- By utilizing the ultrasound dilution technique to measure Rf before and after repositioning, effective ECMO flow can be improved for a more effective ECMO treatment.

TAKE HOME

This ASAIO Journal publication is the first to apply UDT (the ELSA) in a clinical setting to measure recirculation fraction. Quotes from the paper include:

- "To reduce and quantify recirculation with UDT is an easy bedside tool to improve draining cannula position."
- "Bedside UDT was the most important factor in attaining best (cannula) position."
- "The alternative methods to access Rf are all inferior to UDT."
- "UDT is a tool which can guide the physician in improving medical care and assist in understanding physiologic problems not only concerning recirculation but also indirectly in assessing cardiac function over time, etc."
- "The use of ultrasound dilution technology is simple, noninvasive and provides bedside feedback regarding recirculation fraction. Less recirculation means a more effective ECMO therapy."

REFERENCE:

Palmér O, Palmér K, Hultman J, Broman M, "Cannula Design and Recirculation During Venovenous Extra-corporeal Membrane Oxygenation," ASAIO J. 2016; 62(6): 737-742. (Transonic Reference # EC11034AH)

Publication Brief: (Mosier EC11787AHR)

Extracorporeal membrane oxygenation (ECMO) for critically ill adults in the emergency department: history, current applications, and future directions

Mosier JM *et al,* Department of Emergency Medicine, University of Arizona, Tucson, AZ *85724 USA*

Objective:

This 2015 review discusses the existing literature on the potential use of extracorporeal membrane oxygenation (ECMO) in critically ill patients within the emergency department.

Context:

The review begins by providing a short introduction to ECMO to provide context for the following discussion. It describes ECMO as a mode of extracorporeal life support that augments oxygenation, ventilation and/or cardiac output via cannulae connected to a circuit that pumps blood through an oxygenator and back into the patient. ECMO has been used for decades to support cardiopulmonary disease refractory to conventional therapy. While not robust, there are now promising data for the use of ECMO in acute hypoxemic respiratory failure, cardiac arrest, and cardiogenic shock and the potential indications for ECMO continue to increase.

Contents:

After a short introduction and history of ECMO, the review addresses the its current applications that include the following:

- Veno-venous ECMO for severe acute respiratory failure;
- Veno-arterial ECPR for cardiac arrest;
- VA ECMO for shock.

Important programmatic and technical considerations are then discussed, followed by a discussion of contraindications, complications, and ethical challenges associated with the implementation of ECMO.

Conclusion:

The review concludes that since its introduction in the 1950s, extracorporeal life support has gone from the operating room to a promising rescue modality for cardiopulmonary failure in the ICU and even to the emergency department, yet significant hurdles exist. However, there are currently no data to support ECMO as anything other than a rescue therapy to be implemented in experienced centers at this time.

Transonic Tubing Flowmeter shown as integral component in ECMO circuit to continuously monitor flow through tubing Flowsensors attached to the circuit.

In the caption ECMO circuit components and flow through the ECMO circuit are described. Flow begins at the venous drainage cannula which is propelled forward by the pressure gradient generated by the centrifugal pump head. The blood passes through the oxygenator and then returns to the patient in the outflow tubing back into the right atrium (VV) or femoral artery (VA). Gas exchange is regulated by the amount of countercurrent "sweep" gas flowing through the oxygenator and the blood is warmed by the thermoregulator attached to the circuit. Flow, hemoglobin, hematocrit and venous saturation can be continuously monitored by ultrasonic meters attached to the circuit.

Reference

Mosier JM, Kelsey M, Raz Y *et al,* "Extracorporeal membrane oxygenation (ECMO) for critically ill adults in the emergency department: history, current applications, and future directions," Crit Care. 2015;19:431. (Transonic Reference #EC11787AHR)

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Mosier(EC1178AHR-pb) Rev A 2020 USltr

Publication Brief: (Körver ELS9679AH)

Quantification of recirculation as an adjuvant to transthoracic echocardiography for optimization of dual-lumen extracorporeal life support

University of Maastricht, The Netherlands.

OBJECTIVE

To present three representative cases with which to illustrate the benefits of ultrasound dilution technique to quantify recirculation in addition to transthoracic echocardiography during venovenous extracorporeal life support (VV-ECLS).

METHOD

- Transthoracic echocardiography images were taken of cannula positioning in three VV-ECLS patients.
- One flow/dilution sensor was placed on the arterial inlet of a double-lumen catheter, the second on the venous outlet of the catheter.
- Recirculation was measured in three patients by a 10 mL saline bolus into the outlet port of the oxygenator. Ultrasound velocity changes were detected by the flow/dilution sensors and were displayed as a dilution curve and percent recirculation.

RESULTS

- In the first case a 2% recirculation by ultrasound dilution confirmed proper cannula positioning as displayed on the transthoracic echocardiography screen.
- In the second case a 45% recirculation by ultrasound dilution confirmed a suboptimal cannula positioning as displayed on the transthoracic echocardiography screen.
- In the third case, ultrasound dilution registered a 38% recirculation, although the transthoracic echocardiography images showed good positioning of the cannula. The ultrasound dilution recirculation prompted repositioning of the cannula that permitted a decrease in mechanical ventilation and increased arterial saturation.

CONCLUSION

Cannula migration can cause suboptimal VV-ECLS, but resultant recirculation may remain undetected using transthoracic echocardiography alone. Ultrasound dilution proved to be a valuable tool to monitor dual-lumen cannula position during VV-ECLS. We therefore suggest quantification of recirculation in addition to image guidance to prompt interventions that improve oxygenation and decapneization, and provide optimal VV-ECLS.

DISCUSSION

Although transesophageal echocardiography can verify cannula positioning during dual-lumen VV-ELS, recirculation and resultant inadequate lung assist may still occur due to cannula migration. The ultrasound dilution technique's ability to quantify recirculation may be crucial in correctly (re)positioning a double-lumen cannula for maintaining optimal VV-ECLS.

REFERENCE

Körver EP, Ganushchak YM, Simons AP, Donker DW, Maessen JG, Weerwind PW. "Quantification of recirculation as an adjuvant to transthoracic echocardiography for optimization of dual-lumen extracorporeal life support." Intensive Care Med. 2012; 38(5): 906-9.

(Transonic Reference # ELS9679AH)

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THE MEASURE OF BETTER RESULTS.

Publication Brief: (Clements ELS9680A)

Measurements of recirculation during neonatal veno-venous extracorporeal membrane oxygenation: clinical application of the ultrasound dilution technique

State Univ of NY Upstate Medical Center

OBJECTIVE

To report the first clinical application of ultrasound dilution technology's capability to quantify recirculation during neonatal venovenous extracorporeal membrane oxygenation (VV ECMO) and to study various aspects of using ultrasound dilution to quantify recirculation.

METHOD

- A 2.8 kg male neonate born with congenital diaphragmatic hernia was placed on VV ECMO using a single 12 Fr. dual lumen cannula inserted into the right atrium through the internal jugular vein.
- Utrasound dilution sensors were applied to the arterial and venous lines of the ECMO circuit near the dual lumen cannula.
- A 3-5 ml bolus injection of room temperature normal saline was injected into the extracorporeal circuit.
- During the 12-day VV ECMO run, 86 recirculation measurements were performed under a variety of conditions.
- Measurements using injections of platelet concentrates were compared with those made with saline.

RESULTS

- The average recirculation measurement was 34.3% and ranged from 15-57%.
- The reproducibility of recirculation measurements performed within five minutes of one another was within 5.6% of each other.
- Changes in patient positioning resulted in significant changes in recirculation.
- Measurements of platelet injection correlated closely with saline injections (mean difference, .25% +/- 2.8%).

CONCLUSION

In this initial case experience, ultrasound dilution technique provided quick, reproducible beside results that showed changes in recirculation associated with VV ECMO therapy. Application of this technique could provide early data that will assist the clinician in guiding interventions to minimize recirculation.

DISCUSSION

VV ECMO recirculation occurs when a portion of the oxygenated blood that is delivered to the patient through a double-lumen catheter's arterial lumen immediately flows back into the venous lumen and, therefore, doesn't circulate within the patient. Excessive recirculation will result in suboptimal oxygen delivery to the patient. This paper shows that ultrasound dilution technology can be used to quantify recirculation in noenates on VV ECMO.

REFERENCE

Clements D, Primmer J, Ryman P, Marr B, Searles B, Darling E. "Measurements of recirculation during neonatal veno-venous extracorporeal membrane oxygenation: clinical application of the ultrasound dilution technique." J Extra Corpor Technol. 2008;40(3):184-7.

Transonic Reference: ELS9680AH

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THE MEASURE OF BETTER RESULTS.

Publication Brief: (van Heijst ELS9766A)

Recirculation in double lumen catheter veno-venous extracorporeal membrane oxygenation measured by an ultrasound dilution technique

Univ. Med Ctr., Nijmegen, The Netherlands

OBJECTIVE

To compare three different methods (an ultrasound dilution (UD) method, the gold standard SvO2 method, the CVL method) for assessing recirculation during double lumen catheter veno-venous ECMO (DLVV-ECMO), at different ECMO flows.

STUDY

- Nine lambs (weight 4.3-6.5 kg) were placed on DLVV-ECMO by positioning the tip of the double-lumen catheter in the right atrium via the right internal jugular vein.
- Recirculation was measured by each of the three methods at ECMO flow rates of 150, 125, 100, 75, and 50 ml/kg/min.
- UD Flow/dilution sensors were clipped onto the arterial and venous limbs of the double lumen catheter to measure recirculation with the UD method. Mean values of three recirculation measurements were used for comparison with the other methods.
- Blood samples taken from the central venous line were used to determine the oxygen saturation for the CLV and SVO_2 methods.
- Recirculation was measured by each method at ECMO flow rates of 150, 125, 100, 75, & 50 ml/kg.min.

RESULTS

RECIRCULATIONS AT DIFFERENT FLOW RATES IN NINE LAMBS*

FLOW RATE (ml/kg/min)	ULTRASOUND DILUTION (%)	SVO_2 METHOD (%)	CVL METHOD (%)
150	36.0 ± 12.8	45.0 ± 6.9	62.5 ± 6.9
125	32.8 ± 9.3	39.3 ± 9.5	54.8 ± 13.5
100	24.6 ± 9.4	31.7 ± 8.2	39.1 ± 17.6
75	20.2 ± 6.5	24.5 ± 12.6	29.6 ± 15.7
50	13.0 ± 4.0	12.4 ± 10.0	29.6 ± 15.7

*Mean values ± standard deviation

With all methods, recirculation increased with increasing ECMO flow rate. The correlation coefficient between the UD method and SvO_2 method was 0.68 ($p < 0.01$); mean difference was -2.4% ($p = 0.6$). The correlation coefficient between the UD method and the CVL method was 0.48 ($p < 0.01$); mean difference was -18.1% ($p < 0.01$). The correlation coefficient between the SvO2 method and the CVL method was 0.51 ($p < 0.01$); mean difference was -15.7% ($p < 0.01$).

CONCLUSIONS

The ultrasound dilution method is a useful method for measurement of the recirculation fraction in DLVV-ECMO and is easier to use than the other methods.

REFERENCE

van Heijst AF, van der Staak FH, de Haan AF, Liem KD, Festen C, Geven WB, van de Bor M. "Recirculation in double lumen catheter veno-venous extracorporeal membrane oxygenation measured by an ultrasound dilution technique". ASAIO J. 2001 Jul-Aug;47(4):372-6.

(Transonic Reference # ELS9766A)

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THE MEASURE OF BETTER RESULTS.

Publication Brief: (Walker ELS7584A)

The potential of accurate SvO2 monitoring during venovenous extracorporeal membrane oxygenation: an in vitro model using ultrasound dilution.

State Univ of NY Upstate Med Ctr, Syracuse.

OBJECTIVE

To test whether accurate patient mixed venous oxygen saturation (SvO_2) can be calculated once recirculation is determined. It is hypothesized that it is possible to derive patient mixed venous saturations by integrating recirculation data with the ECMO circuit arterial and venous line oxygen saturation data.

METHOD

A test system using sheep blood adjusted to three venous saturations (Low, 30%; Medium 60%; High, 80%) was interfaced via a mixing chamber with a standard VV ECMO circuit. Recirculation, arterial line and venous line oxygen saturations were measured and entered into a derived equation to calculate the mixed venous saturation. The resulting value was compared to the actual mixed venous saturation.

RESULTS

Recirculation held constant at 30.5 +/- 2.0% for all tests. A linear regression comparison of "actual" versus "calculated" mixed venous saturations produced a correlation coefficient of R2 = 0.88. Direct comparison of actual versus calculated saturations for all three test groups respectively are as follows; Low: 31.8 +/- 3.95% vs. 37.0 +/- 6.7% (NS), Med: 61.7 +/- 1.5% vs. 72.3 +/- 1.8% ($p < 0.05$), High: 84.4 +/- 0.9% vs. 91.2 +/- 1.1% ($p < 0.05$).mixed venous saturation. The resulting value was compared to the actual mixed venous saturation.

	n	MEASURED RECIRCULATION	ECMO ARTERIAL O_2 SAT (%)	ECMO VENOUS O_2 SAT (%)	ACTUAL VENOUS O_2 SAT (%)	COMBINED VENOUS O_2 SAT (%)	*p*
Group 1 (Low)	8	31.5 ± 2.4	99.4 ± 0.1	56.7 ± 6.7	31.8 ± 4.0	37.0 ± 6.7	.28
Group 2 (Medium)	11	30.8 ± 1.7	99.3 ± 0.1	80.6 ± 1.7	61.7 ± 1.5	72.3 ± 1.8	.0003
Group 3 (High)	12	29.9 ± 1.7	99.4 ± 0.2	93.7 ± 1.1	84.4 ± 0.9	91.2 ± 1.1	.0001

DISCUSSION

The researchers used ultrasound dilution (measured recirculation) as the standard against which they evaluated the other two methods.

Strong correlation existed between actual and calculated mixed venous saturations. However, in the Med (60% saturation) and High (80% saturation) groups, significant differences were observed between actual and calculated values. The data suggest that, while using quantified recirculation data to calculate SvO2 is promising, a straightforward derivative of the oxygen saturation-based equation may not be sufficient to produce clinically accurate calculations of actual mixed venous saturations.

Reference:

Walker J, Primmer J, Searles BE, Darling EM. The potential of accurate SvO2 monitoring during venovenous extracorporeal membrane oxygenation: an in vitro model using ultrasound dilution. Perfusion. 2007; 22(4): 239-44.

(Transonic Reference # ELS7584A)

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THE MEASURE OF BETTER RESULTS.

Publication Brief: (Darling ELS7309V)

Use of dilutional ultrasound monitoring to detect changes in recirculation during venovenous extracorporeal membrane oxygenation in swine

State University of NY Upstate Medical Center, Syracuse

OBJECTIVE

To evaluate an ultrasound dilution technology's capability to provide accurate recirculation data under changing conditions in a venovenous extracorporeal membrane oxygenation (VV ECMO) swine model.

METHOD

- One 16-kg swine, cannulated with a dual-lumen cannula, was placed on VV ECMO.
- Recirculation was measured by using blood oxygen saturations (r = Spreox - SVO2/Spostox - SVO2) and was then compared with ultrasound dilution recirculation measurements.
- Three ultrasound dilution measurements were made at the following pump flow rates: 200 ml/min, 400 ml/min, 600 ml/min and 760 ml/min. Time to generate results was recorded.
- Ultrasound dilution technique was then used to measure changes in baseline recirculation during (a) cannula repositioning at a pump rate of 500 ml/min; (b) any drug-induced cardiac output changes.

RESULTS

- Comparison of recirculation calculations between the saturation method and ultrasound dilution technique were similar at all flow rates measured.
- Ultrasound dilution technique generated results much faster than the other techniques.
- Ultrasound dilution technique rapidly detected recirculation changes induced by repositioning the cannula or changing cardiac output. Significant differences from baseline recirculation were displayed by the ultrasound dilution technique.

CONCLUSION

Ultrasound dilution technology is a clinically practical way to quantify and monitor recirculation during VV ECMO. It may assist in assessing interventions to improve oxygen delivery.

DISCUSSION

VV ECMO recirculation occurs when a portion of the oxygenated blood that is delivered to the patient through a double-lumen catheter's arterial lumen immediately flows back into the venous lumen and, therefore, never reaches the patient. Since recirculation during VV ECMO reduces oxygen delivery to the patient, recirculation should be monitored to guide clinicians as they intervene to reduce recirculation and optimize their patient's VV ECMO. Quantification of recirculation could help troubleshoot poor VV ECMO situations and offer valuable information in making clinical decisions.

This swine model study suggests that ultrasound dilution technique may be clinically practical to quantify recirculation during VV ECMO.

REFERENCE

Darling EM, Crowell T, Searles BE. "Use of dilutional ultrasound monitoring to detect changes in recirculation during venovenous extracorporeal membrane oxygenation in swine." ASAIO J, 2006; 52(5):522-4. (Transonic Reference # ELS7309V)

transonic
THE MEASURE OF BETTER RESULTS.

Publication Brief: (Melchoir ELS7177V)

A novel method of measuring cardiac output in infants following extracorporeal procedures: preliminary validation in a swine model.

State University of NY Upstate Medical Center, Syracuse, NY

OBJECTIVE

To validate ultrasound dilution cardiac output (CO) measurements against transit-time ultrasound (TTU) perivascular flowprobe and pulmonary artery (PA) catheter thermodilution measurements in a pilot swine model study.

METHOD

- Three anesthetized and heparinized 11-14 kg Yorkshire pigs were included in the study
- Each pig was cannulated to mimic the arterial (aortic arch) and venous (ext. jugular vein or right atrium) cannulation used during standard cardiopulmonary bypass (CPB) and veno-arterial extracorporeal membrane oxygenation (VA ECMO)
- Both venous and arterial lines were instrumented with ultrasonic flow/dilution sensors. A stopcock bridge between the arterial and venous cannulas provided an access port for a 5 - 10 cc bolus saline injection and for use as a controlled AV-shunt.
- A 10-12 mm PAX perivascular flow probe was positioned directly on the PA in two animals and on the ascending aorta in one animal.
- A PA thermodilution catheter was advanced to the PA in the largest animal.
- Baseline CO measurements were recorded from the TTU flowprobe and the PA catheter.
- Cardiac Output (CO) ultrasound dilution measurements (L/min) were performed

RESULTS

The correlation between the ultrasound dilution CO, the perivascular flowprobe, and the PA thermodilution catheter was R^2 =0.94 (n = 3) and 0.81 (n = 1) respectively, from linear regression analysis

CONCLUSION

CO measured by ultrasound dilution technique correlates to other benchmarks CO measurements.

DISCUSSION

In infants, a particularly vulnerable subgroup of patients, technologies for obtaining rapid, quantified measurements of cardiac output (CO) following weaning from cardiopulmonary bypass (CPB) or extracorporeal membrane oxygenation (ECMO) are not readily available. Ultrasound dilution methodology provides rapid CO measurements that could greatly assist clinicians in therapy strategies and decision making in weaning patients from CPB or ECMO.

Reference:

Melchior R, Darling E, Terry B, Gunst G, Searles B. “A novel method of measuring cardiac output in infants following extracorporeal procedures: preliminary validation in a swine model,” Perfusion, 2005;20(6):323-7

Transonic Reference #ELS7177V

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