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Evolution of the United States Military Extracorporeal Membrane Oxygenation Transport Team

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ABSTRACT

Introduction

The use of extracorporeal membrane oxygenation (ECMO) for the care of critically ill adult patients has increased over the past decade. It has been utilized in more austere locations, to include combat wounded. The U.S. military established the Acute Lung Rescue Team in 2005 to transport and care for patients unable to be managed by standard medical evacuation resources. In 2012, the U.S. military expanded upon this capacity, establishing an ECMO program at Brooke Army Medical Center. To maintain currency, the program treats both military and civilian patients.

Materials and methods

We conducted a single-center retrospective review of all patients transported by the sole U.S. military ECMO program from September 2012 to December 2019. We analyzed basic demographic data, ECMO indication, transport distance range, survival to decannulation and discharge, and programmatic growth.

Results

The U.S. military ECMO team conducted 110 ECMO transports. Of these, 88 patients (80%) were transported to our facility and 81 (73.6%) were cannulated for ECMO by our team prior to transport. The primary indication for ECMO was respiratory failure (76%). The range of transport distance was 6.5 to 8,451 miles (median air transport distance = 1,328 miles, median ground transport distance = 16 miles). In patients who were cannulated remotely, survival to decannulation was 76% and survival to discharge was 73.3%.

Conclusions

Utilization of the U.S. military ECMO team has increased exponentially since January 2017. With an increased tempo of transport operations and distance of critical care transport, survival to decannulation and discharge rates exceed national benchmarks as described in ELSO published data. The ability to cannulate patients in remote locations and provide critical care transport to a military medical treatment facility has allowed the U.S. military to maintain readiness of a critical medical asset.

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is a form of extracorporeal life support (ECLS) that can provide cardiac, pulmonary, or combined cardiopulmonary support.[1, 2] ECMO is commonly used as rescue therapy in patients with pulmonary failure, to include severe acute respiratory distress syndrome (ARDS), cardiopulmonary failure, or a myriad of other etiologies.[3–5] Because of the logistical, technical, and

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resource utilization challenges of performing ECMO, only 820 specialized centers provide this therapy.[6]

ECMO referral centers in the U.S. are often arranged in a hub and spoke model.[7] Patients who meet criteria for ECMO are often in an unstable clinical condition supported by many intensive care therapies to include maximal inotropic and vasopressor infusions and maximal mechanical ventilation (MV) settings, all of which are known to exacerbate their condition and lead to increased morbidity and mortality. Many of these patients are often at small, remote hospitals, without tertiary care intensive care capabilities. As a result, they are often referred to higher level medical centers.

The first ECMO cannulation of a patient at a referring hospital and transport of the patient on ECMO was described by Bartlett in 1977.[8] Cornish further developed the concept of traveling to a referring hospital with a portable ECMO system, performing the cannulation at the referring hospital, and then transporting the patient back to their own institution while on ECMO.[9] A 22-year pediatric global ECMO transport experience has also been described.[10] However, a real spike in the number of adult ECMO cases and utilization came after the H1N1 pandemic, which exposed the need for ECMO as an immediate rescue therapy in severe ARDS. [7, 11]

The U.S. military established the Acute Lung Rescue Team (ALRT) in 2005 to transport and care for patients unable to be managed by standard critical care therapies.[12] In 2012, the U.S. military expanded this team to include ECMO capabilities. The U.S. military has further developed this capability to effectively and safely perform patient transports on ECMO from austere and far-forward locations in combat environments.[13, 14]

Current literature describes high-volume center reviews on ECMO transports to include indications and outcomes. The University of Michigan recently reported on their experience from the transport of 221 patients on ECMO between 1990 and 2012.[13] Columbia University[14] and the Karolinksa University Hospital in Stockholm performed reviews as well.[15] The follow-up study from the Karolinska Hospital published in 2019 included over 900 ECMO transports.[16] From 2005 to 2011, the ALRT launched 27 times and evacuated 24 patients from combat zones to Germany.[17] Between 2005 and 2011, and in partnership with civilian University Hospital Regensburg, Germany, overseas U.S. military physicians used ECMO to treat 10 combat casualties with a 90% survival.[14] Current evidence demonstrates that ECMO transport is safe without any relative increase in mortality and complications,[9, 12] with the majority of ECMO transports in the civilian population involving non-trauma patients.

There is growing interest in exploring the combat casualty care potential of military ECMO in trauma patients. As a reflection of this focus, there is a significant increase in preclinical research on various forms of minimally invasive dialysis-like ECLS solutions for combat casualty care and a formal Department of Defense (DoD) Program of Record. The ECLS Capability Area was established to develop and implement novel ECLS-based solutions for combat casualties.[6, 18–20] This research focus is closely aligned and integrated with the clinical U.S. military ECMO program and Center of Excellence at the San Antonio Military Medical Center (SAMMC). In order to maintain currency, the program treats both military beneficiaries and civilian patients referred from the community. The development of this program involved dedicating resources from our Emergency Medical Services, developing an ECMO cannulation and management allowance standard to take on each transport, creating checklists for the acceptance and movement of the patients (Appendix 1 for local ground transport, Appendix 2 for air transport, Appendix 3 for referral form), and establishing emergency credentialing processes for providers. While ECMO transport has been well described as a rescue therapy in civilian trauma patients and case reports from the military medicine literature, to date there has been no comprehensive review of patients who underwent ECMO transport by the U.S. military ECMO center personnel.[14, 15, 21] Thus, we examined all adult ECMO patients transported by the DOD ECMO Center supported by Brooke Army Medical Center (BAMC), the U.S. Army Institute for Surgical Research (USAISR) Burn Center, and 59th Medical Wing (MDW) between January 1, 2012 and December 31, 2019 and described their characteristics and outcomes.

MATERIALS AND METHODS

After we obtained BAMC IRB approval of a protocol for the retrospective study of all previously managed ECMO patients as well as prospective enrollment of patients, which includes informed consent, we conducted a single-center review of all patients transported by the DoD ECMO program from September 2012 to December 31, 2019. Demographic and injury characteristics were analyzed including year of ECMO use, age, gender, ECMO indication, and transport distance range. Outcome variables included survival to decannulation, and survival to discharge. In Table I, statistical analysis was employed to compare the complication rates of ground versus air transport. A two-sample comparison of means t-test was done to calculate p values.

RESULTS

From 2012 to 2019, the U.S. military ECMO program transported 110 patients including transfer between outside facilities, cannulation and transfer to our facility, and transfer from our facility to another ECMO facility for organ transplantation or advanced heart failure care. Demographics are described in Table II. Overall, 80% of the total transports were from a referring facility to our hospital. The remaining 20% transports were transfers from our facility for lung transplantation (6 patients) or advanced heart failure care (5 patients), or were planned transports between two outside hospitals (11 patients). ECMO was initiated by our team at referring hospital for many transports (73.6%). The most

TABLE I. Patient Outcomes: Complications

	Local Transport ($n = 63$)	Distant Transport ($n = 34$)	P value
Complications			
Access Site*	6 (9.5%)	4 (11.8%)	0.592
Acute Renal Failure	32 (50.8%)	10 (29.4%)	<0.0001
Intermittent Hemodialysis	8 (12.7%)	1 (2.9%)	0.063
Skin and Soft Tissue Infection	6 (9.5%)	1 (2.9%)	0.1823
Survival to Decannulation	50 (79.4%)	25 (73.5%)	<0.0001
Survival to Discharge	44 (69.8%)	22 (64.7%)	<0.0001

*includes deep venous thrombosis (DVT), hematoma, infection, pseudoaneurysm, and limb ischemia.

TABLE II. Patient Demographics

	Total ($n = 97$)*
Age (mean in years	42.7 (19-68)
Male gender	67 (69%)
Mode	
Veno-venous (VV)	79 (81%)
Veno-arterial (VA)	12 (12%)
Veno-arterial-venous (VAV)	7 (7%)
Duration of cannulation (average days)	19 (1-94)

*97/110 had complete data in the registry.

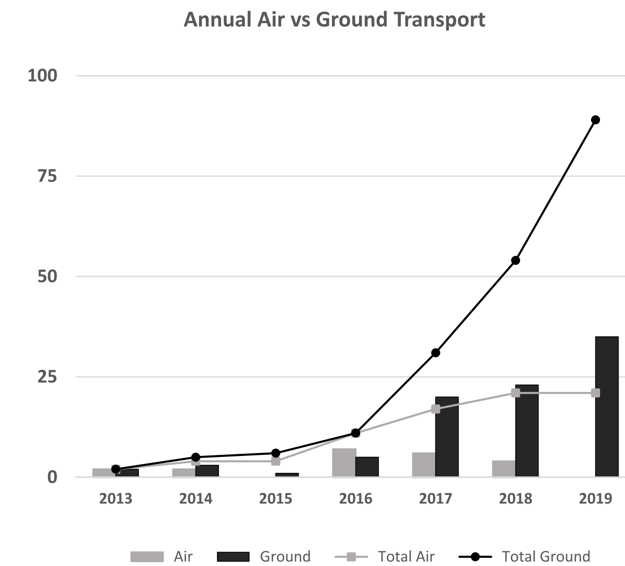

FIGURE 1. Types of U.S. military ECMO program transports from 2012 to 2019 by year.

common indication for ECMO transport was acute respiratory failure (76.9%), followed by cardiogenic shock (9.6%), bridge to lung transplantation (7.7%), and post-cardiotomy shock (5.8%). Trauma was a factor in 7.1% of all patients. Of all transports, 81% of patients required veno-venous (VV) ECMO and 12% required veno-arterial (VA) ECMO, and 7% required veno-venous-arterial (VAV) ECMO. Fifty percent of VA cannulations were central with open chests for failure to come off cardiopulmonary bypass. The remainder of VA cannulations were femoral-femoral configuration. Sixty-one percent of VV configurations were femoral-femoral, while 27% were femoral-internal jugular, and 6% were via a dual lumen single cannula in the internal jugular. 50% of the VAV configurations were femoral-femoral-internal jugular which the others were femoral-femoral-femoral.

Transport distance ranged from 6.5 to 8,451 miles (median air transport distance = 1,328 miles, median ground transport distance = 16 miles). Fourteen transports were over 850 miles and performed by fixed wing air transport.

In patients who were cannulated by our team remotely, overall survival to decannulation was 76% and survival to discharge was 73.3% (Fig. 1). Program growth has been rapid, with 80% of all transports being performed in the last 2 years of analysis (Figs 1 and 2). Outcomes based upon local versus long distance (regional to international) transport are described in Table I demonstrating similar complications and survival rates despite some statistically significant differences. Acute kidney injury [22] was significantly higher in local transports.

DISCUSSION

We examined all the patients transported by the sole U.S. military ECMO program and sought to describe the indications, characteristics, and outcomes of such patients. The U.S. Air Force's 59th MDW, BAMC, and the USAISR Burn Center jointly operate the only ECMO program in the DoD. Our program has two distinctive missions: transport and inpatient care. The inpatient program treats approximately 40 patients per year while the associated transport program conducts approximately 30 transports per year. There is also a strong training and readiness component to the DoD ECMO program. Deployment of ECMO in the adult patient with refractory respiratory and/or cardiac failure, as well as transport of the patient, maintains currency for both inpatient and enroute critical care capabilities. The use of ECMO in patients with burns or trauma has been successful and further increases readiness for use in the combat-injured polytrauma patient in war.

In our analysis, the most common indication for ECMO was severe ARDS (57%). The median air transport distance was 1,328 miles; the median ground transport distance was

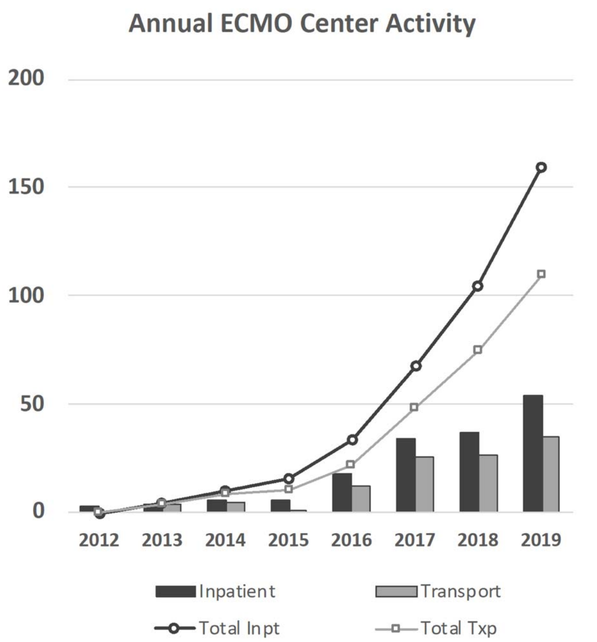

FIGURE 2. Use of U.S. military ECMO program from 2013 to 2019; ECMO inpatient and transport volume by year.

16 miles. Survival to decannulation in patients cannulated by the military ECMO team was 76%, while survival to hospital discharge was 73.3%. Eighty percent of transports occurred in the last 24 months, which the study analyzed.

Like our center, ECMO use has increased in other high-volume centers as an important rescue therapy for refractory ARDS and respiratory failure.[1, 23, 24] ECLS enables a reduction in ventilator settings and has the potential in reducing dependence on mechanical ventilation.[25] ECLS can also improve venous return.[26–28] Due to inherent challenges and the complexity of ECMO, it is thought that higher volume centers have better outcomes. It stands to reason that a retrieval or transport system to consolidate ECMO cases at high-volume centers leads to consolidation of expertise with the requisite tertiary care level consultant services available.[29] Furthermore, ECMO transport is inherently complex and potentially risky. The CESAR trial reported three deaths prior to and two deaths during transport[21] which highlights the need to cannulate at the referring facility and before transporting. Current evidence shows no published data to support the minimum transport numbers a mobile ECMO team should perform to maintain currency.[30] The International ECMO Network developed a consensus statement, which proposed 20 cases on an annual basis as a requirement for competency in an ECMO center of excellence.[29, 31] Because mobile ECMO teams who perform more transports have greater survival rates[32], 20 cases on an annual basis could be the lower end of the spectrum for maintenance of currency. Furthermore, data from the ELSO registry showed that ECMO centers who did more than 30 annual adult ECMO inpatient cases had a significantly lower ECMO mortality than centers who had fewer than 6 cases per year.[10, 33]

Current evidence from a retrospective study of 908 transports out of Stockholm showed a severe complication occurred in 20% of transports and was significantly associated with VA ECMO and fixed-wing transport but were not associated with increased mortality.[15] The University of Michigan studied the ECMO transport of 221 patients over two decades. Of these, 135 (62%) survived to discharge.[13] Review of an additional 27 case series describing ECMO transports of 643 patients showed an overall survival of 61%.[13] After adjusting for age and primary indication for ECMO, survival of transported adult patients was not significantly different compared with all ECMO patients in the international Extracorporeal Life Support Organization (ELSO) registry.[13] Biscotti et al. studied 100 ECMO patients transported by Columbia University where the median transport distance was 16 miles and ranged from 2.5 to 7,084 miles. Of the 100 patients, 81 survived to decannulation, 71 survived to 30 days, and 63 survived to hospital discharge. Of the patients with respiratory failure, 66 (82.5%) survived to decannulation, 59 (73.8%) survived to 30 days, and 54 (67.5%) survived to hospital discharge[14] Investigators at Duke University reviewed 133 ECMO transports where the median transport distance was 88.8 miles (range 0.2–1,434 miles). Survival to decannulation was 66.2% and 76.8%, and to hospital discharge it was 48.1% and 69.6% for VA and VV ECMO, respectively.[34] All current evidence demonstrates the safety and efficacy of ECMO transport without differences in mortality or complications. Our ECMO transport data described here are consistent with this as we demonstrated a low complication and high survival rate among our cohort. While there was a statistically significant difference in survival in the local transports, we feel that this was not clinically significant. Long distance transports involve longer duration of high setting mechanical ventilation as well as time for ECMO team to arrive depending on location can be over 24 hours. Despite these complexities, the survival rate is still well above 70%. The complication of AKI is significantly higher in the local transports. This may be related to careful consideration of multiple organ system failure when accepting the mission to transport these patients. We are currently analyzing indications and use of renal replacement therapy and doing a deeper dive into our AKI cohort to better delineate contributing factors and outcomes. This will better inform whether this organ dysfunction should be considered when evaluating patients for long-distance transports. It is important to note that renal replacement therapy for volume management and AKI is observed in roughly 50% of our inpatient ECMO patient population. There are several limitations to our study. First, it is a retrospective study, thus several prehospital data points were not collected and available at time of analysis. Furthermore, like the previously cited ECMO studies, our study did not compare or match the ECMO patients with in-hospital ECMO patients or other ECMO patients in the ELSO registry. Such a comparison would have been helpful to truly evaluate the survival benefits and complication risks of doing ECMO transport in a military system. Lastly, further analysis needs to be done on the sub-populations of patients who were transported from deployed and combat theater setting, allowing delineation of the role of ECMO in combat.

Based on our findings, numerous case reports, and retrospective studies, future efforts should assess comparative outcomes in larger prospective observational studies of ECMO transport within the military system. Recent studies of the U.S. military's critical care services show the importance of comprehensive reviews of the entire enterprise to better understand resources, outcomes, and unique aspects of the military, such as possible combat casualty care applications.[35,36]

CONCLUSIONS

Utilization of the U.S. military ECMO team has increased rapidly over the past few years. The collaboration between the U.S. Air Force 59th MDW, BAMC, and the USAISR facilitated further development of our transport program to contribute to our inpatient mission. With an increased tempo of transport operations and distance of critical care transport, survival to decannulation and discharge rates remain robust and complications and mortality rates are low. Our experience with a robust inpatient physical therapy program contributes to our overall $> 30\%$ discharge to home rate as patients are mobilized and ambulated regardless of cannulation configuration. The ability to cannulate patients in remote locations and provide critical care transport to a military medical treatment facility has allowed the U.S. military to maintain readiness of a critical medical asset, in preparation for the next major conflict.

SUPPLEMENTARY MATERIAL

Supplementary Material is available at *MILMED* online.

AUTHOR CONTRIBUTIONS

MR, JN, MB, LP, ST, VS, BE, and KG all assisted in compiling, analyzing, and interpreting patient data. Additionally, they wrote and revised the manuscript. JN, LP, BE, KN, and ST assisted in the compilation of the patient database. MR, MB, VS, JL, JD, AB, JC, and PM offered project oversight and assisted in concept proposal and manuscript revision. All authors read and approved the final manuscript.

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