



Adult ECMO in the En Route Care Environment: Overview and Practical Considerations of Managing ECMO Patients During Transport

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Abstract

Purpose of Review The authors' experience as a part of the U.S. Military ECMO program to include the challenges and successes learned from over 200 transports via ground and air is key to the expertise provided to this article. We review the topic of ECMO transport from a historical context in addition to current capabilities and significant developments in transport logistics, special patient populations, complications, and our own observations and approaches to include team complement and feasibility.

Recent Findings ECMO has become an increasingly used resource during the last couple of decades with considerable increase during the Influenza pandemic of 2009 and the current COVID-19 pandemic. This has led to a corresponding increase in the air and ground transport of ECMO patients.

Summary As centralized ECMO resources become available at health care centers, the need for safe and effective transport of patients on ECMO presents an opportunity for ongoing evaluation and development of safe practices.

Keywords Extracorporeal membrane oxygenation · Extracorporeal life support · Critical care air transport · En route critical care

Introduction

The Extracorporeal Membrane Oxygenation (ECMO) Program Medical Director at Brooke Army Medical Center (BAMC) received a call from the US State Department regarding a US civilian hospitalized in Medellin, Columbia. This information involved a 31-year-old male who had influenza and rapidly declined requiring hospitalization and ultimately ECMO. After a brief period of improvement, the Columbian hospital had removed his ECMO support. Unfortunately he suffered another clinical decline and required being placed on ECMO a second time. The patient's family reached out to the State Department to determine if there

was a way to bring him back to the USA. After the Medical Director received this request, all appropriate coordination to include aircraft use and inpatient capability at BAMC were confirmed and approved. The team was assembled based upon schedule and availability for a multi-day mission. The transport coordinator for the program jumped into action to solidify orders, privileges, and all transportation both ground and air for the entire mission. Over the next few days, the team was able to fly to Medellin, transition the patient to our transport equipment, clinically optimize and stabilize the patient, and fly him back to San Antonio, Texas. The host nation facility had provided optimal care during his hospitalization. Unfortunately his severe and prolonged course of acute respiratory distress syndrome had resulted in right heart failure and he ultimately required cardiopulmonary support using ECMO. After stabilizing and optimizing the patient for a few weeks, the BAMC program was able to the patient to a transplant center for the possibility of needing a heart and or lung transplant. Ultimately the patient recovered without ever needed organ transplantation and was discharged to home with his family.

ECMO (extracorporeal membrane oxygenation) is a subset of ECLS (extracorporeal life support) that provides mechanical

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cardiopulmonary support using a centrifugal pump (versus a roller pump, and also the recommended pump for transport) and membrane oxygenator [1, 2]. ECMO continues to be utilized as a salvage treatment for severe, potentially reversible, respiratory or cardiac failure and has historically been most commonly used for severe pulmonary failure secondary to ARDS or other etiologies [3–5]. Given the complexity and required resources, ECMO management is limited worldwide to 1115 centers [6••], a number that has continued to grow over the last decade, but still represents a significant minority of centers in global healthcare.

ECMO centers generally function as a “hub and spoke” model of patient referrals, initiation of support, and ongoing follow-up management. Patients being considered for and ultimately requiring ECMO are commonly unstable and critically ill [7, 8]. Per ELSO guidelines, ECMO is indicated for patients when predicted mortality reaches 80% despite optimal care; however, ECMO is considered when mortality risk approaches 50% [6••]. Given these patient factors, it is generally unsafe for patient transport to ECMO centers prior to cannulation. Cannulation and initiation of support in the referring hospital continues to grow as an optimal treatment strategy given improvements in transport capabilities, and transport is preferably performed following stabilization on ECMO [6••].

Transport of patients on ECMO has occurred since the 1970s with thousands of successful transports across the globe. Historically, the trajectory of ECMO utilization has been heavily influenced by global occurrences, notably the H1N1 influenza and COVID-19 pandemics [1, 9–12]. Ground and fixed wing aircraft compose a majority of transports with rotary wing aircraft composing a small percentage. Given the centralized model of ECMO centers, the safety and efficacy of these transports plays a considerable role in patient outcomes. Ongoing review and advancement of transport practices is essential to maintaining worldwide capabilities.

The United States Air Force Critical Care Air Transport Teams (CCATT) has used ECMO transport capabilities to facilitate the evacuation and transport of wounded and/or critically ill US service members. Starting in 2005, the Air Force implemented the Acute Lung Rescue Team (ALeRT), which included mobile ECMO capabilities, and has continued to improve the air transport of patients around the world [7].

Transport Logistics and Significant Developments

Accepting, retrieving, and successfully transporting a critically ill patient requiring ECMO support is a complex endeavor [13]. While the most critical logistical

consideration is preparation, numerous other factors include communication, patient selection process, timing, mission planning, mode of transport, equipment requirements, and team composition. An essential component of transport logistics is safety for both the patient and medical team, which must permeate all elements of mission preparation, planning, and execution. It is also vital to develop pre-specified processes for communicating and documenting salient clinical information throughout the transport continuum not only for the patient but also the transport process, as regular communication increases efficiency and minimizes the risks of transport [6••].

The first phase of the transport process is the ability of an ECMO-capable center to receive and determine if the referral request is appropriate. Ideally, specific referral criteria should be disseminated to all regional intensive care units to streamline patient selection in a centralized health system and/or considered on a case-by-case basis [13]. The ECMO referral center must understand and communicate its own transport capabilities in order to appropriately accept or defer a request, especially since there is often time sensitivity to the patient’s clinical situation or the referring institution’s clinical management capabilities. Subsequently, the ECMO team must recommend whether a mobile team will cannulate on-site or if the patient will be transported to the ECMO referral center for evaluation. If cannulation is to be performed at the referring institution, then temporary credentialing privileges and medicolegal documentation should be coordinated before the transport to avoid on-site delays. The requirements for such documentation vary and are completely up to the referring hospital. Credential files are maintained in an online repository and send to relevant licensing and privileging authorities as required. When traveling to retrieve military personnel, there are no special requirements. Additionally if the transport does not include cannulation, this process is usually not required. Finally, often when retrieving and/or cannulating internationally credentials and privileges are not a usual requirement. The transport coordinator works with each referral facility to determine what they require and provides documents as appropriate.

Determining the best mode of transport for an ECMO patient is based on several factors, as outlined in Table 1. ECMO transport programs should determine access to these various modes of transport, whether through dedicated transport platforms (such as a specific ECMO ambulance) or streamlined protocols with the local prehospital Emergency Medical Services (EMS) system for Adult Cardiac Life Support (ACLS) capable transport. Similar equipment and consumable supplies are needed for in-hospital vs out-of-hospital ECMO transports. However, the out-of-hospital environment poses unique challenges requiring careful planning and special modification to allow the transport team to

Table 1 Factors for determining the best mode of ECMO transport [6••, 13]

	Ground ambulance	Helicopter	Fixed wing aircraft
Team and equipment capacity	Sufficient (4–5 team members)	More limited (3–4 team members)	Variable (usually > 4 team members)
Noise	Relatively little	Very loud	Loud
Distance range	Up to 250 miles (400 km) or less than 3–4-h transport time	Up to 400 miles (650 km) or less	Any distance
Weight limitations	Relatively unlimited (based on space)	Limited (impacted by distance and weather)	Variable (depending on aircraft and conditions)
ECMO equipment and patient loading and securing	Relatively easy	Relatively easy	Variable (depending on equipment and aircraft)
Weather	Low impact	High impact	High impact
Cost	++	+++	++++

ECMO = extracorporeal membrane oxygenation, km = kilometers

function as a self-contained unit that manages the patient and troubleshoots complications en route [13]. While the team must travel with a comprehensive set of equipment and supplies, size and weight constraints of the transport platform require careful selection of necessary equipment and back-up supplies [13]. Equipment used for air transports must be certified for air worthiness with appropriate documentation that is readily available. Supplies must be inventoried regularly to ensure readiness of the prepared package and avoid using expired items. Two crucial components of ECMO transport equipment are reliable sources of oxygen and power, not only on the transport platform but also during transitions between platforms; this can be one of the major pitfalls in planning. Mission planning should be managed by a transport coordinator who is experienced in all aspects of the process. The coordinator can select and schedule the mode of transportation, coordinate access to referring facility and all permissions, provide instructions and preparatory orders for the referring facility, and return details including bed and team assignment. BAMC basic equipment and supply list is provided as Fig. 1.

The composition of an ECMO transport team varies internationally, nationally, and according to each institution and the individual patient's clinical and transport scenario; typical team compositions include intensivists, surgeons, ECMO specialists, nurses, respiratory therapists, emergency medical service providers, and trainees from any of these disciplines or others based on space availability. One of the ECMO physicians is designated as the team leader who is responsible for planning, executing, and communicating the transport mission at all levels. At a minimum, there should be an experienced physician with significant ECMO experience and an ECMO specialist to manage the patient and circuit [14•]. At BAMC, for training and currency purposes, an ECMO transport usually includes 2 staff ECMO physicians plus a physician in training, 1–2 ECMO nurse specialists who manage the ECMO pump, and 1 CCAT nurse who fulfills the typical bedside ICU nursing role. This composite

can be adjusted based on duration of mission or transport to ensure enough coverage and appropriate expertise included. International consensus has found that 20 transports per year are appropriate for a program to maintain effective ECMO transport capability [15], and skill simulation and training enable high performance for successful transports.

Special Patient Populations

Given the versatility of ECMO and the diversity of cardiopulmonary disease, patient populations may differ significantly with each presenting unique patient treatment and transport challenges. The transport logistics are highly dependent on the patient's needs as well as concerns for transport crew safety.

Acute respiratory distress syndrome (ARDS) is the most common severe pulmonary disease to warrant VV-ECMO treatment. The recent COVID-19 pandemic has significantly increased the quantity and duration of treatment over a very short period of time. COVID, as a highly infectious respiratory illness, also presents the unique transport challenge given the risk of airborne transmission of the virus. Personnel concerns about safety and infection prevention are warranted given the importance of a continued need for hospital workers and, in the military, a ready fighting force. Best practices for transport of COVID patients on ECMO include full personal protective equipment with standard airborne precautions, as well as the use of special transport containers on aircraft to isolate the patient from other patients or crew members (Fig. 2).

Another unique patient category that has increased over the past decade are patients placed on ECMO while in cardiac arrest (eCPR). While ECMO has been initiated for out-of-hospital cardiac arrest in Europe and some parts of the USA, a more common use of eCPR is in-hospital [16, 17]. These programs are highly resource-dependent in emergent situations. Programs require well-developed protocols,

Cannulation Folding Pack	
Pocket 1 Hand Sanitizer Surgical Hats (7) Masks (7)	Pocket 2 Sterile Gloves: 6.5 (5) 7.5 (5) 7.0 (5) 8.0 (5)
Pocket 3 CHG prep sticks (10) Green Tape	Pocket 4 Sterile Burn Dressing Packs (4)
Pocket 5 US probe covers (3) Needle Book (1) Skin Marker (2) Razors (2) Scalpels: size 10 (1) size 11 (1) size 15 (1)	Pocket 6 Sterile Disposable Instrument tray (2) Tubing clamp w/guard, sterile, non disposable (2)
Pocket 7 Sterile Bowl (1) NS 500ml bag (1) Cath tip Syringe- 60ml (2) Bag decanter (2)	Pocket 8 CHG Tegaderm (5) Tubing securement devices (4 clear) Foley strap (2) 3/8" Y connector (2) 3/8" straight connector (2) 3/8" x 1/2" straight connector (2) 0-silk sutures (10) 2-0 Ethilon nylon sutures (10) Large Bore Pigtail (1) Hoffman Clamp (1)
Pocket 9 5fr Micropuncture kits (5) 3 ml syringes (4) Pressure tubing (2) Male-male connectors (2) Pinnacle sheaths 7fr (2) Arrow Sheaths 7fr (2)	
Pocket 10 Sterile Gowns: X large (4)	Pocket 11 Livanova dilators (2) Avalon Dilators (2) Amplatz wires: stiff (2) super stiff (2) InQwire (1)
Pocket 12 Half drapes (3) Sterile towel packs (4) Pannus retention straps (2) Coon's dilator 14fr (1) 60 or 50ml LL syringe (1) banding gun (1) Skin stapler (1) 3/8" tubing pack (1) Emergency Priming line (1)	
Center of Pack Large Vascular Drape (1)	

ECMO Emergency Surgical Kit Inventory

- o Full size sterile patient drape
- o Sterile half sheets (2)
- o Sterile gowns (2)
- o Hats (6)
- o Masks (6)
- o Sterile gloves- 6.5 (2), 7 (2), 7.5 (4), 8 (2)
- o 60 ml catheter tip syringes (2)
- o Chloraprep swabs (6)
- o Sterile OR towel packs (3)
- o 3/8 x 3/32 sterile tubing pack
- o 3/8 x 3/8 straight connectors (2)
- o 3/8 x 3/8 connectors w/ luer (2)
- o 3/8 x 3/8 x 3/8 "y" connector (2)
- o Normal saline- 1000 ml bag
- o Normal saline- 500 ml bag
- o Bag decanters (2)
- o Sterile lap pad package (2)
- o Suture- 0 silk, curved needle (6)
- o Suture- 2.0 Ethilon, curved needle (6)
- o Scalpel- 10 blade (2)
- o Scalpel- 11 blade (2)
- o Scalpel- 15 blade (2)
- o Sterile basin
- o Sterile tubing clamps (6)
- o Sterile scissors (2)
- o Sterile needle drivers (2)
- o Tie bands- (1 pkg)
- o CHG Tegaderm (2)
- o Red needle book

SOP for Maintenance of ECMO Transport Equipment and Supplies

The ECMO Transport Program consists of multiple pieces of durable medical equipment, supplies and medicine necessary to support the cannulation of a patient at an outside hospital and transport back to Brooke Army Medical Center (BAMC). The team may also be called upon to transport a patient who is already on ECMO support from one hospital to another (taxi service), or retrieval of a patient on ECMO and bring back to BAMC.

In order to maintain mission readiness, the following maintenance must occur:

Equipment:	Maintained by:	Service Schedule:	Other:
IV pumps	59th Medical Logistics	Bi- Annual	
Suction machines (Zoll)	59th Medical Logistics	Bi- Annual	
Defibrillator/monitor (Zoll)	59th Medical Logistics	Bi- Annual	
Transport Vents	59th Medical Logistics	Bi- Annual	
ECMO machine (Cardiohelp)	59th Medical Logistics/ BAMC Biomed	Quarterly	
Water heater (Microtemp LT)	59th Medical Logistics/ BAMC Biomed	Quarterly	
ECMO Medicine Box	ECMO Transport Coordinator	Quarterly	Return/ exchange meds 90 days prior to expiration
Narcotic Box	Main Pharmacy	None	Return to pharm after each transport
Oxygen Tanks	ECMO Transport Coordinator	None	Resupply with full tanks after each mission
ECMO specific supplies	ECMO Transport Coordinator	Quarterly	Check expiration/ sterile integrity on all supplies
ECMO specific supplies	ECMO Transport Coordinator	Each mission	Restock after each mission
CCATT specific supplies	ECMO Transport Coordinator	Quarterly	Check expiration/ sterile integrity on all supplies
CCATT specific supplies	ECMO Transport Coordinator	Each mission	Restock after each mission
ECMO Van transport log	ECMO Transport Coordinator	Monthly Reports	Submit log monthly Maintenance as needed (oil change), refuel

Fig. 1 ECMO transport equipment and supplies

Fig. 2 Special isolation transport container



guidelines, criteria, and experienced teams. Responding team members should have extensive rehearsal and simulation training. The role of eCPR remains controversial as the last decade has observed a tenfold increase in its use, but no significant change in odds of survival and only a 29% survival-to-discharge rate [18].

Some patients on ECMO support will require heart or lung transplants to liberate them from the circuit. The managing institution may not always have transplant capabilities; therefore, it is critical that ECMO teams must coordinate with transplant centers regarding patient eligibility and

listing with requirements as appropriate per UNOS transplantation guidelines.

Pediatric and neonatal transport require special equipment to include the stretcher configuration, containers, specific pediatric and neonatal critical care equipment and supplies, and a team of specialists to include neonatal intensive care nurse and pediatric critical care physicians which is not within the scope of this review and program description.

Military members that have been wounded in combat that require ECMO support and transport also require specific trauma and surgical critical care needs. They may often have

amputations, drains, wound vacuum dressings, tracheostomies, external fixators, splints, and ongoing medical management of coagulopathy, bleeding, and other organ support. This complex situation and multitude of equipment requires careful planning by the team and the transport coordinator regarding the stretcher and litter configuration, movement between facilities and transportation modalities, and extra supplies and equipment for these long missions from places of active military conflict around the world. Standard supplies and equipment are utilized for all transports, but collaboration with aeromedical evacuation and ground transportation crews is critical as each transport may have unique needs.

Complications and Troubleshooting

Given the patient population selected for transport, there is a high risk for complications and clinical decompensation. While ECMO provides a safety net for transport of selected critically ill patients, the same complications that are prevalent in the hospital environment must be considered for transport, in addition to the inherent risks of the transport itself [19, 20].

When planning for an ECMO transport to include considerations of the potential complications, the mission is divided into four phases of transport: (1) patient selection, (2) pre-transport, (3) patient packaging, and (4) transport. Each phase of the mission carries unique challenges. Successful transport requires planning, anticipation, and risk mitigation.

Patient Selection

During the patient selection phase, it is paramount to clearly establish patient history, disease transmission risk, clinical course, and active medical conditions. Pertinent medical history is crucial to mitigate transport risk, which include current medications, time of administration, need for vasopressors, hemodynamic stability, bleeding complications, and history of pneumothorax. As transport times may vary from hours to days, it is paramount that plans ensure no transport-related delays in care. Routine (yet critical) treatments, such as antibiotic administration, must be continued uninterrupted to prevent worsening of underlying clinical conditions during transport and avoid any unexpected delays. The BAMC referral flyer and referring hospital guidance is included as Fig. 3 and the intake form is included as Fig. 4.

Transport teams typically carry standard critical care medications, to include vasopressors, but the transport stock supply is usually relatively limited. During the planning phase, knowing whether the patient requires vasoactive medications may help determine the appropriate mode of



transport, the appropriate ECMO modality (veno-venous vs veno-arterial), and help with medication planning. When the medications are known ahead of time (especially vasopressors, sedation, and antibiotics), it should be requested that the sending facility provide all the anticipated medications to ensure timely administration and that there is an adequate supply for the entirety of the mission. Estimated medication needs based on mission duration follow the principles of the USAF Critical Care Air Transport team practices of ensuring 24–72 h of medications depending on the estimated flight time.

During the patient selection phase, it is critical to understand the patient's risk of common transport-related complications. Bleeding is the most common complication encountered with ECMO cannulation, so awareness of the patient's hemoglobin, platelets, coagulation profile, and anticoagulation status will help guide decisions to mitigate bleeding risk [19]. As there is no monitoring or testing of coagulopathy in the en route environment, it is critical for the team to assess and treat as necessary prior to transport and prioritize repeat testing upon arrival at destination facility. Per our institutional policy for ECMO transports, regardless of the patient's condition, we request that all referring facilities prepare (on standby) four units of packet red blood cells for cannulation; if unused, the transport team brings them with the patient. If a concern for major bleeding exists, additional blood products may also be requested. Lastly, it is important to always review chest imaging prior to transport for endotracheal tube position and presence of a pneumothorax. Asymptomatic, small, undrained pneumothoraces may rapidly become significant during transport, particularly with air transport due to the partial pressure changes. In general, regardless of perceived resolution of pneumothorax, established chest tubes should remain in place during transport, and chest tubes are usually placed when an undrained pneumothorax is identified.

Pre-transport

Prior to transport, several factors must be considered including local vs destination weather, crew rest status, availability of aircraft or mode of transportation, and equipment status. Weather conditions can have a major impact on transport mode and timing. There should be no delay in ECMO support once the team has arrived to the patient. Cannulation should be performed and ECMO support started as soon as possible. The team must have a formulated plan to support direct care of the ECMO patient for 24–48 h in place if return transport is delayed. Using a shift rotation of those qualified to manage an ECMO patient is crucial. This allows for constant supervision while allowing the team adequate rest periods.

Fig. 3 ECMO referral and guidance

San Antonio Military Medical Center Adult ECMO Program

The San Antonio Military Medical Center (SAMMC) now accepts civilian patients for Extracorporeal Membrane Oxygenation (ECMO). When required to ensure a safe transfer, our team can initiate ECMO at your hospital before transporting the patient.

CONSIDER EARLY REFERRAL FOR:

- Hypoxemic respiratory failure with $P/F \leq 100$ or **plateau pressure** > 30 cmH_2O despite optimal ventilator management
- Respiratory acidosis with $\text{pH} < 7.20$ despite optimal ventilator management
- Initiation of ARDS rescue therapies** (PEEP > 15 cmH_2O , prone positioning, HFOV, iNO, prolonged paralysis)
- Respiratory failure with significant barotrauma** (pneumatoceles, pneumothoraces, subcutaneous emphysema, bronchopleural fistula)

ECMO IS CONTRAINDICATED IN:

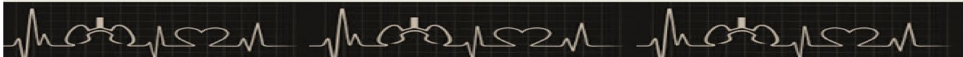
- End stage liver disease** or **malignancy** with poor prognosis
- Severe neurological impairment** or **debilitation** prior to acute illness
- Age > 75
- Primary disease process is **irreversible** and not amenable to transplant

*Note: Contraindication to anticoagulation is *not* necessarily a contraindication to ECMO!

We have a multidisciplinary team of professionals with years of combined experience and training in leading ECMO centers.

We would be grateful for the opportunity to provide cutting-edge care for your patient. You can contact an ECMO physician for referral or consultation at
(210) 916-ECMO

Alternatively, call the SAMMC hospital operator at (210) 916-2500 and ask for the ECMO physician on call, or page the MICU fellow at (210) 513-9812.



To ensure that the appropriate equipment is available and functioning prior to travel, pre-transport checklists are used to lessen the cognitive burden. Checklists are necessary, especially during times of high operational tempo, to ensure functioning IV pumps, available backup ECMO circuits, and adequate cannulation supplies. Additionally, personnel rosters may ensure adequate crew rest and prevent ill-prepared teams [21]. The equipment and supplies are inventoried and replaced and/or replenished immediately after each transport. A second set of equipment and supplies is always available in case of concurrent or immediately consecutive transports. The assigned ECMO nurse specialists and transport

coordinator are responsible for performing these inventories utilizing the checklist.

BAMC provides military-related support for worldwide ECMO evacuation, including austere settings; therefore, it becomes critically important to understand the patient's local environment to help the team anticipate space and resource limitations. The majority of the ECMO cannulations from our institution occur in hospitals within the USA, where resources are typically plentiful; during the COVID-19 surge, however, even US hospitals faced space, medication, and blood product limitations that impacted ECMO retrieval activities. In our experience, several cannulations were performed in makeshift

Fig. 3 (continued)



SAN ANTONIO MILITARY HEALTH SYSTEM ADULT ECMO PROGRAM

Thank you for your referral and the opportunity to serve your patient's needs. Once we accept the referral our team will leave for your facility as soon as possible.

What to Expect

Our team will initiate ECMO in the ICU. ECMO cannulas are inserted percutaneously using the Seldinger technique. For veno-venous (VV) ECMO we will use one femoral vein and the right internal jugular vein, or bilateral femoral veins. For veno-arterial (VA) ECMO we will use one femoral vein and one common femoral artery. We will connect the cannulas to the ECMO circuit using a "wet" technique to avoid getting air in the circuit.

Oxygen saturation will increase after flow is initiated. Significant hypotension often complicates the first few minutes on ECMO. If the patient stabilizes on ECMO we will immediately begin preparations for transport. However, if there are complications or ongoing instability we may remain in your facility for a few hours before departing.

Please address the tasks below before we arrive to expedite ECMO initiation.

Administrative

- Fax patient face sheet to our program coordinator if not already done. Fax and all contact info at bottom of page.
- Photocopy records and transfer imaging studies to a disk.
- Ensure the patient's family understands that ECMO is a rescue therapy and that there are risks involved, including risks during transport to San Antonio Military Medical Center. Please document this conversation in the chart.
- Have a blank consent for invasive procedures available.
- Have the patient's legal surrogate present or available by phone to consent for treatment.
- Provide our physician's credentialing information to your credentials office, administrator on call or Chief Medical Officer and request emergency privileges.

Patient Preparation

- Give 1 unit of platelets if < 100 . Have another unit available to transfuse during procedure.
- Administer FFP if INR > 2.0 . Should have coagulation labs collected within previous 12 hours.

ICU Preparation

- Have ultrasound at bedside.
- Have digital chest x-ray available during cannulation.
- Have crash cart in the room or in the hallway just outside.
- Have a norepinephrine infusion at the bedside.
- Type and cross for 4 units of PRBCs/FFP and have at least 2 units PRBCs in the room during cannulation.
- Have two bedside tables available for use during cannulation.

Personnel

- Please have someone meet the team on arrival and escort them to the patient.
- We will bring personnel to place the ECMO cannulas and operate the pump. We rely on the referring facility for bedside nursing, respiratory therapy, radiology and other support.
- We welcome your trainee's presence at the bedside and will involve them where possible.
- We do not require assistance from your physician staff. However, we welcome any assistance they are able to provide.

ECMO Referral line 210-916-ECMO (3266)

ECMO Fax • 210-916-0008

ECMO Transport Coordinator • Bernadette Elliott • Bernadette.S.Elliott.civ@mail.mil • Office 210-916-6902 • Cell 210-860-2867

ECMO Coordinator • Kathryn Negaard • Kathryn.A.Negaard.civ@mail.mil • Office 210-916-0444 • Cell 228-424-6584

ECMO Physician • Maj Matt Read • Matthew.D.Read2.mil@mail.mil • Office 210-916-2745 • Cell 210-305-1671

ECMO Physician • LCDR Mauer Biscotti III • Mauer.Biscotti.mil@mail.mil • Office 210-916-3774 • Cell 570-407-1979

ECMO Medical Director • Col Phillip Mason • phillip.e.mason2.mil@mail.mil • Office 210-916-4528 • Cell 940-867-8001

Demographics and Basic Mission Information

ECMO Transport coordinator name & contact info:		ECMO physician name & contact info:	
Patient name:		Referral date/time:	
Patient SSN:		Patient DOB & age:	
Patient gender:		ICU phone:	
Beneficiary status:	AD, Retired, Dependent, Non-beneficiary, etc	Referring facility name/location:	
Service requested:	Transport, inpatient, both	SAMMC inpatient approval:	Approved (incl approver name), pending, N/A
Citizenship status:	US citizen, legal perm resident, etc. Required for international transports only	Referring physician contact information:	
Requires SECDDES: (Y/N)		POC for emergency credentials: (If required)	
Within 185 miles: (N/A if not SECDDES)			
Insurance policy #1: If applicable. Include policy #, group #, phone, etc if available.		Insurance policy #2: If applicable. Include policy #, group #, phone, etc if available.	
Diagnoses:			
Clinical summary: (Complete description of case that can be copied into PMR if required)			
Proposed mission plan: (Describe exactly what needs to be accomplished. Include mode of transport, approximate timeline, etc.)			

Fig. 4 ECMO transport intake form

SECDES Application Data

Complete this additional information if SECDES application is required. Otherwise this entire section is N/A.

<p>Guidance for personnel completing SECDES application: Use data on page 1 to complete demographics, clinical data, diagnosis, etc. All personnel receiving inpatient care should be approved at Fully Reimbursable Rate (FRR). Medical specialty required is “critical care medicine with ECMO capability.” Attending physician will be ECMO Team Lead. Other required fields can be completed by copying text below into the application document.</p>			
<p>Recommended length of designation:</p>	<p>Default 60 days for inpatient care. 60 days</p>	<p>Military air transport requested:</p>	
<p>Reason for designation:</p>	<p>Modify default text as needed. If default text is accurate it can be used “as is.”</p> <p>SECDES authorization is being requested IAW AFI 41-210 to allow military personnel to provide Extracorporeal Membrane Oxygenation (ECMO) to named civilian patient who is not otherwise eligible for care within the military health system. Approving this request will offer potentially lifesaving care to the patient that is otherwise not readily available, while accomplishing vital training objectives that are directly applicable to caring for combat casualties and other military beneficiaries.</p>		
<p>Justification:</p>	<p>Modify default text as needed. If default text is accurate it can be used “as is.”</p> <p>AFI 41-210, para 4.17.3.2, ECMO Program. ECMO is a technically demanding therapy with documented lifesaving potential in critically ill and injured patients, including combat casualties. The 59th Medical Wing maintains the DOD's only expeditionary ECMO and ECMO transport capability, and works closely with the DOD's only inpatient ECMO program located San Antonio Military Medical Center. The primary limiting factor in sustaining this capability is the low volume of ECMO cases in the beneficiary population. The case under consideration represents a valuable opportunity to exercise skills with direct applicability to the care of combat casualties that cannot otherwise be sustained. The patient under consideration for SECDES authorization is critically ill and has failed to improve with optimal conventional therapies. It is the referring physician's opinion that ECMO offers the best chance for survival. After review of the case, our ECMO physician's concur with this assessment. The referring hospital cannot provide the required care and such care is not commonly available locally in the civilian sector.</p>		
<p>Diagnosis in layman's terms:</p>		<p>Patient's home address: (only required if mil air requested)</p>	
<p>Brief case history: (Can be based on clinical summary above but must be understandable to non-medical personnel. Include long-term prognosis.)</p>			

Fig. 4 (continued)

PMR Data

Complete this additional information if a PMR is being generated by 59MDW or SAMMC PAD. Otherwise this entire section is N/A.

Guidance for personnel completing PMR: Use data on page 1 to complete demographics, clinical data, diagnosis, etc. Attending physician will be ECMO Team Lead. All personnel on “ECMO team personnel list” should be listed as medical attendants.			
Precedence:	“Urgent” is default, “Priority” in some cases	Altitude restriction:	Case by case decision, usually 5000
Non-medical attendants: (name, relation to patient, DOB)			
Items requiring waivers:	Maquet Cardiohelp ECMO system (power requirement 100-240 VAC, 50/60 Hz, 2 amps)		
	Cincinnati Sub Zero Microtemp LT blanket heater (power requirement 100-240 VAC, 50/60 Hz, 1.75 amps)		

Fig. 4 (continued)

hospital rooms that were previously dialysis units, human resource offices, or converted PACUs. Atypical cannulation settings pose risks for patient monitoring and infection control, and may limit team activities due to space constraints. Understanding the treatment area prior to arrival allowed teams to bring additional supplies and request changes to patients’ location to ensure safe cannulation and packaging.

Patient Packaging

Although there is often a rush to rapidly place the patient on ECMO soon after team arrival, once support is established the priority should be ensuring safe patient packaging for transport. There is a standard load plan for transport by aircraft, which includes patient headfirst in the aft right of the aircraft. Knowing this configuration determines the positioning of the monitors, IV pumps, ECMO pump, and other equipment for easy accessibility from the patient’s left side. Conveniently, this positioning works for the ambulances too, as patient’s on ground transports are loaded headfirst with the personnel bench to the patient’s left side.

During the patient packaging phase, teams must pay close attention to patient position, patient restraint, sedation, and securing all tubes and lines. Prior to movement the patient must generally be deeply sedated and/or paralyzed to minimize the risk of pain and movement during transport, which could result in inadvertent tube and line dislodgement. All ventilator tubing connections should be reinforced to prevent inadvertent disconnection. Adequate venous access,

including central venous access, should be obtained prior to movement. Central venous lines and arterial lines should be secured with sutures, and IV tubing should be organized to prevent snagging during transport. Chest drains, if present, must be assessed for drainage volume and the presence of an air leak; chest drain collection devices should be replaced prior to departure if full or nearly full. Naso- and/or orogastric tubes and Foley catheters must also be secured appropriately. Lastly, monitors and IV access sites must be functioning and easily accessible at all times to allow continuous assessment and rapid treatment as necessary [21].

Our team has found that a percutaneous access with 2 single-lumen cannulas in the femoral-femoral configuration for either VV- or VA-ECMO is the safest transport cannula configuration for a variety of reasons: (a) ease of securement, (b) positioning of the ECMO pump between the patient’s legs, and (c) lower risk of cannula movement/dislodgement compared to a configuration that involves the internal jugular (IJ) vein. Bilateral femoral cannulas create an area on the thighs where sutures and additional securement devices and be placed and accessed easily. Having the drainage and return tubing close to the pump (as the pump is usually placed between the patient legs for transport) reduces the possibility of tubes pulling or snagging while in transport. It is more difficult to secure an IJ return cannula when the tubing is over the patients head. The risk of dislodgement may be increased. Although rarely used, the ECMO team is equipped with dual-lumen cannulas should patient circumstances require a dual-lumen cannulation strategy.

Transport

The transport phase is the most dangerous period of time, but appropriate planning reduces the risk of complications and poor outcomes. Several important transport-specific considerations include ensuring adequate oxygen supply for all phases of transport, and preparing for the various unique environmental stresses of movement and flight. When transporting a patient, oxygen supplies must be adequate to cover movement to the ambulance or ground transport time to the aircraft. These oxygen requirements should be calculated based on the patient's oxygen requirement, oxygen supply canister/machine/source, and the duration of time that oxygen is needed during transport. Additional oxygen beyond calculated requirement should be determined by each team on a case-by-case basis based on patient and transport characteristics. In contrast to standard critical care transports with a ventilated patient, an additional oxygen tank is required to for ECMO transports for the ECMO blender. Ensuring a full and back-up oxygen supply that accounts for transport time will avoid a potentially catastrophic situation. If fixed wing transport is required, knowing the type of aircraft ahead of time is critical as certain military airframes like the C-130 do not have an integrated oxygen supply whereas C-17 s include this capability. Depending on the mode of transport, power sources should be established to ensure adequate voltage, current, and wattage for connections to all electrical equipment for the duration of the transport.

Other environmental factors must be accounted for during the transport phase. Vibration from ground and/or air travel may worsen patient pain and discomfort. To mitigate these factors, additional care must be taken to ensure that the patient is appropriately padded, secured, and provided with adequate levels of analgesia and sedation. Patients must also be protected from the extreme temperature changes. Patients will be exposed to ambient air when moving to and from the hospital to the transport vehicle; furthermore, temperature control may not be possible during flight. Invasive temperature monitoring is mandatory as is ensuring the patient is adequately covered with blankets when appropriate. Additionally, during flight patients must be provided appropriate hearing protection. Lastly, the standard cabin altitude for a fixed wing aircraft is around 8000 feet; at this cabin altitude gas expands nearly 35% when compared to sea level, so trapped air (i.e., pneumothoraces, pneumomediastinum, and gastrointestinal tract gas) may rapidly become clinically significant [19]. This reinforces the fact that in all phases of care the transport team must ensure appropriately functioning chest tubes (if present), drains, and gastric decompression. It is also standard protocol to assess the endotracheal tube cuff pressure prior to departure, at altitude, and after landing with a specific pressure goal of 20–30 mmHg per cuff manometer.

The most common complications during ECMO transports include bleeding, hypotension, tube/line dislodgement, and equipment failure [19–21]. Ensuring adequate blood and resuscitation product availability during transport is paramount. Also, coagulation studies generally cannot be monitored on long fixed wing transports so decisions to not titrate,

to decrease, or even to stop full-dose anticoagulation must be considered. Appropriate planning, comprehensive knowledge of the individual patient's medical condition, ensuring adequate supply of medications and blood, functioning equipment, and anticipating the environmental stresses of transport will reduce the risk of complications associated with ECMO transport.

Observations and Approaches

Transport of critically ill and/or injured patients via rotary or fixed aircraft is an essential aspect of combat casualty care with crossover applicability to civilian medical care. CCAT teams provide the basic critical care platform to transport critically ill patients across long distances via aircraft to higher levels of care. These teams consist of a critical care physician, a critical care nurse, and a respiratory therapist; teams are deployed with a standardized set of equipment and medications that are frequently used during transport.

Transfer of patients to higher levels of care without degrading the care en route has always been an essential portion of the military view of en route care. As a result of extremely complex wounding patterns in theaters of operations, the Acute Lung Rescue Transport (ALeRT) team was developed and positioned at Landstuhl Regional Medical Center in Germany to serve as an adjunct to CCAT teams. ALeRT teams provided additional en route capability (including advanced ventilation and ECMO) when patient needs exceeded the capabilities of the CCAT teams. The ALeRT team in Germany stood down in 2014 and the ALeRT responsibilities were transferred to the BAMC ECMO team in San Antonio.

ECMO augmentation of CCAT capability significantly increased the safety associated with transporting the most severely ill patients. This has resulted in the ability to project the specialized trauma and burn and medical capabilities housed at BAMC to serve patients, worldwide. The Institute of Surgical Research (ISR) Burn Unit also located in BAMC has a dedicated Burn Flight Team (BFT). The members of this team have been prioritized for available seats as non-Air Force trainees in the CCAT Initial and Advanced courses as well as model their equipment after the CCAT allowance standard. Collaboration between the ECMO team and BFT who attend the CCAT initial and advanced training courses allows for highly specialized care to be delivered prior to, during, and immediately after flight for transfer to the highest level of care.

Conclusions

Over the past several decades there have been significant increases in en route critical care notably with providing ECMO transport capabilities. The ability to safely transport

critically ill patients to ECMO facilities is an essential component of a hub and spoke model of care; this allows the concentration of expertise at larger higher-volume hubs and the ability to rescue patients as needed from smaller, less capable facilities. Many high-volume centers have demonstrated that specialized ECMO transport teams can successfully transport patients on ECMO [22–26]; however, the process of accepting, retrieving, and successfully moving a critically ill patient requiring ECMO is a complex endeavor requiring preparation and planning for the multitude of logistical considerations. The United States Air Force implementation and advancement of ECMO transport as an augmentation to CCAT teams has allowed global patient movement capabilities available to service members and also civilians [27••]. Overall, current literature and our institutional experience supports the practice of on-site cannulation followed by transport of these patients on ECMO as safe and with low relative mortality when performed by well-trained teams using stringent protocols [28, 29, 30•].

Declarations

Ethics Approval All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

Conflict of Interest The authors declare no competing interests.

Disclaimer The views expressed are the authors' own and do not represent those of the US Air Force or Department of Defense.

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