Title

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Journal

Journal of Cardiothoracic and Vascular Anesthesia, 35(10)

ISSN

1053-0770

Authors

Odish, Mazen F
Yi, Cassia
Chicotka, Scott
et al.

Publication Date

2021-10-01

DOI

10.1053/j.jvca.2021.05.047

Peer reviewed

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Journal of Cardiothoracic and Vascular Anesthesia 35 (2021) 2869–2874

Contents lists available at ScienceDirect

Journal of Cardiothoracic and Vascular Anesthesia

journal homepage: www.jcvaonline.com

Special Article

Implementation and Outcomes of a Mobile Extracorporeal Membrane Oxygenation Program in the United States During the Coronavirus Disease 2019 Pandemic

Mazen F. Odish, MD[*,1], Cassia Yi, RN, MSN[†], Scott Chicotka, MD[‡], Bradley Genovese, MD[‡], Eugene Golts, MD[‡], Michael Madani, MD[‡], Robert L. Owens, MD[*], Travis Pollema, DO[‡]

[*]*Division of Pulmonary, Critical Care, and Sleep Medicine, University of California, San Diego, San Diego, CA*

[†]*Department of Nursing, University of California, San Diego, San Diego, CA*

[‡]*Division of Cardiovascular and Thoracic Surgery, University of California, San Diego, San Diego, CA*

The coronavirus disease 2019 (COVID-19) pandemic began in the United States around March 2020. Because of limited access to extracorporeal membrane oxygenation (ECMO) in the authors' region, a mobile ECMO team was implemented by April 2020 to serve patients with COVID-19. Several logistical and operational needs were assessed and addressed to ensure a successful program, including credentialing, equipment management, and transportation. A multidisciplinary team was included in the planning, decision-making, and implementation of the mobile ECMO. From April 2020 to January 2021, mobile ECMO was provided to 22 patients in 13 facilities across four southern California counties. The survival to hospital discharge of patients with COVID-19 who received mobile ECMO was 52.4% (11 of 21) compared with 45.2% (14 of 31) for similar patients cannulated in-house. No significant patient or transportation complications occurred during mobile ECMO. Neither the ECMO nor transport teams experianced unprotected exposures to or infections with severe acute respiratory syndrome coronavirus 2. Herein, the implementation of the mobile ECMO team is reviewed, and patient characteristics and outcomes are described.

Key Words: extracorporeal membrane oxygenation; COVID-19; coronavirus disease 2019; severe acute respiratory syndrome coronavirus 2; SARS-CoV-2; coronavirus; mobile ECMO; transportation

EXTRACORPOREAL MEMBRANE oxygenation (ECMO) is an advanced mechanical circulatory support therapy for refractory cardiac and/or respiratory failure.[1] This technology has been used increasingly for adults in the United States since the 2009 H1N1 influenza pandemic and again in 2020 as a result of the coronavirus disease 2019 (COVID-19) pandemic.[2] Mobile ECMO is deployed when critically ill patients at outside facilities are too clinically unstable to transfer to a regional ECMO center. Mobile ECMO has been used safely and successfully in both the pediatric and adult populations in many countries for decades.[3-8] Southern California has only a few ECMO centers serving a large geographic region that has been disproportionately affected by COVID-19.[9-11] Herein, the process and outcomes of implementing a mobile ECMO team during the COVID-19 pandemic to ensure equitable care throughout the region is described.[12-15]

[1]*Address correspondence to* Mazen F. Odish, MD, Division of Pulmonary, Critical Care, and Sleep Medicine, University of California, San Diego, 9300 Campus Point Dr, Mail Code #7381, La Jolla, CA 92037-7381.

E-mail address: modish@health.ucsd.edu (M.F. Odish).

https://doi.org/10.1053/j.jvca.2021.05.047

Methods

Decision to Activate the Mobile ECMO Team and Transportation Planning

Clinicians at outside facilities consulted the ECMO team through the authors' hospital's transfer center and completed an ECMO-specific transfer document (Table S1). The transfer center then contacted the ECMO coordinator who organized a multidisciplinary conference with a pulmonary intensivist and cardiothoracic (CT) surgeon within 60 minutes. ECMO candidacy was determined using internal and regionally shared ECMO criteria based on Extracorporeal Life Support Organization (ELSO) guidelines (Table S2).[16] If the patient was an appropriate ECMO candidate, clinical stability was assessed with the referring provider to determine the need for mobile ECMO versus conventional transfer. To maximize benefit of limited ECMO resources during the pandemic, patients with COVID-19 were not offered venoarterial ECMO nor ECMO-supported cardiopulmonary resuscitation because of a paucity of evidence for any survival benefit in patients with COVID-19 and to minimize healthcare exposures during cannulation.[17-19]

Similar to conventional transfers, bed availability was determined before acceptance. ECMO resources were evaluated before acceptance, and mobile ECMO only was offered if at least three ECMO circuits were unused. This ensured that ECMO could be offered to internal candidates while maintaining a backup circuit.

If the mobile ECMO team was activated, the mode of transportation was determined in collaboration with the contracted air and ground transportation services. This was done by assessing the number of team members required, total weight of individuals and equipment, and distance from the authors' center. A summary of these considerations, which were adapted from the ELSO transportation guidelines, is provided in the Supplement (Table S3).[20] The mobile team could be deployed from initial consult to leaving the authors' center as quickly as 90 minutes. Deployment time depended on the severity of patient illness, staffing and bed availability, insurance approval, and the hospital transfer agreement.

Credentialing Logistics

Credentialing for the CT surgeon was obtained before mobile team activation. During normal business hours, the medical credentialing office at the referring facility was used for privileging. If the mobile ECMO activation occurred after hours, the referring physician contacted his or her institution's chief medical officer for approval. No other specialties providers other than the CT surgeon on the mobile ECMO team were credentialled at the referring facility. The authors' institution's ECMO coordinator or surgical administrative assistant coordinated with the referring facility to ensure the receipt of required documents.

Patient Management Before Cannulation

After accepting a patient for mobile ECMO, the authors' institution's multidisciplinary team instructed the referring physician on further management including ventilator strategies, fluid balance, vascular access, and timing of supination (if patient was in the prone position). The referring facility was provided further with a standardized list of equipment and medications to have at the bedside for immediate use during bedside ECMO cannulation (Table S4). Upon arrival to the referring facility, the ECMO team assumed care of the patient, including ventilator and medication management. The ECMO cannulation was completed entirely by the authors' team and was documented by the CT surgeon in the authors' institution's electronic medical record upon patient admission to the authors' center.

Mobile ECMO Team Composition

The mobile ECMO team required a minimum of the following three members: (1) a CT surgeon who received emergency credentials at the outside institution; (2) an intensivist, CT surgery fellow, or advanced practice nurse/ECMO coordinator for management of the patient and cannulation assistance; and (3) a perfusionist to manage the ECMO circuit during cannulation and transportation. Additional team members were invited for training and educational purposes depending on transportation seat availability. The on-call team consisted of three CT surgeons; seven perfusionists; and six others, including pulmonary critical care physicians, CT surgery fellows, and advance-practice nurses. One rotating CT surgeon was on call at all times; however, during activations, all members were contacted to determine availability.

ECMO Cannulation at Outside Facilities

ELSO has guidelines for ECMO transportation with equipment recommendations.[20] The authors' center used the Maquet Cardiohelp (Getinge, Rastatt, Germany) system because of its light weight (22 lbs, 10 kg) and compact size.[21] The Cardiohelp and all disposable equipment required for cannulation were brought by the mobile ECMO team (see supplement [Table S4 and Fig S1] for equipment storage and list, respectively). During the COVID-19 pandemic, the ECMO team also brought its own personal protective equipment (PPE) to ensure no extra burden was placed on the referring facility as a result of any regional PPE shortages. PPE included full face shields, N95 respirators, isolation gowns, sterile gowns and gloves, and surgical caps.

Upon arrival, the mobile ECMO team ensured appropriate patient sedation and neuromuscular blockade as needed. If a central or arterial line was not present, the mobile ECMO team members placed one before cannulation. Patients with severe acute respiratory distress syndrome (ARDS) who were in the prone position were supinated only after the mobile ECMO team arrived in order to minimize the time that the patient may be hypoxemic.

All the mobile ECMO patients in this series required veno-venous ECMO and were dual-site cannulated (femoral and internal jugular [IJ]). The largest drainage cannula appropriate for the patient's venous anatomy was used, ideally a 25-to-29

Fr multistage venous drainage cannula. No single-site, dual-lumen cannulae were placed. This eliminated the need for transesophageal echocardiography or fluoroscopy during cannulation. Furthermore, severely hypoxemic ARDS patients often require high ECMO flow goals, and single-site catheters may pose ECMO flow limitations. All cannulations were performed at the bedside percutaneously with ultrasound guidance in the intensive care unit (ICU). Cannula position was confirmed with bedside chest x-ray. Once the patients were on ECMO support, they were placed on partial rest ventilator settings (ie, respiratory rate and tidal volumes were reduced). Positive end-expiratory pressure was maintained or only mildly reduced to prevent oxygen desaturation during transportation. The goal oxygenation saturation was >94% before transfer to the authors' center. The arterial partial pressure of carbon dioxide was adjusted by the ECMO sweep gas flow rate to maintain normal pH (7.35-7.45). Mild-to-moderate respiratory acidosis was tolerated in an effort to reduce rapid changes in the arterial partial pressure of carbon dioxide because of concern for increased neurologic complications in patients on ECMO.[22,23] Two separate arterial blood gases were reviewed before transportation to adjust the ECMO sweep gas flow rate. The mobile ECMO team then oversaw the transport of the patient back to the authors' center.

ECMO Transfer Logistics

The authors' institution contracted with air and ground transportation services for ECMO transport. Before inception of the mobile ECMO team, high-fidelity mock ECMO transfers were conducted with the ambulance and air transport teams using actual transport vehicles (including helicopters). These mock scenarios included the authors' center-specific ECMO equipment and other patient support devices such as infusion pumps, chest tubes, intra-aortic balloon pumps, and Impella (Abiomed, Danvers, MA) heart pumps or other ventricular assist devices that may have been present. Equipment, personnel, physical space, lighting, and climate all were assessed. After each mock transfer, the involved teams debriefed and determined required modifications using a needs assessment tool. Multiple adjustments to personnel and equipment were made, and patient transportation guidelines were developed. All ECMO staff were trained in helipad safety. During the COVID-19 pandemic, training on PPE use and adherence during transportation were performed according to Centers for Disease Control and Prevention guidelines.[24] Annual ECMO training and competencies are required of all staff involved in ECMO transports.

Admission to ECMO Center

All patients who were admitted to the authors' institution underwent computerized tomography imaging of the head, chest, abdomen, and pelvis within 24 hours of admission. The head imaging was performed because of the increased risk of neurologic injuries in ARDS, ECMO, and, possibly, COVID-19.[23,25] The majority of mobile ECMO patients had no recent neurologic examination because of sedation and neuromuscular blockade administration before ECMO cannulation. In addition, some patients' conditions were too unstable for safe transport to radiology before ECMO. The mobile ECMO team gave direct sign-out to the pulmonary and critical care medicine, nursing, and perfusion teams who then assumed primary care of the patient in the authors' center's ICU.

Results

From April 2020 to January 2021, the mobile ECMO team was activated 22 times (Table 1 describes patient characteristics). Mobile ECMO was deployed to 13 different facilities in four southern California counties (Fig S2). The farthest transfer was approximately 136 miles (218.9 km) away. No patients were declined mobile ECMO as a result of resource limitations, such as equipment (ie, ECMO circuit), team, or ICU bed availability. There were two fixed-wing transfers, one helicopter transfer, and 19 ambulance transfers. No patient complications occurred during mobile ECMO transport. Transportation delays occurred three times, twice because of inexperience with ECMO transports with noncontracted ambulance teams and once because of an ambulance malfunction. No mobile ECMO team members had a symptomatic severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection or tested positive (nasal polymerase chain reaction testing) during asymptomatic screenings held regularly by the ECMO center.

During cannulation, one patient had a kinked guidewire but no other complications occurred, and ECMO safely was initiated . No in-house patients with COVID-19 ARDS who were placed on ECMO during the study period experienced cannulation complications. All mobile ECMO patients had a femoral drainage and right IJ return cannula. None of the patients required an alternative cannulation strategy. During the study period, two in-house patients required alternative ECMO cannula configurations from the authors' standard right femoral drainage and right IJ return sites. One patient had a femoral-femoral cannulation because of internal jugular stenosis. The other patient required a single-site, dual-lumen cannula (Avalon Elite Bi-Caval Dual-Lumen Catheter; Getinge) as a result of bilateral iliac vein occlusions.

Four patients previously had undiagnosed intracerebral hemorrhages found on head computed tomography at admission. Twenty-one patients had COVID-19 and one had e-cigarette or vaping product use–associated lung injury.[26] Eleven of the 21 (52.4%) patients with COVID-19 survived to hospital discharge. The patient with e-cigarette or vaping product use–associated lung injury also survived to hospital discharge. During the same period, 45.2% (14 of 31) of patients with COVID-19 cannulated in-house survived to hospital discharge.

Discussion

A mobile ECMO program was implemented successfully in southern California during the COVID-19 pandemic. Because the pandemic disproportionately affected the state of

Table 1
Patient Characteristics and Outcomes

Patient Characteristics	
Median age (IQR), y	48.5 (39-53.8)
Male sex, n (%)	17 (77.3)
Race, n (%)	
Asian	1 (4.5)
White	21 (95.5)
Hispanic or Latino, n (%)	19 (86.4)
Medical history	
Diabetes, n (%)	9 (41)
Asthma, n (%)	3 (13.6)
Obstructive sleep apnea, n (%)	1 (4.5)
Peripartum	1 (4.5)
Body mass index, mean ± SD	32.7 ± 5.5
SOFA score at ICU admission, mean ± SD	9.36 ± 3.2
Length of intubation pre-ECMO, median (IQR), d	4 (2-6.8)
Length of total intubation, median (IQR), d	23 (10-39)
Etiology of ARDS	
COVID-19, n (%)	21 (95.5)
EVALI, n (%)	1 (4.5)
Mobile ECMO farthest distance, miles (km)	131 (210.8)
Ambulance transfers, n (%)	19 (86.4)
Helicopter transfers, n (%)	1 (4.5)
Fix-wing transfers, n (%)	2 (9.1)
ECMO complications	
Digit or limb ischemia requiring amputation, n (%)	1 (4.5)
Renal replacement therapy, n (%)	8 (36.4)
Intracerebral hemorrhage or stroke, n (%)	5 (22.7)
Pneumothorax, n (%)	4 (18.2)
Bacterial pneumonia, n (%)	11 (50)
Required ECMO recannulation, n (%)*	1 (4.5)
Tracheostomy placement, n (%)	13 (59)
ECMO days, median (IQR)	17 (10-24)
Hospital length of stay, median (IQR), d†	23 (15-39)
COVID-19 survival to discharge, n (%)	11/21 (52.4)
Survival to discharge, n (%)‡	12/22 (54.5)

Abbreviations: ARDS, acute respiratory distress syndrome; COVID-19, coronavirus disease 2019; ECMO, extracorporeal membrane oxygenation; EVALI, e-cigarette or vaping product use–associated lung injury; ICU, intensive care unit; IQR, interquartile range; SD, standard deviation; SOFA, sequential organ failure assessment.

* Extracorporeal membrane oxygenation recannulation 96 hours after initial decannulation due to worsening acute respiratory distress syndrome.

† Length of stay at extracorporeal membrane oxygenation center.

‡ One patient with acute respiratory distress syndrome due to e-cigarette or vaping product use–associated lung injury.

California, the mobile team was essential to ensure equitable access to ECMO throughout the region during the COVID-19 surge.[27] Overall the mobile ECMO team treated 22 patients (21 with COVID-19 ARDS) in 13 facilities across four counties over ten months. The mobile ECMO survival rate (52.4% [11 of 21]) was similar to that for in-house cannulations (45.2% [14 of 31]) and the ELSO database (~50%) for patients with COVID-19.[28] No significant patient complications occurred during transportation, and there were no unprotected SARS-CoV-2 exposures or infections among the mobile ECMO team.

Multidisciplinary assessment for patient selection and mobile ECMO deployment is essential. Team decision-making for ECMO candidacy prevents the burden of decision on a single provider and may reduce the moral distress of triaging and allocating a limited resource for critically ill patients.[18] It further ensures that appropriate ECMO criteria are followed. Because of the COVID-19 pandemic, our ECMO criteria was shared with the other local ECMO centers (Southern California ECMO Consortium) to ensure there was equitable access to ECMO across our region.[34] Because the ECMO patient census was shared within the county, the authors' center never turned down a mobile ECMO as a result of equipment or ICU bed limitations. The criteria (see Table S2) prioritized maximal community benefit of ECMO during the pandemic. ECMO mortality and complications increase with age; however, the authors' center's ECMO criteria did not have a specified age cutoff because of concerns for ageism, although ELSO criteria include aged >65 years as a relative contraindication.[16,19,29] Similar to other regional ECMO centers, ECMO rarely was offered to a patient with COVID-19 older than 65. Finally, multidisciplinary decisions on candidacy helped establish buy-in and commitment from the CT surgery and intensivist teams, who provided long-term care for these patients at the authors' institution.

To minimize complications and cannulation time, it is essential that the mobile team is trained together and is composed of physicians and specialists who have extensive experience in ECMO cannulation and management.[30] Mobile ECMO team members vary across centers, usually based on local expertise. These teams may include CT surgeons, intensivists (pulmonary or anesthesia), interventional cardiologists, and emergency medicine physicians who perform the cannulation with an assisting ECMO specialist or perfusionist.[31] Because of the relatively low number of mobile ECMO activations, the specialty makeup likely is not as important as physician ECMO experience. Because the mobile ECMO team formed out of necessity during the COVID-19 pandemic, the authors' cannulating team intentionally remained small to limit practice variation and to limit team member exposure to SARS-CoV-2. In order to streamline processes and troubleshoot unforeseen issues, the authors initially did not use their existing ECMO call structure. However, the mobile program now is being expanded to use the standard on-call ECMO team members.

The authors' center's ECMO program had been in existence for more than a decade but was restructured and more formalized in 2017. Because it was an established program, no new service line was created to start the mobile ECMO team. The team does not accrue any additional cost to the institution. The cost for all ECMO supplies and transportation and perfusion personnel is billed to the patient (or insurance). The authors recognize that maintaining a robust mobile ECMO program inevitably requires more team members and institutional compensation of team members' time and efforts.

During the study period, there were no significant complications with cannulations, all of which were performed in the patient's ICU room. Previous mobile ECMO reports have had complications in up to 21% of cannulations, with the majority performed in operating rooms in some countries.[13] One common complication during cannulation was guidewire kinking,

occurring once in the present cohort; thus, the authors used an Amplatz super-stiff wire (see Table S4) to prevent this complication. During the study period, no complications occurred during in-house ECMO cannulations. However, two in-house patients required an alternative cannulation configuration from the authors' standard IJ/femoral sites as a result of venous stenosis. Thus, all mobile ECMOs were equipped to perform a femoral-femoral cannulation if necessary.

There were multiple unique aspects to mobile ECMO during the COVID-19 pandemic. As discussed in the Methods section, training and bringing familiar PPE is essential. Furthermore, the number of nonmobile ECMO team members in the room was minimized to reduce exposure to SARS-CoV-2. Many of the referring facilities had a high census of patients with COVID-19, requiring higher patient ratios with locums or alternative ICU nurse staffing. Thus, the mobile ECMO team assumed full care of the patient upon arrival, highlighting the advantages of a critical care nurse or physician as a part of the team. Furthermore, because of the pandemic surge, some of the ECMO cannulations occurred in small overflow ICUs. All cannulations were performed at the bedside because of potential patient instability with movement and to limit unnecessary patient transports that would increase the risk of SARS-CoV-2 exposure to healthcare staff. The mobile ECMO team requested supination (if in prone position) of the patient after arrival to minimize potential desaturation episodes. For patients with unstable conditions during supination previously, the team prepared the room and equipment (eg, sterile table, opened all supplies, ultrasound) for ECMO cannulation and central venous access. Arterial catheterizations (if necessary) occurred in the radial artery with the patient in the prone position.

Ensuring an appropriate neurologic examination before cannulation is essential. However, a neurologic examination was limited because of deep sedation and/or neuromuscular blockade, and most patients were unable to supinate long enough to undergo computed tomography imaging before ECMO support. The ECMO team found four previously undiagnosed intracerebral hemorrhages upon arrival to its ECMO center (two of these patients transitioned to comfort care and died within 24 hours of admission). Many patients with COVID-19 had been treated with empirical therapeutic anticoagulation before ECMO, which may have contributed to this. Therefore, the heparin bolus was decreased during cannulation in patients with COVID-19, from 70-to-80 U/kg to 40-to-50 U/kg. Anticoagulation of patients with COVID-19 is beyond the scope of this article but is under active investigation.[32]

After transfer, the mobile ECMO team debriefed and discussed quality improvement measures and patient safety issues. Long-term sustainability of a mobile ECMO team requires consistent team training to maximize efficiency and patient safety and a dedicated call schedule with multiple committed members to minimize burnout. The ECMO transports, similar to previous reports, were safe and well-tolerated.[33] Each center should determine the appropriate transportation modality based on travel time, personnel capacity, and equipment considerations. The authors of the present review found that helicopter transfers may save minimal-to-no time compared with ambulance transfers if the center is fewer than 100 minutes (accounting for local traffic patterns) via ambulance from the authors' center. The ELSO transport guidelines for ECMO patients highlight many transportation issues that may be encountered (see Table S3).[20] Ultimately, ECMO experience varies among medical transportation teams, highlighting the importance of training.

Conclusions

Herein, the authors have described their experience and outcomes in the first ten months of developing and deploying a mobile ECMO team during the COVID-19 pandemic. The authors' hope is that their experience may help other centers establish their own mobile ECMO team.

Acknowledgments

The authors thank the extracorporeal membrane oxygenation team at their institution, which includes physicians, advanced practice nurses, intensive care unit nurses, perfusionists, nurse- extracorporeal membrane oxygenation specialists, pharmacists, respiratory therapists, social workers, palliative care providers, and physical and occupational therapists. Special thanks to Rance Duyan and South Coast Perfusion.

Conflict of Interest

The following two funding sources had no involvement in this study: M. Odish currently is receiving a grant (T32GM121318) from the National Institute of General Medical Sciences, National Institutes of Health and R. Owens currently is receiving a grant (R01HL142114) from the National Heart, Lung, and Blood Institute, National Institutes of Health.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2021.05.047.

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