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ASAIO Journal 2023 How to Do It Article

Using Cardiohelp, Quadrox, and Nautilus Extracorporeal Membrane Oxygenators as Vascular Access for Hemodialysis, Continuous Renal Replacement Therapy, and Plasmapheresis: A Brief Technical Report

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The use of intermittent hemodialysis (iHD), and continuous renal replacement therapy (CRRT), along with extracorporeal membrane oxygenation (ECMO) in patients with acute kidney injury (AKI) and end-stage renal disease (ESRD) is very common. In this technical report, we describe the methods to perform these dialytic therapies safely and effectively using the ECMO circuit in lieu of a separate dialysis catheter. Specifically, we describe in detail how to connect these kidney replacement therapy modalities to a Quadrox, Nautilus, and Cardiohelp HLS (combined oxygenator and pump) oxygenator. The dialysis (iHD or CRRT) inlet is attached to the post-oxygenators Luer-Lock, whereas the return is attached to the pre-oxygenator Luer-Lock, both with a dual lumen pigtail. We also discuss the technical aspects of performing plasmapheresis in conjunction with ECMO and iHD or CRRT. Finally, we highlight the fact that the reported technique does not require modifying the ECMO cannulas/tubing which helps maximize safety.

Key Words: ECMO, dialysis, plasmapheresis, therapeutic plasma exchange, continuous renal replacement therapy, Cardiohelp, Nautilus, Quadrox

According to the Extracorporeal Life Support Organization (ELSO) registry, acute kidney injury (AKI) requiring hemodialysis occurred in 23.5% of patients on extracorporeal membrane oxygenator (ECMO) in 2021 during the coronavirus disease-2019 (COVID-19) pandemic.[1] Additionally, COVID-19 also disproportionately affected patients with end-stage kidney disease (ESKD) receiving maintenance intermittent hemodialysis (iHD), some of whom required ECMO. The ability to provide dialysis through the ECMO circuit is important as it obviates the need for additional central venous access requirements.[2–4] This not only reduces cost (~$165 per central line) but also lowers the risk of central line-associated bloodstream infections (CLABSI), which is estimated at 84,000–204,000 annually (additional costs ~$30,000 per case) in the United States.[5–7] In many technical reports, connecting continuous renal replacement therapy (CRRT) to ECMO is done by the addition of Luer-Locks in the ECMO cannulas/tubing; however, we believe that this has many disadvantages that are described below. In this technical report, we describe in detail our protocol of successfully and safely connecting CRRT performed using the PrismaFlex and PrisMax (Baxter Inc., Deerfield, IL) machines, or iHD performed using Fresenius 2008T machines (Fresenius North America, Waltham, MA) to ECMO oxygenators, specifically the Nautilus oxygenator (Medtronic, MN), the Quadrox oxygenator (Getinge, Sweden), and the Cardiohelp HLS oxygenator (Getinge).

In this report, we refer to iHD, sustained low-efficiency dialysis, and CRRT collectively as dialysis modalities. We also describe the protocol of connecting the Optia therapeutic plasma exchange (TPE) machine to the CRRT and ECMO circuit in patients requiring concomitant TPE (see the Supplemental Digital Content, http://links.lww.com/ASAIO/B58).

Protocol to Connect Dialysis Modalities to Extracorporeal Membrane Oxygenation Oxygenators

Supplies

The supply list can be found in sTable 1, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58.

- PrismaFlex or PrisMax tubing set (for CRRT).
- Duel-port Y-pigtails (centurion parallel Y-extension set).
- Three-way stopcocks (2).
- Intravenous tubing.
- 0.9% sodium chloride.
- Trisodium citrate for anticoagulation. Other institutions may use acid citrate dextrose solution A, regiocit, and heparin.

Equipment

PrisMax or PrismaFlex machines (CRRT) or Fresenius 2008T machines (iHD).

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Submitted for consideration January 2023; accepted for publication in revised form June 2023.

Disclosure: The authors have no conflicts of interest to report.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML and PDF versions of this article on the journal's Web site (www.asaiojournal.com).

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DOI: 10.1097/MAT.0000000000002005

Table 1. Common Scenarios and Complications of Running Dialysis Modalities (Specifically CRRT) on ECMO Circuits and Recommended Solutions

Complications/Issues	Causes	Recommendation
High CRRT draw pressures	Kink along CRRT line	Inspect and ensure lines are free of kinks and occlusions.
	Coughing or suctioning of patient	Wait until after patient ceases coughing or after suctioning then press continue on the CRRT machine to resume treatment.
	Catheter arterial limb rests and sucks up against the wall of vessel	Reverse catheter port connections. Flush with 10 ml NS syringe to test patency.
	Patient limb or head position interferes with blood flow	Reposition limb (in femoral catheters) or head orientation (in IJ catheters). Flush with 10 ml NS syringe to test patency.
	Clotting or fibrin sheath	Return blood to the patient and call acute dialysis to change CRRT cartridge and restart treatment.
High CRRT return pressures	Kink along CRRT line	Inspect and ensure lines are free of kinks and occlusions.
	Patient limb or head position interferes with blood flow.	Reposition limb (in femoral catheters) or head orientation (in IJ catheters). Flush with 10 ml NS syringe to test patency.
	Clotting or fibrin sheath	Return blood to patient and call acute dialysis to change CRRT cartridge and restart treatment.

CRRT, continuous renal replacement therapy; ECMO, extracorporeal membrane oxygenation; IJ, internal jugular; NS, normal saline.

Dialysis Modality Settings and Anticoagulation (Institution Specific)

- Blood flow rates
  a. 250–400 ml/min (iHD).
  b. 100–200 ml/min (CRRT), start at 100 ml/min, and may increase based on clotting/clearance needs.
- The upper-pressure alarm limit is set at 350 mm Hg on the outlet line of CRRT
- Duration of treatment
  a. iHD: varied between 2 and 4 hours based on clinical need.
  b. CRRT: 24 hours.
- Anticoagulation
  a. Hourly normal saline flushes during iHD to prevent filter clotting. Heparin is not used as an anticoagulant in iHD at our institution.
  b. Regional citrate anticoagulation using trisodium citrate for CRRT, with a target post-filter ionized calcium of 0.2–0.30.

Technique for Connecting Dialysis Modalities (Intermittent Hemodialysis and Continuous Renal Replacement Therapy) to Extracorporeal Membrane Oxygenation

The below protocol is for connecting CRRT or HD to the ECMO circuit, see Figure 1 and Video (Supplemental Digital Content). If performing TPE and CRRT concurrently, then see instructions in sFigure 1, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58. **See Table 1** for common complications of running dialysis modalities on ECMO circuits and recommended solutions.

1. All oxygenators (HLS—Cardiohelp oxygenator, Quadrox oxygenator, and Nautilus oxygenator) have dual-port Y-pigtails connected before circuit priming (see Figures 2 and 3).
   a. Y-pigtails are placed if the circuit lacks them or are replaced if clotted.
   b. Prior to connection to dialysis modalities, the Y-pigtails are tested to ensure easy blood removal and return.
2. Attach three-way stopcocks to the Y-pigtails pre- and post-oxygenator.
3. Attaching the dialysis modalities parallel to the ECMO unit in tandem.
   a. The dialysis modality RETURN line should be connected to the ECMO venous pigtail (Y-connector) on the pre-oxygenator side (see Figures 1–3).
   b. The dialysis modality ACCESS (draw) line should be connected to the ECMO arterial pigtail (Y-connector) on the post-oxygenator side (see Figures 1–3).
4. Initiation, monitoring, and management of dialysis modalities per institutional policy.
   a. Recommend that lines from ECMO are to disconnect by an ECMO specialist.
5. Termination of dialysis modality
   a. ECMO specialist claps the side of the pigtail that is connected to CRRT.
   b. The dialysis modality lines are disconnected.
   c. ECMO specialist flushes ECMO pigtails, ensuring no air entrainment.

Technique for Obtaining Pre- or Post-Oxygenator Blood Gasses With Extracorporeal Membrane Oxygenation Circuit Connected to a Dialysis Machine With a Y-pigtail

The dual-port Y-pigtails that are in place on both the pre- and post-oxygenator allow for blood gas acquisition without requiring the disconnection of dialysis lines. During the

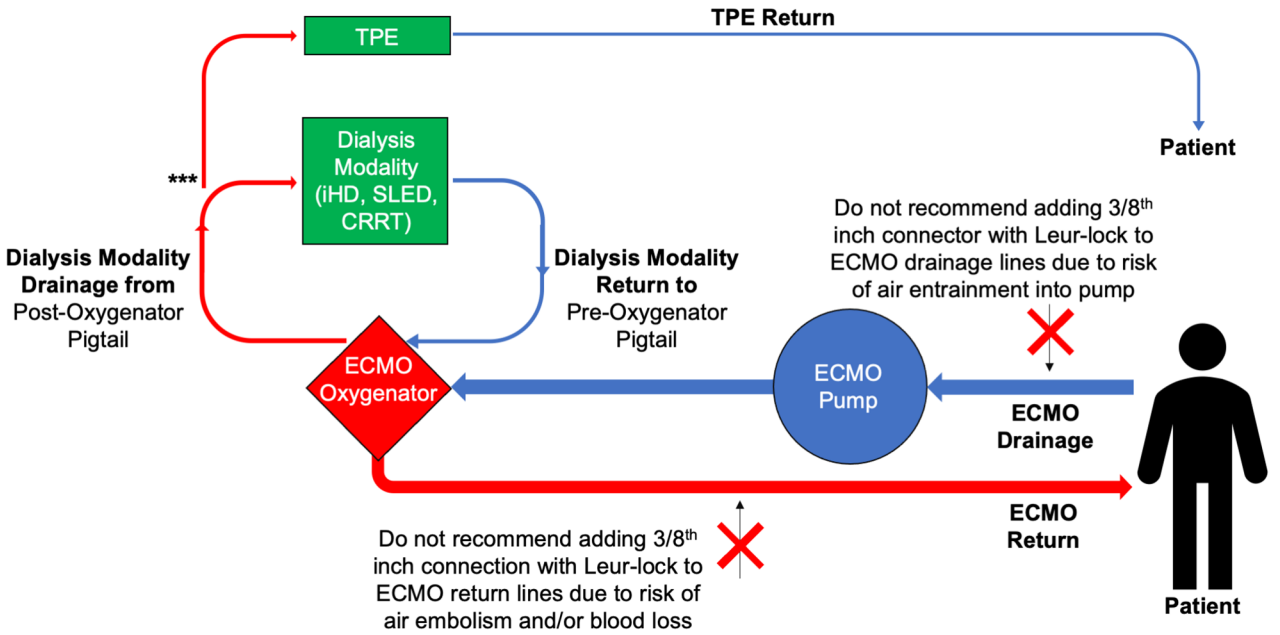

Figure 1. Schematic to connect dialysis modalities (iHD, CRRT) and TPE to ECMO circuit in tandem. ***If using TPE without a dialysis modality (iHD, CRRT), then the return is directly to the patient. If using TPE concurrently with a dialysis modality (iHD, CRRT), then see the Supplemental Digital Content, http://links.lww.com/ASAIO/B58. CRRT, continuous renal replacement therapy; ECMO, extracorporeal membrane oxygenation; iHD, intermittent hemodialysis; TPE, therapeutic plasma exchange.

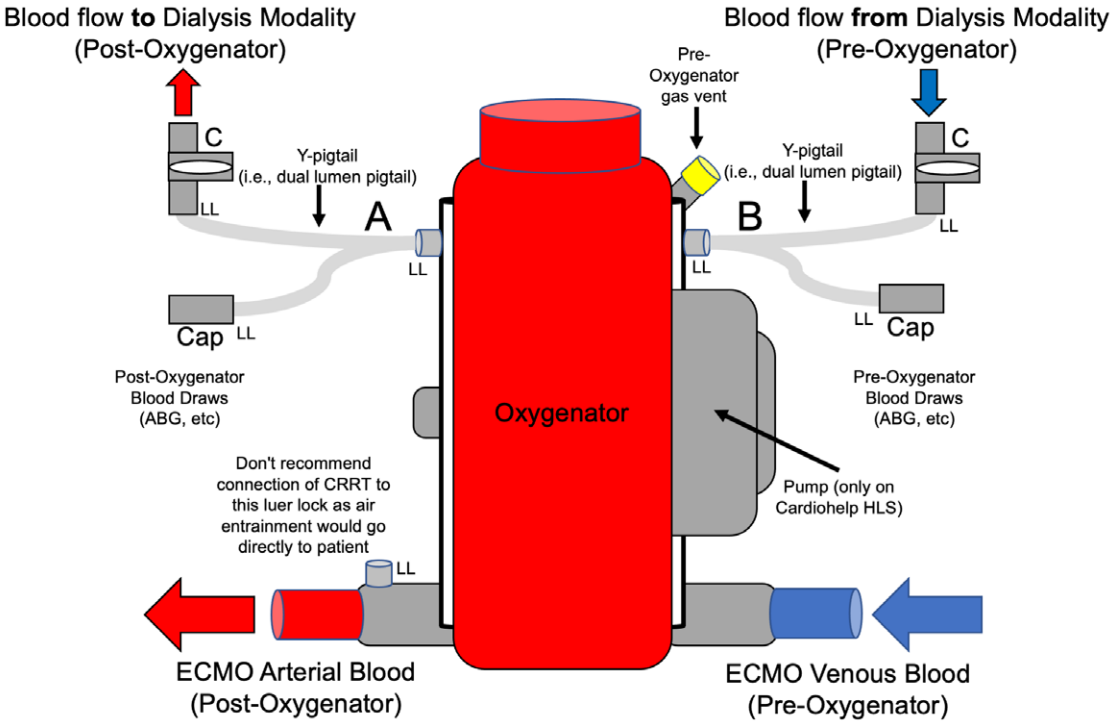

Figure 2. Technical drawing of dialysis modality connection to oxygenator. **A**: Blood flow from ECMO to dialysis modality, post-oxygenator side. **B**: Blood flow from dialysis modality to ECMO, pre-oxygenator side. **C**: Three-way stopcock. CRRT, continuous renal replacement therapy; ECMO, extracorporeal membrane oxygenation; LL, Luer-Lock.

blood draw, the port of the Y-pigtail that is connected to dialysis should be clamped, and dialysis should be momentarily paused. This will prevent pressure changes in the dialysis circuit while blood is being drawn. The blood can then be drawn from the second port of the Y-pigtail and the line can be flushed per institutional guidelines. Dialysis can then be immediately resumed by unclamping the line and resuming treatment.

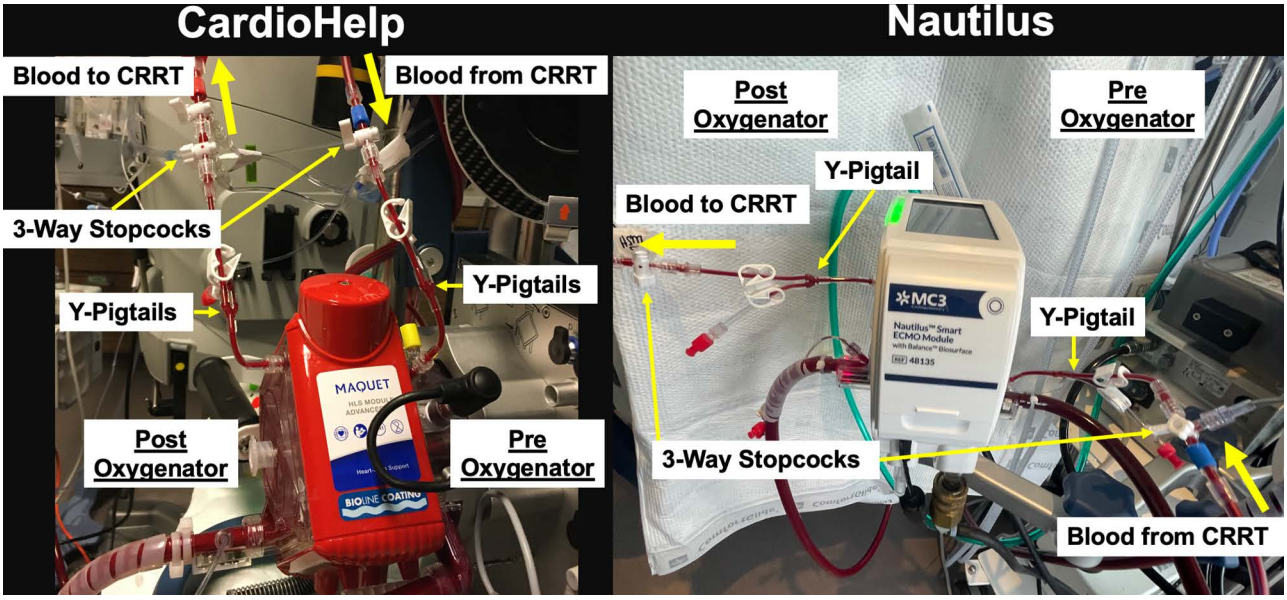

Figure 3. CRRT circuit connected to Cardiohelp HLS and Nautilus oxygenators. A Quadrox oxygenator (Getinge, Sweden) would have the same configuration (Y-pigtail and three-way stop cock connection) as the Cardiohelp HLS. CRRT, continuous renal replacement therapy.

Results

Our protocol was implemented on September 1, 2020. From then to March 31, 2023, a total of 68 patients on ECMO were placed on CRRT using the described procedure above (see sTable 2, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58, for patient characteristics). Of the 68 patients, five (7.4%) required CRRT to be run through a dedicated dialysis catheter. Two of these cases were due to a clot in the superior corners of the Cardiohelp oxygenator. The other three cases were during veno-arterial ECMO, with patients who required high blood flow requirements with a relatively small arterial cannula (15 French); thus, the post-pump (and oxygenator) pressures were >350 mm Hg, which were incompatible with our CRRT machine.

Discussion

In this "How To Do It" article, we describe how to connect various types of dialysis modalities to Cardiohelp HLS, Quadrox, and Nautilus oxygenators. We preferentially run all dialysis modalities through ECMO and without using additional non-tunneled central line dialysis catheters. This reduces the risk of bleeding, clots, and CLABSI and may also reduce the cost of dialysis catheter placement and the requirement of heparin/citrate locks to prevent clotting. We encourage early mobility as part of the institutional policy for all intensive care unit (ICU) patients including those on ECMO and therefore fewer catheters facilitate this.

Our protocol is simple to perform and should be safer than the traditional connection of dialysis to a dedicated central line (see sFigure 1, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58 and Table 3, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58 for advantages and disadvantages). For example, if air entrainment occurs, the air will be trapped after the pump in the oxygenator where it can be removed, thus protecting the patient from an air embolism. The air entrainment would be post-ECMO pump, preventing air from entering the pump, which could decrease blood flow or catastrophically air-lock the centrifugal pump resulting in no ECMO blood flow. The use of Y-pigtails connected to the oxygenator allows for the drawing of pre- and post-oxygenator arterial blood gasses without dialysis circuit disconnection. Of note, there is a small and likely negligible decrease in ECMO efficiency (~2.5% if running at 4 L/min of ECMO blood flow) because ~100 ml/min of ECMO blood is shunted to the dialysis modality.

There are multiple disadvantages to connecting dialysis to ECMO by splicing in a 3/8th inch connector with a Luer-Lock to the ECMO drainage and/or return lines (see Figure 1 and sTable 3, Supplemental Digital Content 1, http://links.lww.com/ASAIO/B58). These extra Luer-Lock connections have the potential to crack, clot, or become dislodged. Additionally, due to negative pressures distal to the venous cannula (pre-pump), compromise to the 3/8th inch Luer-Locks on the venous side can result in air entrainment and pump air-lock. A pump air-lock can catastrophically decrease or cease all ECMO flow and may require a complete circuit exchange. Compromise of the 3/8th inch connector with Luer-Locks on the post-pump return side can result in blood loss. Finally, compromising Leur-Locks post-oxygenator not only can result in blood loss but also any air entrainment results in an air embolism. Unfortunately, we do not have a direct comparison of other circuit designs; this is a potential research opportunity across institutions that use a different configuration.

We hope our protocol will make it easier to provide dialysis modalities to patients requiring ECMO and minimize complications for this critically ill population.

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