Extracorporeal Life Support Organization (ELSO)

Identification and management of recirculation in venovenous ECMO

Authors:

Darryl Abrams, MD (New York, US)

Daniel Brodie, MD (New York, US)

Disclaimer

These guidelines describe useful and safe practice for extracorporeal life support (ECLS, ECMO) but these are not necessarily consensus recommendations. These guidelines are not intended as a standard of care, and are revised at regular intervals as new information, devices, medications, and techniques become available. These guidelines are intended for educational use to build the knowledge of physicians and other health professionals in assessing the conditions and managing the treatment of patients undergoing ECLS / ECMO. These guidelines are not a substitute for a health-care provider's professional judgment and must be interpreted with regard to specific information about the patient and in consultation with other medical authorities as appropriate. In no event will ELSO be liable for any decision made or action taken in reliance upon the information provided through these guidelines.

Extracorporeal Life Support Organization (ELSO) Clinical Guideline

Key words and abbreviations

CVL central venous line
ECMO extracorporeal membrane oxygenation
IVC inferior vena cava
SVC superior vena cava
SaO_2 saturation of arterial blood
$S_{pre}O_2$ saturation of blood entering the membrane oxygenator
$S_{post}O_2$ saturation of blood leaving the membrane oxygenator
SvO_2 saturation of venous blood returning to the vena cavae

Overview

Recirculation is a phenomenon, exclusive to venovenous ECMO, in which reinfused oxygenated blood is withdrawn through the drainage cannula without passing through the systemic circulation.[1] Because recirculated blood does not contribute to systemic oxygen delivery, its presence decreases the efficiency with which ECMO provides oxygenation. Whether the amount of recirculation has clinical significance, and whether it requires intervention, depends on the degree to which the patient is dependent on ECMO for oxygenation.[2]

Of note, recirculation should be distinguished from differential venous oxygenation that may occur in venoarterial circuits when there is residual native cardiac output and impaired native gas exchange. Poorly oxygenated blood will supply the upper body whereas the lower body will be perfused by well-oxygenated blood. The well-saturated blood returning to the IVC may be taken up by the drainage cannula, a phenomenon that may be interpreted as a form of recirculation. However, because the blood has already passed through the systemic circulation prior to reuptake by the circuit, this does not constitute recirculation in the classical sense.

Factors affecting recirculation

Cannula configuration and positioning

In two-site venovenous ECMO with femoral and internal jugular cannulation, the reinfusion jet is directed toward the drainage port. When the drainage and reinfusion cannulae are in closer proximity, one can expect a higher amount of recirculation. Changes in patient positioning may likewise affect the amount of recirculation, though this relationship is less predictable.[3]

Pump speed, cannula size, and extracorporeal blood flow

Increases in pump speed and ECMO blood flow rate correlate with increases in recirculation, with varying relationships depending on cannula type, size, and position, and method used to measure recirculation.[4-6] The use of larger cannulae may mitigate the amount of recirculation by allowing for higher blood flow rates with less negative venous pressure in the drainage limb.

Changes in intra-thoracic, intra-cardiac, and intra-abdominal pressures

Increases in intra-thoracic and intra-cardiac pressure (i.e. pneumothorax, pericardial tamponade) will impede venous return to the heart, which may preferentially direct reinfused extracorporeal blood flow toward the drainage cannula, increasing recirculation. Extreme elevations in these pressures may lead to cessation of extracorporeal blood flow altogether.[7-9] Effects on increased intra-abdominal pressure are less well defined.

Direction of ECMO blood flow

In two-site venovenous ECMO with femoral and internal jugular cannulation, the direction of drainage and reinfusion impacts the amount of recirculation. Femoral drainage and atrial reinfusion via the internal jugular vein (femoro-atrial flow) results in less recirculation than femoro-atrial flow, making femoral drainage and atrial reinfusion the preferred direction of blood flow for this configuration.[10]

Identifying and quantifying the amount of recirculation

Percent recirculation is quantified by the following equation:

Recirculation (%) = $(S_{pre}O_2 – SvO_2)/(S_{post}O2 – SvO_2)$ x100;

However, SvO_2 is difficult to measure because of the presence of reinfused oxygenated blood. Several methods have been used to quantify the amount of recirculation (Table 1). None of these methods has been definitively shown to accurately measure the percent recirculation, though trends in each of these values, in conjunction with assessments in SaO_2, may be useful in identifying changes in the amount of recirculation and, therefore, efficiency of the ECMO circuit over time.

Method of estimating % recirculation	Description
CVL[*4,11,12]	Formula: $(S_{pre}O_2 – SvO_2)/(S_{post}O_2 – SvO_2)$ x100 SvO_2 estimated by measuring venous saturation of blood from SVC or IVC via central venous catheter
SvO2[*4,5,11]	Formula: $(S_{pre}O_2 – SvO_2)/(S_{post}O_2 – SvO_2)$ x100 $SvO_2 = S_{pre}O_2$ when sweep gas turned off and ventilator used to achieve an equivalent SaO_2
Ultrasound dilution[#12]	Saline injected into reinfusion limb; ultrasound sensor detects differences in dilution between drainage and reinfusion limb
Thermodilution[#6]	Cold saline injected into reinfusion limb; thermistor-tipped catheter detects changes in temperature in drainage limb
Trending $S_{pre}O_2$[#13,14]	Observation of changes in $S_{pre}O_2$ and SaO_2 over time; increasing SpreO2 and decreasing SaO2 suggest clinically relevant recirculation

Table 1. Methods of estimating the amount of recirculation

*requires estimation of SvO_2
#independent of SvO_2

Interventions to reduce recirculation

Increasing distance between cannulae

Increasing the distance between drainage and reinfusion ports in a two-site venovenous ECMO configuration, by withdrawing one or both cannulae, is the most direct way to reduce the amount of recirculation. However, there is no standard distance that should be maintained between ports. Chest radiography and ultrasonography may be used to assess cannula positioning. It is recommended that the femoral drainage cannula be positioned with the side ports in the hepatic IVC, as this portion of the IVC is least likely to collapse and impede venous drainage when under negative pressure. Maintaining this position may limit how far the drainage cannula can be withdrawn. Any manipulation of cannulae requires that close attention be paid to the $S_{pre}O_2$, blood flow, and negative venous pressure.

Alterations in ECMO circuit configuration

- Use of a bicaval, dual-lumen cannula

  Bicaval dual-lumen cannulae permit venovenous ECMO via a single venous access site.[15] When properly positioned, which usually requires both echocardiographic and fluoroscopic guidance, drainage ports are located in the SVC and IVC and the reinfusion jet is directed toward the tricuspid valve.[16] Recirculation with this configuration may be as low as 2%, although malposition of the cannula may significantly increase the rate of recirculation.[17] Any adjustment of the cannula after its initial insertion should be done under echocardiographic guidance to ensure appropriate orientation of the reinfusion jet.

- Addition of a drainage cannula

  Given the relationship between pump speed, negative venous pressure and recirculation, an additional drainage cannula may permit comparable blood flow rates to be achieved at lower pump speeds and at less negative pressure, thereby lowering the amount of recirculation.[18]

- Manipulation of the reinfusion cannula

  Attempts have been made to alter the reinfusion cannula in a two-site configuration in order to direct the reinfusion jet toward the tricuspid valve, with or without simultaneous repositioning of the drainage cannula.[19,20] Given the limited data, such approaches are not generally recommended.

References

1. Fortenberry JD, Pettignano R, Dykes F. Principles and Practice of Venovenous ECMO. In: Van Meurs K, Lally D, Peek G, Zwischenberger J, eds. *ECMO Extracorporeal Cardiopulmonary Support in Critical Care. 3*. Ann Arbor, MI: Extracorporeal Life Support Organization; 2005:94.

2. Abrams D, Bacchetta M, Brodie D. Recirculation in venovenous extracorporeal membrane oxygenation. *ASAIO J.* 2014:In press.

3. 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.* Sep 2008;40(3):184-187.

4. van Heijst AF, van der Staak FH, de Haan AF, et al. Recirculation in double lumen catheter veno-venous extracorporeal membrane oxygenation measured by an ultrasound dilution technique. *ASAIO J.* Jul-Aug 2001;47(4):372-376.

5. Anderson HL, 3rd, Otsu T, Chapman RA, Barlett RH. Venovenous extracorporeal life support in neonates using a double lumen catheter. *ASAIO Trans.* Jul-Sep 1989;35(3):650-653.

6. Sreenan C, Osiovich H, Cheung PY, Lemke RP. Quantification of recirculation by thermodilution during venovenous extracorporeal membrane oxygenation. *J Pediatr Surg.* Oct 2000;35(10):1411-1414.

7. Lansdorp B, Hofhuizen C, van Lavieren M, et al. Mechanical ventilation-induced intrathoracic pressure distribution and heart-lung interactions*. *Crit Care Med.* Sep 2014;42(9):1983-1990.

8. Mesquida J, Kim HK, Pinsky MR. Effect of tidal volume, intrathoracic pressure, and cardiac contractility on variations in pulse pressure, stroke volume, and intrathoracic blood volume. *Intensive Care Med.* Oct 2011;37(10):1672-1679.

9. Zwischenberger JB, Cilley RE, Hirschl RB, Heiss KF, Conti VR, Bartlett RH. Life-threatening intrathoracic complications during treatment with extracorporeal membrane oxygenation. *J Pediatr Surg.* Jul 1988;23(7):599-604.

10. Rich PB, Awad SS, Crotti S, Hirschl RB, Bartlett RH, Schreiner RJ. A prospective comparison of atrio-femoral and femoro-atrial flow in adult venovenous extracorporeal life support. *J Thorac Cardiovasc Surg.* Oct 1998;116(4):628-632.

11. Cornish D, Clark R. Principles and practice of venovenous extracorporeal membrane oxygenation. In: Zwischenberger J, Bartlett R, eds. *ECMO, Extracorporeal Cardiopulmonary Support in Critical Care*. Ann Arbor, ELSO1995:87-107.

12. 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.* Sep-Oct 2006;52(5):522-524.

13. Rais-Bahrami K, Rivera O, Mikesell GT, Seale WR, Sell JE, Short BL. Improved oxygenation with reduced recirculation during venovenous extracorporeal membrane oxygenation: evaluation of a test catheter. *Crit Care Med.* Oct 1995;23(10):1722-1725.

14. Rais-Bahrami K, Walton DM, Sell JE, Rivera O, Mikesell GT, Short BL. Improved oxygenation with reduced recirculation during venovenous ECMO: comparison of two catheters. *Perfusion.* Nov 2002;17(6):415-419.

15. Javidfar J, Brodie D, Wang D, et al. Use of bicaval dual-lumen catheter for adult venovenous extracorporeal membrane oxygenation. *Ann Thorac Surg.* Jun 2011;91(6):1763-1768; discussion 1769.

16. Javidfar J, Wang D, Zwischenberger JB, et al. Insertion of bicaval dual lumen extracorporeal membrane oxygenation catheter with image guidance. *ASAIO J.* May-Jun 2011;57(3):203-205.

17. Wang D, Zhou X, Liu X, Sidor B, Lynch J, Zwischenberger JB. Wang-Zwische double lumen cannula-toward a percutaneous and ambulatory paracorporeal artificial lung. *ASAIO J.* Nov-Dec 2008;54(6):606-611.

18. Ichiba S, Peek GJ, Sosnowski AW, Brennan KJ, Firmin RK. Modifying a venovenous extracorporeal membrane oxygenation circuit to reduce recirculation. *Ann Thorac Surg.* Jan 2000;69(1):298-299.

19. Lin TY, Horng FM, Chiu KM, Chu SH, Shieh JS. A simple modification of inflow cannula to reduce recirculation of venovenous extracorporeal membrane oxygenation. *J Thorac Cardiovasc Surg.* Aug 2009;138(2):503-506.

20. Bonacchi M, Harmelin G, Peris A, Sani G. A novel strategy to improve systemic oxygenation in venovenous extracorporeal membrane oxygenation: the "chi-configuration". *J Thorac Cardiovasc Surg.* Nov 2011;142(5):1197-1204.

Figures

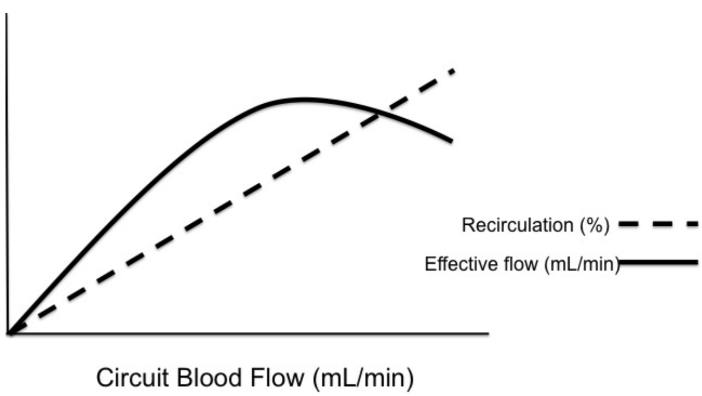

Figure 1. Impact of recirculation on effective blood flow. At higher circuit flows, recirculation increases and effective circuit blood flow decreases. Reproduced from Abrams D, Bacchetta M, Brodie D. Recirculation in venovenous extracorporeal membrane oxygenation. *ASAIO J.* 2014;In press.