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NON-CARDIAC SURGERY FOR PATIENTS ON ECMO

Surgical Specialty:	Multiple
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Background:

- General Considerations
  - **Extracorporeal Membrane Oxygenation (ECMO)** is a prolonged form of cardiopulmonary bypass used to temporarily support patients with respiratory and/or cardiac failure unresponsive to maximal conventional therapy[1].
  - Two primary forms of ECMO exist: Veno-venous (VV) and Veno-arterial (VA)
  - Nomenclature: The first term describes where the blood is removed from the patient, i.e. V for venous. The second/third terms describe where the blood is returned to the body, i.e. V for venous or A for arterial[2].
    - Deoxygenated blood is drained from the venous system, propelled through the ECMO circuit where carbon dioxide (CO_2) is removed and the blood is oxygenated and then returned to either the venous system (veno-venous ECMO) or the arterial system (veno-arterial ECMO)[1].
  - Pediatric patients on ECMO support may need to come to the operating room, cardiac catheterization lab, or other locations for various reasons and, depending on institutional practices, may be cared for by a non-cardiac pediatric anesthesiologist. A fundamental understanding of ECMO and clinical practice pearls is essential for safe patient management.
- Basic Considerations
  - **Veno-venous (VV) ECMO:** Used in respiratory failure with preserved cardiac function.
    - Oxygenated blood is returned to the patient's venous system.
    - Requires the heart to pump the oxygenated blood returning to the patient from the circuit.
    - Cannulation via the right internal jugular vein utilizing one double-lumen cannula is preferred.
      - Double-lumen cannulas contain both drainage and reinfusion ports.
      - Must be positioned carefully to not impede flow.
      - Increased risk of "recirculation" (oxygenated blood returning from the circuit gets "sucked in" by the venous drainage port instead of being pumped to the lungs)[2].
    - Two-site cannulation is most commonly performed via the right internal jugular (return cannula) and femoral veins (drainage cannula)[1].

- **Veno-arterial (VA) ECMO:** Used in cardiac failure with or without respiratory failure.
  - Oxygenated blood is returned to the patient's arterial system.
    - Direct arterial return creates the potential for systemic air or clot embolization.
  - Peripheral cannulation via the right internal jugular and right common carotid artery is the most common practice in pediatric VA ECMO[1,2].
    - Femoral vessels can be used for larger patients (approximately >20 kg) but have the risk of limb ischemia.
  - Central cannulation is performed through a median sternotomy with cannulas placed directly in the right atrium and ascending aorta.
    - Less common.
    - Generally used for patients who are unable to be weaned from cardiopulmonary bypass in the OR or for patients who require venting of the left atrium.

- Basic ECMO Circuit Components
  - Access cannulas
    - Site and size to be determined by patient size, clinical indication for ECMO, and flow requirements per above.
  - Circuit tubing
  - Venous saturation monitor
    - Monitors the oxygen saturation of the venous drainage in the ECMO circuit (equivalent to the mixed venous saturation or S_vO_2 of the patient).
  - Mechanical pump
    - Centrifugal pump: Creates a pressure gradient through rotational kinetic energy that actively pulls blood in and pushes it forward[2].
      - Most common.
      - Dependent on both preload and afterload.
    - Roller pump: Propels blood forward via a rotating roller head compressing blood-filled tubing against a plate[2].
      - Not dependent on afterload.
      - Use has significantly decreased in favor of centrifugal pumps. Mainly seen in neonatal circuits[2,3].
  - Membrane oxygenator (artificial lung)[2]
    - Consists of a large thin membrane that allows gas to diffuse across it.
    - Blood is oxygenated and carbon dioxide is removed via countercurrent exchange.
      - Deoxygenated blood flows in one direction across the membrane and oxygenated gas flows in the opposite direction.
    - The fraction of delivered oxygen (F_DO_2) of the gas mixture can be adjusted.
    - The oxygenated gas flowing through the membrane is called the sweep gas flow or simply, sweep, and is measured in L/min.
      - The sweep determines carbon dioxide (CO_2) removal, with higher sweeps leading to greater CO_2 removal.
  - Heat exchanger
    - Maintains a controlled temperature of the blood. This makes it difficult for patients on ECMO to manifest a fever and other means to detect infection and sepsis may be needed, e.g. the need for higher flow rates as discussed below.

- Key Considerations for ECMO Management
  - Cannula size and position

- Pump speed in revolutions per minute or RPMs
  - Determines ECMO blood flow rate (mL/kg/min).
  - Goal blood flow rates for VA ECMO[2]:
    - Infants: 100 – 160 mL/kg/min
    - Pediatric: 75 – 90 mL/kg/min
    - Adult: 50 – 70 mL/kg/min
  - VV ECMO goal flow rates are higher - approximately 120% of VA ECMO flow rates[1].
  - Flow may need to be increased dramatically to meet the demands of a hyperdynamic or increased metabolic state such as sepsis.
  - The need for increased flow rates may alter the plan for cannulation.
- Sweep gas flow (L/min)
  - Increasing the sweep flow increases CO_2 removal and vice versa.
- Fraction of delivered oxygen (F_DO_2)
  - Usually set at 100% initially and then adjusted down if P_aO_2 is above goal.
- Transfusion goals (can be institution-specific and patient dependent)[2]
  - Platelet count >80,000 – 100,000 /mcL
  - sometimes lowered to >50,000 /mcL in the setting of significant consumption
  - Fibrinogen >100 – 150 mg/dL
  - Hematocrit (Hct) >35 – 40%
  - Consider underlying patient comorbidities and anticipated procedural blood loss.
- Ventilator settings (can be institution-specific and patient dependent)
  - Goal is to minimize ventilator-induced lung injury by optimizing positive end-expiratory pressure (PEEP) and minimizing plateau pressure[1].
    - Limit peak inspiratory pressure (PIP) to <20 – 25 cmH_2O.
    - Utilize higher PEEP of 8 – 12 cmH_2O.
      - PEEP may need to be increased in the setting of significant pulmonary edema/hemorrhage.
    - Lower respiratory rate of 8 – 10 breaths per minute.
    - Limit tidal volume (TV) to 6 – 8 ml/kg.
    - Fraction of inspired oxygen (F_iO_2) usually 21% – 40%.
  - Can be institution-specific.
- Anticoagulation management
  - Systemic anticoagulation is required to decrease thromboembolic complications.
  - Unfractionated heparin 50 – 100 units/kg is typically given at the time of cannulation and then an infusion of either heparin or bivalirudin is started[1].
  - Heparin: Most common. Requires antithrombin III (ATIII) to function. Can be reversed with protamine[1-3].
    - Heparin requirements can progressively increase due to the consumption of coagulation factors including ATIII.
    - Neonates have significantly lower levels of ATIII compared to children and adults[3] and may require repletion with fresh frozen plasma or recombinant ATIII.
    - Easy to monitor activated clotting time (ACT) via point-of-care testing with a goal ACT of 180 – 220 seconds[1]. Can also follow heparin level (anti-Xa) – goal 0.3 – 0.7 IU/mL.
    - Heparin-induced thrombocytopenia (HIT) is a rare but potential complication[2].

        - Bivalirudin: Direct thrombin inhibitor and does not require ATIII. No reversal agent[1] and has a half-life of about 25 minutes in patients with normal renal function.
            - Goal: activated partial thromboplastin time (aPTT) of 70 – 90 seconds (or approximately 1.5x baseline).
    - Significant bleeding can occur – an antifibrinolytic infusion, topical thrombin, recombinant factor VII, and/or transiently holding bivalirudin/heparin are all potential interventions.
- Patient Considerations
    - ECMO is a bridging – not destination – therapy.
    - Code status should be discussed with the family and primary care team prior to the procedure.

Anesthetic Planning:

- Pre-Anesthetic Evaluation
    - Labs/Diagnostics
        - Review most recent arterial blood gas (ABG), complete blood count (CBC), complete metabolic panel (CMP), and coagulation studies -usually ACT, aPTT; sometimes Xa level, heparin correlation
        - Review the most recent chest X-ray (CXR), transthoracic echocardiogram (TTE) if indicated.
    - Discussions to have with ECMO/ICU team prior to proceeding with a non-cardiac procedure:
        - Cannula(s): Location and size, any positioning concerns.
        - Goal and current ECMO flow rate (ml/kg/min).
        - Current sweep flow (L/min).
        - Current anticoagulation strategy - medication and infusion rate, monitoring strategy including ACT, aPTT, et.] and goal lab values, recent trend in coagulation labs, and goal platelet and fibrinogen levels).
        - Circuit condition – identify any clots/fibrin strands that increase risk of thromboembolic event or circuit malfunction
- Specific or Unique Room Set-Up Requirements
    - Airway
        - Patients will likely be intubated – have emergency airway supplies ready.
        - Patients are typically on protective ventilator settings as described previously to minimize ventilator-induced trauma and lung collapse[1-3] and will be institution-specific.
            - PIP <20 – 25 cmH_2O, PEEP 8 – 10 cmH_2O, RR 8 – 10, TV 6 – 8 ml/kg.
            - Minimize F_iO_2 to limit pulmonary toxicity while maintaining adequate end-organ oxygen delivery.
        - Be prepared to provide full ventilatory support in case of circuit catastrophe, or if there is a plan to trial off or exchange the circuit.
    - Drugs/Infusions
        - Patients will typically be on a variety of infusions including but not limited to:
            - Anticoagulants**:** Heparin, bivalirudin as described previously. May be temporarily stopped perioperatively – discuss with surgery/ICU team.
            - Sedatives and analgesics**:** Dexmedetomidine, midazolam, morphine, fentanyl infusions are common.

        - Paralytics**:** Institution and patient dependent. Consider paralysis for most surgical procedures on ECMO and prior to transport to minimize the risk of movement and cannula dislodgement.
        - Antifibrinolytic: Institution and patient dependent. Aminocaproic acid or tranexamic acid infusions are common, especially if there have been problems with bleeding. Consider perioperative antifibrinolytic infusion depending on the procedure and risk of bleeding[2].
        - Vasoactive medications: As needed for underlying comorbidities.
- Monitors
    - Standard ASA monitors including pulse oximetry, end-tidal CO2 [$ETCO_2$], continuous electrocardiogram [EKG], noninvasive blood pressure [NIBP], and temperature.
        - Pulse oximetry and NIBP lose accuracy with decreased pulsatility (VA ECMO).
        - Five-lead EKG should be used.
    - Invasive arterial blood pressure (IABP) monitoring
    - Central venous pressure (CVP)
        - Less reliable indicator of volume status in patients on VA ECMO[1]. Decreased CVP and line "chatter" can be indicators of hypovolemia.
            - Line chatter is visible shaking of the venous drainage tubing that occurs when the pump is attempting to drain more volume than the current venous return allows.
        - Trends are still useful, e.g. an acute increase in CVP can indicate venous cannula obstruction, tamponade, tension pneumothorax, or abdominal compartment syndrome[1].
    - Near-infrared spectroscopy (NIRS) monitoring (cerebral +/- somatic sensors).
    - Consider transesophageal echocardiogram if concerns for cardiac comorbidities, verification of cannula positioning, or for diagnosis of cannula concerns. Careful placement given increased bleeding risk, or consider cardiac POCUS (point-of-care ultrasound) if feasible.
- Access
    - Long-term central venous access may or may not be available depending on the patient's clinical course and comorbid conditions.
        - Know the availability of your patient's ECMO circuit for medication and volume administration if needed.
    - Consider using ultrasound for placement of peripheral IVs (if needed) to improve first-attempt success rate and decrease risk of bleeding from multiple attempts.
- Blood Availability
    - Patients on ECMO support should always have blood products available including packed red blood cells [PRBCs] and fresh frozen plasma [FFP] at a minimum. – Confirm product availability with primary team/ECMO specialist.
    - Discuss anticoagulation goals, recent labs, and surgical needs to determine the need for additional products such as platelets and/or cryoprecipitate
- PICU Bed Availability
    - All ECMO patients will be in an intensive care unit (usually NICU, PCICU, or PICU; possibly adult ICU depending on the institution).

- Other Indicated Resources
  - Is a backup circuit needed? Consider this if there have been concerns with the existing circuit including clot/fibrin burden and discuss with surgical/ICU teams.
  - ECMO specialist or perfusionist availability. Institutional practices may vary in terms of who manages the ECMO circuit in the ICU and when the patient travels to the OR – additional resources are necessary to ensure safe patient transport and for potential circuit emergencies during operative procedures.
  - Respiratory therapy – patients are often on rest ventilator settings which can usually be replicated on anesthesia ventilators used in the OR. For patients with severe underlying respiratory disease, an ICU ventilator may need to accompany the patient.

Intraoperative Considerations:

- Induction and Maintenance
  - Patients will typically be on sedatives and analgesics (+/- neuromuscular blockade) via continuous infusions.
  - **ECMO support has a substantial impact on drug pharmacokinetics[3-5].**
    - In general, the volume of distribution (V_d) is increased due to an increase in blood volume and sequestration of drug by the ECMO circuit.
      - More pronounced in drugs that are highly lipophilic or protein-bound (greater drug extraction by the ECMO circuit).
    - Clearance is generally decreased due to renal and/or hepatic dysfunction.
  - **The dose required for therapeutic effect is usually significantly higher in most sedatives and analgesics[3-5].**
    - Dexmedetomidine, midazolam, fentanyl, hydromorphone, morphine, and/or ketamine are the most commonly used.
    - Fentanyl is more highly adsorbed by the circuit than morphine or hydromorphone[4].
  - Consider adequate anesthetic depth for specific procedural needs.
    - An example is cardiac catheterization which may not require much additional sedation/analgesia compared to a congenital diaphragmatic hernia (CDH) repair, which will require escalation of both. This can be achieved by increasing or bolusing from existing infusions, or providing additional medications.
  - Volatile anesthetic can also be used but will be less effective due to low minute ventilation on ECMO rest settings
- Positioning
  - The surgical positioning needs must be considered in the setting of cannula(s) position and may be limited.
  - All patient repositioning must involve close communication with the ECMO specialist to ensure cannula stability and maintenance of adequate ECMO blood flow.
  - Patients are at high risk for pressure injury – pad and protect the patient accordingly.
- Hemodynamic/Physiologic goals
  - Maintain established ICU hemodynamic goals given patient age and comorbid conditions.
  - NIBP measurements and pulse oximetry are unreliable in the setting of decreased pulsatility with VA ECMO support, and the arterial pressure waveform is dampened. Monitor mean arterial pressure (MAP) on arterial line and S_aO_2.

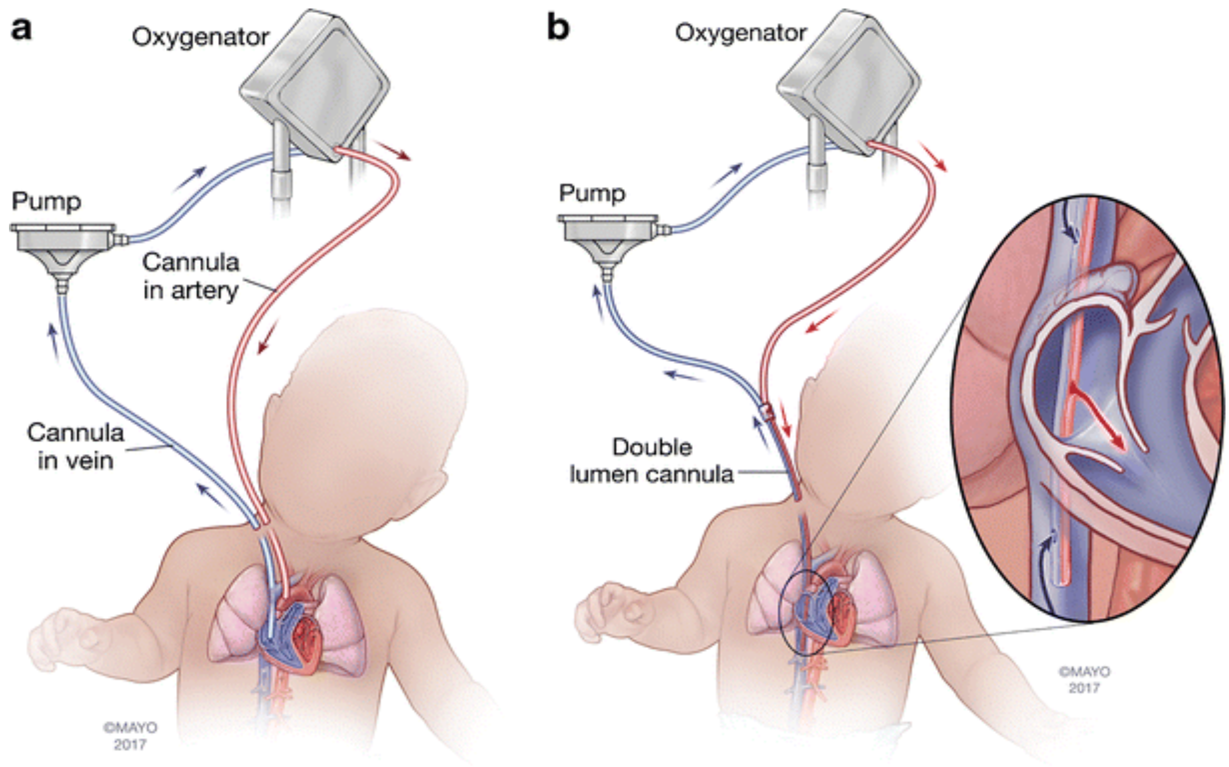
- Serial lactates and NIRS trends can be also be used to evaluate perfusion and oxygen delivery.
- Surgical Considerations
  - As discussed above.
- Emergence/Disposition
  - With rare exceptions, these patients will return to the ICU intubated and sedated following their procedure.
  - Thorough ICU handoff is critical to relay volume needs, transfusion requirements, flow concerns, sedation and analgesic needs, etc. during the case.
  - If anticoagulation was held perioperatively, handoff should include appropriate timing to resume.

Case-Specific Complications/Pitfalls

- Troubleshooting Problems on ECMO
  - Hypoxemia
    - Verify oxygen supply to the circuit, pump integrity, and cannula positioning. Check if ECMO flow rates are decreased. Consider increasing pump flow rate and/or F_dO_2 if post-oxygenator arterial saturation or $_2$ <100%. (this is a bit confusing to me – could author please clarify this? Do they mean $SP0_2$ < 100%)
    - Check for increased oxygen consumption – has the ECMO venous oxygen saturation or S_vO_2 decreased? Has the arteriovenous (AVO_2) difference increased? Consider increasing F_dO_2 (if ECMO arterial saturation is <100%), increasing pump flow rate, and/or giving additional sedation/analgesia orneuromuscular blockade. Correct hyperthermia if present by lowering circuit temperature Consider pRBC transfusion to increase arterial oxygen content.
    - Has the patient's native cardiac output increased? An increase in cardiac output increases the amount of blood pumped to the lungs without first going through the ECMO circuit. Consider attempts to improve lung function (if feasible).
    - Consider lower S_pO_2 target if hemodynamics, lactate, and AVO_2 are normal.
    - VV-ECMO – Is the S_vO_2 (ECMO venous oxygen saturation) high? Verify appropriate cannula position because this could indicate recirculation that can occur when oxygenated blood returning to the patient gets sucked in by the venous drainage catheter instead of being pumped to the lungs.
  - Hypercapnia/Acidosis
    - Increase sweep gas flow to increase CO_2 removal.
    - Investigate cause and treat accordingly:
      - Increased CO_2 production, eg. fever, hypermetabolic state
      - Decreased CO_2 clearance - (worsening native lung function or oxygenator function
      - Decreased renal function with impaired compensation.
  - Insufficient Flow
    - Manifested by inadequate O_2 delivery, hypotension (on VA ECMO) or hypoxemia (on VV or VA ECMO).
    - <u>**Venous side (most common cause of flow issues)**</u> –negative venous pressures on the circuit suggest there is inadequate venous drainage from the patient.
      Possible causes:

            - Cannula – Is it malpositioned or kinked? Is it too small (excessive resistance)?
            - Venous reservoir – Is it low? Rule out hypovolemia and treat with volume and/or blood products.
            - Patient – Is there high intraabdominal pressure or intrathoracic pressure? Consider abdominal compartment syndrome, surgical manipulation, tamponade, pneumothorax and treat accordingly.
        - Oxygenator – Is there evidence of increased clot burden? This could manifest as an increased gradient across oxygenator or decreased P_aO_2 post-oxygenator.
        - Arterial side – Has the positive outlet pressure increased?
            - Cannula – Is it malpositioned or kinked? Is it too small (excessive resistance)? Is there clot within the cannula or the arterial limb of the circuit?
            - Patient – Is the systemic vascular resistance (SVR) high? SVR can be elevated due to excessive vasoactive medications, inadequate sedation/analgesia, improving cardiac function, seizures → treat accordingly.
    - Hypotension
        - VV ECMO – Typically does not contribute unless massive bleeding, decreased cardiac output. Usual assessment and management of hypotension.
        - VA ECMO – Increase ECMO blood flow and rule out mechanical obstruction causing a decrease in flow, e.g.cannula malposition or kinking, occlusive clot in circuit. Then proceed with usual assessment and management of hypotension.
        - Both VA and VV ECMO – If significant vasoplegia is present within 24 – 48 hrs of initiation of ECMO, consider post-cannulation syndrome which is a SIRS-like response to initiation of ECMO. If refractory to standard vasopressors like epinephrine, norepinephrine and vasopressin, other treatment options include angiotensin II, steroids or methylene blue.
- Complications
    - Bleeding – Common; associated with increased mortality[2].
        - Systemic anticoagulation, consumptive coagulopathy and platelet dysfunction, frequent development of acquired von Willebrand syndrome, and hyperfibrinolysis contribute to bleeding risk[2]. Other risk factors include VA ECMO support, recent cardiac surgery, age > 1 year, and longer duration of ECMO.
        - Consider decreasing or stopping systemic anticoagulation temporarily, starting an antifibrinolytic,consider higher platelet and fibrinogen goals and transfuse accordingly.
    - Accidental decannulation – Rare but potentially catastrophic.
        - ECMO specialist must clamp lines immediately; give volume, adjust ventilator to emergency back-up settings, provide hemodynamic support as needed.
        - Will need ECMO reestablished ASAP.
    - Thromboembolic/cerebrovascular event
        - Can be due to thrombus or air in the circuit.
        - Risk higher in VA ECMO versus VV ECMO.
    - Air in circuit – **Air distal to the oxygenator is an emergency**. ECMO specialist will need to clamp arterial line and investigate cause; adjust ventilation to emergency

back-up settings and provide hemodynamic support as needed until flow can be resumed.



The extracorporeal membrane oxygenation (ECMO) circuit.
a. Illustration of veno-arterial ECMO in a child with the outflow cannula in the right atrium via the right internal jugular vein, external pump and oxygenator, and return cannula in the aortic arch via the right carotid artery.
b. Illustration of a dual-lumen veno-venous ECMO in a child. One lumen in the cannula carries deoxygenated blood to the oxygenator from the superior vena cava and inferior vena cava, while the second lumen returns oxygenated blood to the right atrium (inset).

References

1. Zaleski KL, Nasr VG. ECMO Primer for the Pediatric Anesthesiologist. *Int Anesthesiol Clin*. 2019;57(4):72-83. doi:10.1097/AIA.0000000000000249 PubMed Link
2. Dalton HJ, Censoplano N, Preston T, et al. Extracorporeal life support. In: Zimmerman JJ, Clark RSB, Furhman BP, et al eds. *Furhman and Zimmerman's Pediatric Critical Care*. 6th ed. Philadelphia, PA: Elsevier; 2022:655-678.
3. Valencia E, Nasr VG. Updates in Pediatric Extracorporeal Membrane Oxygenation. *J Cardiothorac Vasc Anesth*. 2020;34(5):1309-1323. doi:10.1053/j.jvca.2019.09.006 PubMed Link
4. Zimmerman KO, Dallefeld SH, Hornik CP, Watt KM. Sedative and Analgesic Pharmacokinetics During Pediatric ECMO. *J Pediatr Pharmacol Ther*. 2020;25(8):675-688. doi:10.5863/1551-6776-25.8.675 PubMed Link
5. Anton-Martin P, Modem V, Taylor D, Potter D, Darnell-Bowens C. A retrospective study of sedation and analgesic requirements of pediatric patients on extracorporeal membrane oxygenation (ECMO) from a single-center experience. *Perfusion*. 2017;32(3):183-191. doi:10.1177/0267659116670483 PubMed Link

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