Interhospital ECMO Transport: Regional Focus

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Utilization of extracorporeal membrane oxygenation (ECMO) has increased dramatically over the last decade. Despite this trend, many medical centers have limited, if any, access to this technology or the resources necessary to manage these complex patients. In an effort to improve the current infrastructure of regional ECMO care, ECMO centers of excellence have an obligation to partner with facilities within their communities and regions to increase access to this potentially life-saving technology. While the need for this infrastructure is widely acknowledged in the ECMO community, few reports describe the actual mechanisms by which a successful interfacility transport program can operate. As such, the purpose of this document is to describe the elements of and methods for providing safe and efficient mobile ECMO services from the perspective of an experienced, high-volume tertiary ECMO center of excellence in the Southeastern United States.

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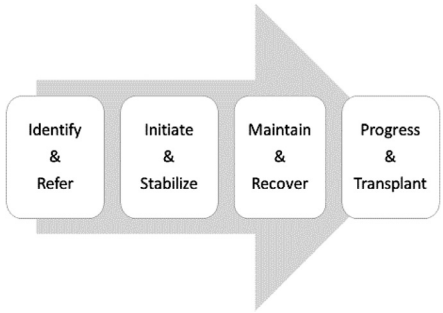

Spectrum of ECMO referral center capabilities.

Central Message

ECMO centers of excellence, using validated protocols, may increase ECMO access within their communities and enable successful interfacility transport.

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is an adaptation of cardiopulmonary bypass used to support patients with severe, life-threatening cardiogenic shock, and/or respiratory failure.[1] High-volume adult ECMO centers, defined as those cannulating more than 30 patients per year, have demonstrated improved rates of survival compared to centers performing fewer cannulations.[4–7] This trend likely reflects the effect of multidisciplinary teams with significant expertise, and availability of advanced technologies and organ failure therapies such as transplantation and durable mechanical circulatory support.[2,3] Therefore, medical centers with absent or incomplete ECMO capabilities and/or experience can potentially improve patient outcomes by partnering with experienced ECMO centers.[4,8] This manuscript describes our experience and recommendations for establishing and maintaining a regional ECMO service.

TECHNIQUE

Outreach and Preparation

Successful regionalization of ECMO care in the United States requires coordination of complex independent health systems. Education, outreach, and relationship building are the cornerstones of this program. Increasing patient access to ECMO care begins with evaluation of the regional healthcare landscape and needs assessments. Marketing the ECMO center of excellence's ability to provide regional support and the center's willingness to collaborate is largely undertaken by word of mouth, but formal communication is also necessary. In 2013, the formalization of the Duke ECMO transport program began with a mass mailing to physicians who had historically referred patients to Duke for cardiac surgery, heart failure, and thoracic transplant. The contents of this mailing included a list of services offered, statistics related to patient outcomes, and synopses of patient success stories. These mailings created dialogue that cultivated relationships between centers, leading to numerous formal lectures, meetings, and collaborative training sessions for referring centers. Multidisciplinary process and clinical simulation are especially beneficial to promoting a culture of mutual respect and safety. While some referring centers may wish to focus on patient

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selection and salvage ECMO provided by the quaternary center, others will desire to develop their own ECMO capabilities. Referring centers are categorized as (1) those without ECMO capabilities and *without* cardiopulmonary bypass, (2) those without ECMO capabilities but *with* cardiopulmonary bypass, (3) those with temporary ECMO capabilities, and (4) those with long-term ECMO capabilities (Fig. 1). Continuing education and support are tailored to the needs of the referring center with patient-centered care as the highest priority.

Communications: Patient Selection, Triage, and Transfer Planning

Our center has established a hotline for ECMO referral, which provides a direct 24-hour point of access for any referring center. All ECMO referrals are funneled through a single point of entry operated by Duke Life Flight Communications (DLFC). DLFC works with the ECMO coordinator to organize a conference call between the referring providers and the appropriate members of the Duke ECMO transport team (Fig. 2). The Duke ECMO transport team consists of the ECMO coordinator, an ICU intensivist and/or ECMO surgeon, an ICU charge nurse, and the Duke Life Flight charge nurse. The goal of this initial conference call is to determine the appropriateness of ECMO support as well as timing and location for initiation of support. In the case of established ECMO centers, the call will determine the appropriateness of transfer to Duke. In all cases, the multidisciplinary team provides management guidance to the referring providers to help stabilize the patient, followed by a determination of whether to defer ECMO or prepare for cannulation. Approximately half of all external calls to Duke requesting ECMO consultation are accepted for transfer. Of patients that are accepted, approximately half are cannulated at the referring center prior to transport. The appropriateness of cannulation and/or transport is at the discretion of the receiving institution, and recommendations are supported with institutional data and the experience of our multidisciplinary ECMO team. Additional medical management guidance is offered if desired for patients not accepted for transfer.

When transfer is indicated, the team coordinates with DLFC, pilots, and Emergency Medical Technician (EMTs) to determine the safest mode of transport for the patient and ECMO transport team. Urgency and geographic location of ECMO cannulation is determined based on patient stability and viability as well as logistics associated with transport such as distance, mode, weather, and local resources (Fig. 3).

We do not currently provide external cannulation for extracorporeal cardiopulmonary resuscitation (ECPR) due to time constraints for ECMO cannulation team arrival. Remaining

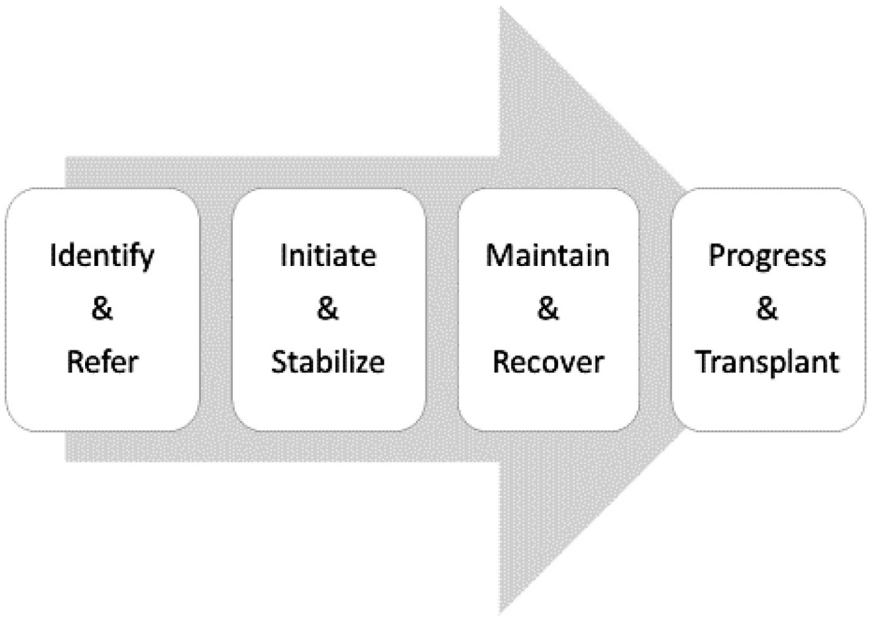

Figure 1. Spectrum of ECMO referral center capabilities. Referring centers are categorized by resource availability. Institutions without ECMO capabilities and *without* cardiopulmonary bypass are supported in their identification of potential ECMO candidates. These patients are supported with medical management and transferred to Duke, or cannulated by the Duke ECMO transport team. Institutions without ECMO capabilities but *with* cardiopulmonary bypass may need to refer patients for emergent ECMO conversion due to failure to wean from cardiopulmonary bypass or may bridge into ability to initiate ECMO with modified cardiopulmonary bypass circuitry for emergent to urgent ECMO transport. Referring centers with temporary ECMO capabilities typically collaborate with the Duke ECMO team regarding patient identification and cannulation recommendations. These patients are typically transferred to Duke due to local resource limitations on an urgent basis. The Duke ECMO referral system is also activated to support fully capable ECMO centers in patient selection as well as troubleshooting and management. ECMO transfers from centers with long-term ECMO capabilities are often for advanced heart/lung failure therapies and transplant evaluation, but also when local capacity has been exceeded.

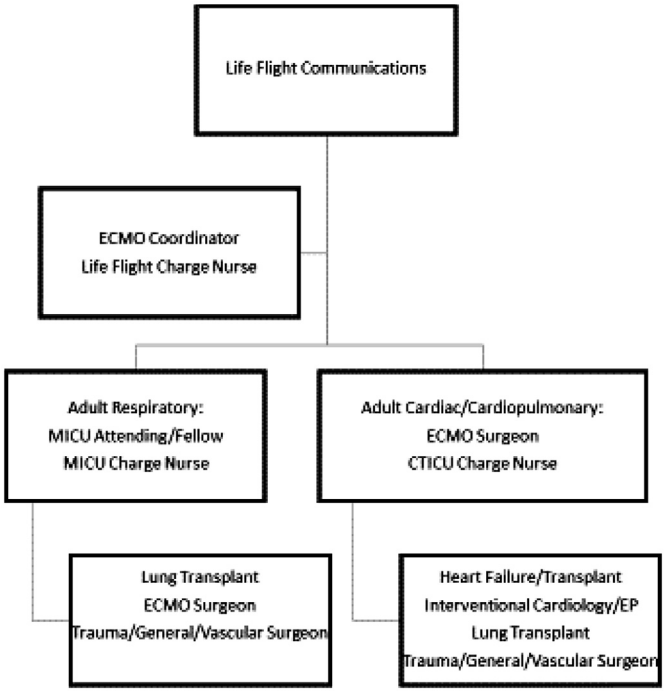

Figure 2. Communication teams. All requests for ECMO consultation, referral, or transfer are initiated via Duke Life Flight Communications. When the call is received, the referring facility is put in touch with the ECMO coordinator. The coordinator requests patient demographics and a brief relevant history. Based on that information, the caller will be connected with the adult respiratory ECMO team or the adult cardiac/cardiopulmonary ECMO team. The physicians work with the outside hospital to determine best clinical course of action and the coordinator remains available for logistical coordination, data references, and perfusion recommendations. The Life Flight charge nurse is on the line to assess transport capabilities. The appropriate ICU charge nurse is on the call to facilitate bed placement and arrival preparations. Additional consultants will be added to the conference call as needed.

patient selection and cannulation recommendations largely resemble that of our internal ECMO practices (Fig. 4). For patients who are decompensating or on cardiopulmonary bypass at centers that do not have ECMO capabilities, we provide emergent ECMO transport resources 24 × 7. For example, patients undergoing cardiotomy who are unable to be weaned from bypass at a center without temporary mechanical circulatory support (within the state of North Carolina) are nearly always accepted for transport. We strive for an emergent departure from Duke within 60 minutes of acceptance of the patient. In the most urgent of cases, weather and geography permitting, we dispatch a separate cannulation team via rotor wing aircraft to stabilize the patient while awaiting the arrival of the remainder of the transport team via ground mobile ICU transport. However, the acceptance, cannulation, and transfer of a rapidly decompensating patient are dependent on the projected patient viability until arrival of the cannulation team and initiation of support.

At referring centers with limited ECMO capabilities, the patient may be initiated on ECMO support by the referring team and maintained while awaiting transfer. In this scenario, the team can achieve improved hemodynamic and/or respiratory stability, control bleeding, and when indicated, perform a detailed neurologic examination prior to transfer. This scenario allows a more controlled environment for transport and a more focused approach to patient care.

Transfers originating from established ECMO centers are typically initiated to pursue advanced heart and lung failure therapies such as ventricular assist device implantation or transplant evaluation. These transfers are thoroughly investigated and usually scheduled electively.

Our team is ever conscious of the burden placed on families and caretakers associated with long distance transfers. We therefore strive to support local management within the capabilities of the referring hospital. It is imperative for a discussion to be had regarding patient and family wishes. While insurance information is queried, financial status is not an isolated contraindication to cannulation or transfer.

Resource Mobilization

Our usual cannulation and transport team includes a cardiothoracic surgeon, a perfusionist, and 2 critical care transport providers (critical care transport nurses, paramedics, and respiratory therapists). For transport of patients stable on ECMO support at an outside facility, the transport team consists of critical care transport providers and a perfusionist. All members of the transport team are covered by hospital-purchased malpractice insurance while operating as an entity of Duke. For surgeons entering referring facility operating suites, emergency privileges are often granted.

Standardized mobile ICU vehicles, medical helicopters, and medical fixed wing aircraft are all routinely available to our program. The Duke Life Flight ground critical care ambulance fleet consists of a quad chassis (International, Kenworth) supported by a mobile ICU platform. A Eurocopter (EC) 145 dual engine single-pilot IVR/VFR-rated rotor wing is also owned by Duke Life Flight. If longer transport is needed, local medical fixed wing organizations contract to transport the Duke ECMO team in Cessna citation jets or King Air turbo propeller aircrafts.

The availability of equipment and supplies is variable from center to center; therefore, we have standardized our mobile ECMO inventory. Cases requiring initiation of support by Duke cannulation and transport teams require additional supplies as outlined in Tables 1–3. In addition to standard mobile ICU monitoring and support, our critical care transport team provides portable infusion pumps, ventilators, an intra-aortic balloon pump console (Cardiosave, Maquet, Rastatt, Germany), Impella (Abiomed, Danvers, MA) console, suction, and inhaled nitric oxide as needed. Emergency back-up equipment and supplies are also taken as described in Tables 1–3. Prior to departure, the entire transport team verifies that all supplies are available and equipment is functioning properly. A pretransport

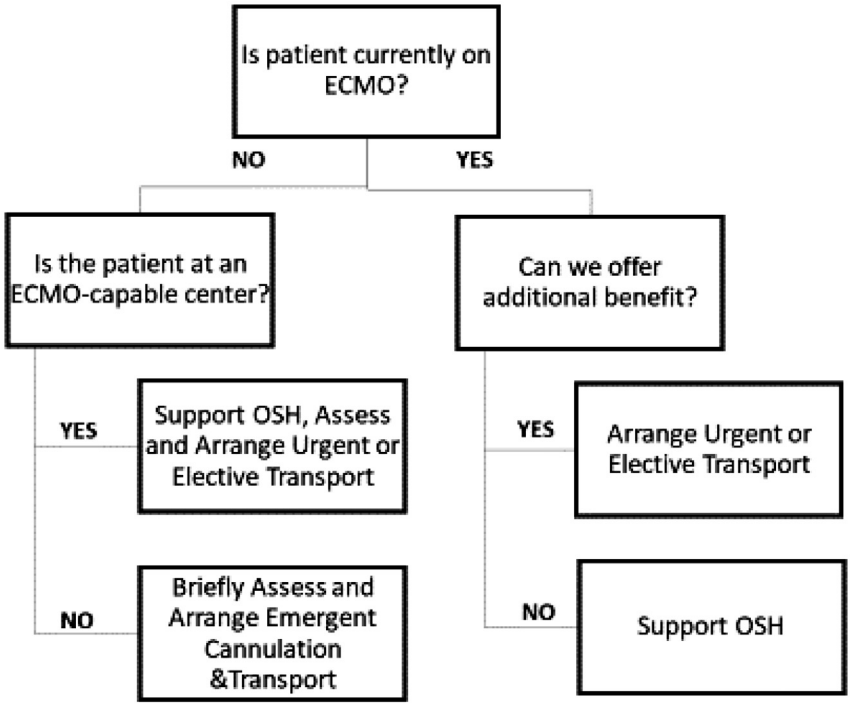

Figure 3. Triage. ECMO transport triage typically follows the above algorithm of urgency based on referring intuition ECMO capabilities, outside hospital (OSH).

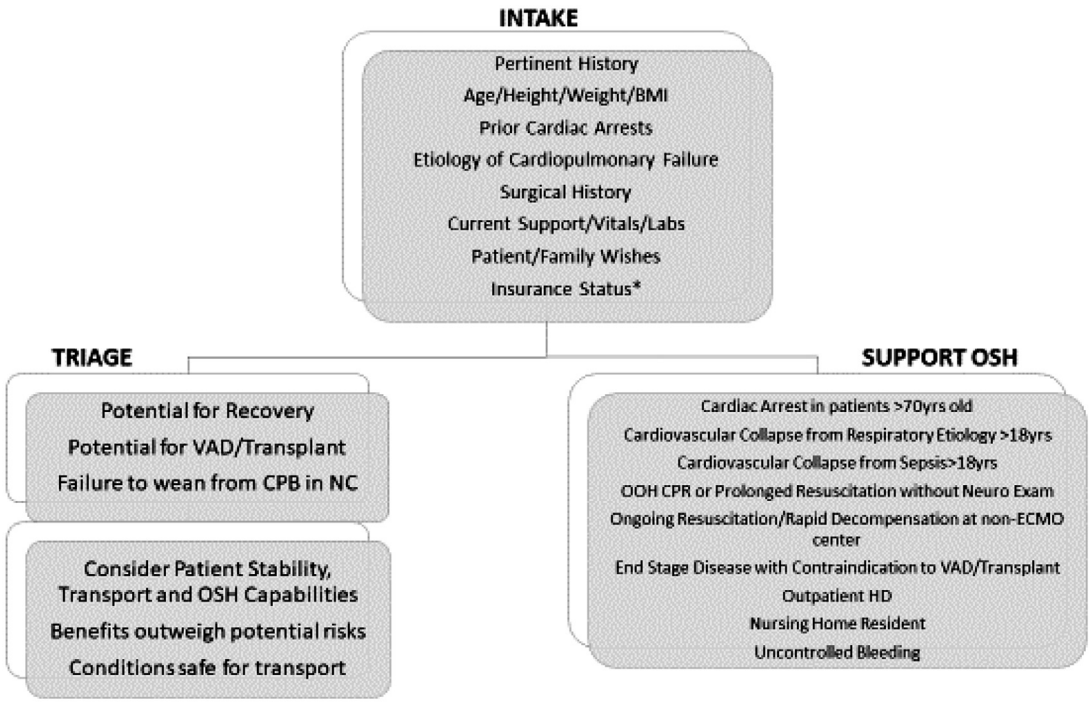

Figure 4. ECMO transport assessment. Intake information is reviewed and candidacy for ECMO roughly follows these guidelines. An attempt is made to determine insurance status prior to transfer. The absence of insurance coverage is not used as a sole determinant of transfer or ECMO acceptance for potentially viable patients, particularly those with reversible disease. The OSH is supported, but the patient denied ECMO transport or transfer as an ECMO candidate for a myriad of reasons associated with poor survival outcomes. Failure to wean from cardiopulmonary bypass within the state of North Carolina is nearly universally accepted for transfer if separation to ECMO is successful and bleeding is controlled. Safety of the patient and the transport team is the highest priority.

Table 1. Life Flight and Perfusionist Equipment/Supply Lists

Life Flight Critical Care Equipment	Transport Perfusionist Equipment/Supplies
Three-channel multidrip Alaris IV pump	ECMO transport backpack*
• x4 pumps (12 drip minimum capacity)	• See Table 2
Zoll X Series transport monitor/defibrillator	ECMO console with handcrank*
• 12 lead continuous EKG monitoring	• CardioHelp, Maquet, Rastatt, Germany
• Continuous quantitative/qualitative waveform capnography	Multiplug powerpack extension cord*
• Sp02	Sterile, sealed, ECMO circuit*
• Dual temperature probe	• CardioHelp, Maquet, Rastatt, Germany
• Three invasive pressure waveform capability	Heater*
• Biphasic defibrillation	• Microtemp LT, Cincinnati Sub Zero
• Transcutaneous pacing	Primed ECMO circuit†
• Respiratory monitoring	• CardioHelp, Maquet, Rastatt, Germany
• NIBP	Sterile ECMO pack†
• ECG monitoring	• See Table 3
Hamilton Medical T-1 transport ventilator	Cannulae and associated insertion kits†
• All pressure and volume assist modes	
• Nitric oxide capability	
Medtronic transvenous pacemaker	
iSTAT analyzer (Abbott Labs, Princeton, NJ) and CG7 cartridges	

*Mandatory for all ECMO transports.
†Taken as situation dictates to convert patient to Duke ECMO circuit or for remote cannulation.

briefing is performed, which reviews specific transport vehicle safety and designated team roles.

Collaborative Care

A conference call to discuss a detailed, updated patient report takes place prior to the ECMO team's arrival. Requests for patient preparation are confirmed. The referring facility is asked to provide fresh preparations of the patient's continuous infusions (including sedatives, paralytics, and vasoactive medications) in volumes sufficient for 2 times the expected duration of transport. Cross-matched, type specific blood products are requested for routine resuscitation as well as potential catastrophic complications during transport. The amount varies based on clinical situation, but typically ranges from 2−4 units of red blood cells, 0−2 units of fresh frozen plasma, and 1−2 packs of pooled platelets. We will deem patients unfit for transport if requiring more volume resuscitation than 4 red blood cells, 2 fresh frozen plasma, and 2 platelets over the anticipated travel timeframe. If the patient is cannulated after our transport team's arrival, the referring hospital arranges an appropriate environment for cannulation (operating room, catheterization lab, or an intensive care unit room) as well as any imaging modalities that will be necessary to confirm cannula positioning prior to departure. Finally, it is important that the local clinical team is available to medically manage the patient during cannulation, interventions, and transition of care.

Upon arrival and after appropriate introductions, the transport team reviews the condition of the patient and assesses the safety and appropriateness of cannulation and/or transport. If the patient is unstable despite being on ECMO, the transport team will work with the local team to stabilize the patient prior to transport. Patients with uncontrolled bleeding or hemodynamic instability despite ECMO support and resuscitation will not be transported. If the patient is persistently critically unstable and the movement of the patient may cause further deterioration, a conference call is performed with the on-site Duke ECMO team, the referring facility staff, and the receiving Duke intensivist to discuss patient management. Conversion of ECMO modality, the addition of venting strategies, or surgical intervention may be necessary prior to transport and requires intense cross-facility collaboration.

Prior to transport, cannula positioning is confirmed using echocardiography, fluoroscopy, and/or x-ray. ECMO cannulas are securely sutured in place, dressed using sterile technique, and reinforced with additional sutures and securement devices to prevent dislodgement. Prior to departure, large bore central venous access for emergency volume resuscitation as well as an arterial line for blood pressure and blood gas monitoring is placed. The patient is connected to the transport monitor, intravenous medications are transferred to the transport intravenous pumps and the patient is connected to the transport ventilator as well as any adjunctive support devices such as intra-aortic balloon pump, Impella, or inhaled nitric oxide tank. Once all team members are ready and a time out is completed, the patient is transferred to the transport stretcher. An arterial blood gas is obtained and, if necessary, changes are made to the ECMO and ventilator settings. A final callback to Duke receiving providers confirms patient preparedness for transport.

Transition of Care: ECMO Transport

After the patient is in the receiving facility's possession, ongoing communication with the home institution is critical. Approximately 1 hour from arrival to Duke (or on departure

Table 2. ECMO Backpack Supply Inventory

ECMO Backpack Contents	
Sterile surgical ECMO tray	ECMO med kit
Weitlander 2	25% Albumin 50 mL 2
Army Navy 2	Heparin flushes (100 units/mL) 5 mL 2
Tonsil 1	Heparin injection (1000 units/mL) 10 mL 2
Fine right angle 1	CaGlu 100 mg/mL 10 mL 2
Pump clamps 6	$NaHCO_3$ 1 mEq/mL 50 mL 4
Curved clamp 1	Alcohol pads 4
Forceps 2	10 cc syringes 4
Mayo needle holder 2	3 cc syringes 10
Universal scissors 1	60 cc syringes 6
Fine scissors 1	18 gauge needles 20
Scalpel handle 1	
1 ECMO suture/dressing/cannulation kit	ECMO tubing/connector kit
2-0 silk "pops" 4	Male/male adapters 2
0 surgilon 4	High flow stopcock 4
0 monosof 4	Large bore "walrus" tubing 2
2-0 ethibond SH 4	3/8 tubing stub 1
2-0 ethibond SH-2 4	Long 3/8 tubing 1
3-0 ethibond RB-1 4	1/4″ Quick prime line 1
2-0 polysorb GS-21 2	Spring-load quick prime line 1
3-0 biosyn 2	Custom manifold pack 1
Uterine needle 2	1/4″ Straight connector 3
Umbilical tape 2	3/8″ Straight connector 3
2-0 silk ties 2	1/4″ × 3/8″ Reducing connector 2
0 silk ties 2	3/8″ Luered connector 2
French eye needle 2	1/4″ Luered connector 2
Sterile scissors 2	1/4″ × 3/8″ Luered connector 2
Disposable scalpel 2	1/4″ Tubing stub 2
Chloroprep 4	3/8″ Tubing stub 2
10 blade 2	Blood filters 2
Sterile tubing clamps 2	Perfusion adapters (M) 2
CHG Tegaderm dressing 6	Perfusion adapters (F) 2
Sterile gauze 4 × 4 8	
Foley anchor 4	
Radiopaque keepers 3	
220 cm Avalon dilators 2	
6 fr sheath 2	
7 fr sheath 2	
8 fr sheath 2	
Stiff glide 2	
Amplatz super stiff 1	
Rosen wire 3	
5 fr micropuncture 3	
Pink needle 3	

from the referring facility or landing at a local airport), the transport team provides a detailed report to the receiving ICU nurses and providers at Duke. This report includes an estimated time of arrival, review of the patient's current condition, cannulation details, infusions, and device settings as well as any anticipated needs (ie, hemodialysis, additional surgical interventions, or imaging) upon arrival at Duke. The patient's admission is pended to the receiving unit in the Duke electronic medical record at that time to allow necessary in-patient orders in preparation for arrival. During the return to Duke, patient hemodynamics, arterial blood gases via an on-board iSTAT analyzer (Abbott Labs, Princeton, NJ) and ECMO parameters are monitored closely. Critical changes in patient status are communicated directly with the receiving ICU attending and ECMO surgeon.

Although now quite rare, the most feared complication of transport is acute patient decompensation or circuit malfunction while en route. For patients transported by ground,

Table 3. Sterile ECMO Pack

Sterile ECMO Pack	
1	Large full drape/sheet
1	Gown, large w/towel
1	Basin
1	Needle counter
1	Chest/breast drape
2	Surgical gowns
1	#11 blade
1	Sponge/lap pack
1	Incise drape
1	csr wrap
2	20 mL syringes
1	#15 blade
12	Towels
1	Prep kit

Table 4. Duke University Hospital ECMO Transport Experience January 2016 to December 2017

Total Patients Transported on ECMO	
Cardiac	132
ECPR	51
Respiratory	23
VA	58
VV	71
Age	61
Range	18–79 y
Median	52 y
Survival to hospital discharge	52%
Non-ECPR survival to hospital discharge	61%

interventions to remediate these complications are first attempted on board. If unsuccessful or if the patient acutely requires physical resources not available on board, the ECMO transport vehicle is re-routed expeditiously either (1) back to the sending facility, (2) to the receiving facility, or (3) to the nearest hospital emergency room for temporary stabilization. These deviations are of course communicated to all parties involved.

Transition of Care: ICU Admission

The transport team is met either in the ambulance bay or the helicopter pad by available members of Life Flight to assist with unloading and egress directly to the receiving ICU. Adult patients with respiratory failure requiring VV ECMO are admitted to the Medical Intensive Care Unit, whereas all other adult patients are admitted to the Cardiothoracic Intensive Care Unit. Upon arrival in the ICU, emergent clinical needs are addressed first. The patient is then transitioned to an ICU bed, attached to a monitor, and reconnected to a standard ventilator. Patient medications are transitioned to the prepared standardized Duke formulary infusions. Hospital power, gas, and vacuum sources are confirmed, and labs are drawn, including an arterial shock panel, complete blood count, basic metabolic panel, type and screen, and coagulation profile. Chest x-ray and echocardiogram are ordered. Care during this period is collaborative between critical care transport, perfusion services, and intensive care. Once the patient is connected to our monitoring devices and no immediate interventions are required, a single report format is used to hand-off care to the multidisciplinary ICU team beginning with the Life Flight team lead, followed by the surgeon (if utilized), and then the perfusionist.

COMMENT

Interfacility transfer of ECMO patients is a complex process that requires a dedicated, well-equipped team and significant planning. We previously published our referral experience demonstrating that 66.2% of VA ECMO patients survived to decannulation and 48.1% survived to hospital discharge. Among hospital survivors, the Kaplan-Meier estimate of 1-year survival was 82.4%.[9] Similarly, 76.8% of VV ECMO patients who were transported to Duke survived to decannulation and 69.6% survived to hospital discharge. Of hospital survivors, the Kaplan-Meier estimate of 1-year overall survival was 95.5%. From the termination of that analysis through December 2017, we safely transported an additional 132 adult patients to Duke on ECMO; 92% of patients originated from across the state of North Carolina. Our ECMO referral and consultation system had been activated over 600 times in the same time frame by institutions in North Carolina, Virginia, South Carolina, Tennessee, Ohio, Georgia, and Florida. Of the patients transported on ECMO from January 2016 through December 2017, 38% were cannulated for cardiac indications, 44% for respiratory, and 21% during ECPR; 54% supported with VA ECMO and 46% with VV ECMO (Table 4). Median age was 52 years old and hospital survival was 55%. When ECPR patients are excluded, survival to hospital discharge is 61%.

As also described by the University of Michigan and New York-Presbyterian Hospital, with proper infrastructure in place, ECMO transport can certainly be performed safely and efficiently.[10,11] We believe our approach to process, outreach and education distinguish our program and have contributed to our success. Significant time and resources have been dedicated to disseminating our growing body of ECMO knowledge within the region with a focus on patient selection and stabilization. While much attention is paid to referral processes, we routinely provide consultations to regional hospitals not only regarding patient selection for potential cannulation and transfer to our institution, but as a customer service to any and all querying hospitals—even other local, regional, and national quaternary care referral centers. Ultimately, our goal is to increase access to ECMO and improve the associated patient outcomes across the Southeastern United States. We recognize

it is in the best interest of patients and their families to stay within their communities and support systems whenever possible. Much work still remains regarding patient selection, efficient utilization of limited resources, and propagation of expertise. Investment in robust data collection and analysis, advances in electronic record sharing, and improvements in telemedicine will continue to refine regionalized collaborative ECMO care.

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