The Use of Extracorporeal Membrane Oxygenation in Severely Burned Patients: A Survey of North American Burn Centers

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Respiratory failure and acute respiratory distress syndrome can occur in burn patients with or without inhalational injury and can significantly increase mortality. For patients with severe respiratory failure who fail conventional therapy with mechanical ventilation, the use of venovenous extracorporeal membrane oxygenation (ECMO) may be a life-saving salvage therapy. There have been a series of case reports detailing the use of ECMO in burn patients over the last 20 years, but very little is currently known about the status of ECMO use at burn centers in North America. Using a web-based survey of burn center directors in Canada and the United States, we examined the rate of usage of ECMO in burn care, barriers to its use, and the perioperative management of burn patients receiving ECMO therapy. Our findings indicate that approximately half of the burn centers have used ECMO in the care of burn patients, but patient volume is very low on average (less than 1 per year). Of centers that do use ECMO in burn care, only 40% have a specified protocol for doing so. Approximately half have operated on patients being actively treated with ECMO therapy, but perioperative management of anticoagulation varies widely. A lack of experience and institutional support and a perceived lack of evidence to support ECMO use in burn patients were the most commonly identified barriers to more widespread uptake. Better collaboration between burn centers will allow for the creation of consensus statements and protocols to improve outcomes for burn patients who require ECMO.

Pulmonary injuries in burn patients present with highly variable pathophysiology but can represent a serious insult in addition to skin injury. More than 30 years ago, Shirani et al[1] suggested pulmonary injuries have an additive effect on mortality in patients with burns and demonstrated a 40% increase in mortality with concomitant pneumonia. Furthermore, Williams et al[2] reported that between 1989 and 2009, respiratory failure was responsible for 29% of deaths in patients at a major pediatric burn center. It has been estimated that approximately 40% of burn patients who require mechanical ventilation will develop Acute Respiratory Distress Syndrome (ARDS). The mortality rate associated with this complication is 40% when no comorbidities are present and can reach as high as 50% in patients with severe burns.[3] ARDS can be caused by the burn trauma itself (eg, smoke inhalation or inflammation secondary to the burn) or can result from excessive fluid resuscitation, ventilator-associated pneumonia, ventilator-associated lung injury, and other causes. Classically, refractory hypoxemia due to ARDS has been managed with supportive care including protective low tidal volume ventilation, deep sedation, neuromuscular blockage, advanced ventilator modes, and prone positioning.[4]

Extracorporeal membrane oxygenation (ECMO) is a form of extracorporeal life support that can provide respiratory support (venovenous configuration) or cardiac support (venoarterial configuration) for patients with respiratory or cardiopulmonary failure.[5] The first report of its successful use was in a young male with posttraumatic lung injury in 1972.[6] Initially, a high mortality rate in adults led to skepticism of its role in the treatment of respiratory failure, but it quickly became the standard of care for respiratory distress syndrome in neonates and the pediatric population. Advances in both ECMO technologies and its delivery have made it significantly safer, as highlighted during the H1N1 epidemic of 2008 when ECMO use resulted in the survival of patients who had failed conventional therapies.[7] In 2009, the CESAR trial demonstrated that ECMO use in adults with ARDS improved 6-month survival to 63%, as compared to 47% in those treated with standard therapies.[8] As a result, ECMO has become more widely used as a treatment in the management of influenza-related ARDS and, less commonly, respiratory failure in trauma and shock patients.

The role of ECMO in the care of burn patients has not been well elucidated. The first reported successful use of ECMO in a burn patient with ARDS occurred in 1998, in a 26-year old with respiratory failure secondary to inhalation burns.[9] Since that time, there have been a number of case reports and case series documenting varying levels of

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success in the treatment of burn patients with severe respiratory failure.[9–13] One of the major concerns with using ECMO in burn patients that may have limited its adoption thus far has been the risk of bleeding, especially in those requiring operative intervention. The Extracorporeal Life Support Organization (ELSO) recommends the use of an antithrombotic agent during ECMO treatment, as clotting within the ECMO circuit is possible due to the large surface area required, turbulent flow, and contact with nonendothelial material like the filter membrane.[14] Anticoagulation therapy in conjunction with numerous skin grafts in a severely burned patient leads to a common clinical scenario described by Ainsworth et al,[15] when anticoagulation efforts can create a challenging state in which there is both not enough anticoagulation to prevent clot formation in the ECMO membrane oxygenator, but also enough anticoagulation to cause bleeding from the burn wound or oozing from vascular or tracheostomy tube insertion sites.

While the use of ECMO in patients with severe ARDS has increased over the last two decades, very little data exist to describe how often and in what context it is being used in the burn population. Therefore, the main objective of this study was to quantify the actual use of ECMO in adult patients with severe burns in North American burn units. The existing literature shows that ECMO is a viable treatment option for ARDS in burn patients. We hypothesized that burn care practitioners may be reluctant to use it due to a perceived lack of evidence that supports its use, unfamiliarity with its application, and worries about safety. As such, our secondary objective was to identify factors that influence the decision of burn care providers on whether or not to use ECMO in the care of their patients. We also hypothesized that the use of anticoagulation therapy in severe, perioperative burn patients would be the main concern identified regarding the use of ECMO in this patient population.

METHODS

Study Design

A survey of burn unit directors at registered burn centers in the United States and Canada was designed and distributed using the secure Research Electronic Data Capture (REDCap) web platform.[16] American burn centers were identified from a database of hospitals registered with the American Burn Association (ABA). Canadian burn centers included all institutions with at least one dedicated burn surgeon belonging to the Canadian Burn Association (CBA). These professional associations were selected since they represent the majority of burn care centers in North America. Any centers that did not treat adult burn patients were excluded from the survey. Ethical approval for this study was obtained from the research ethics boards of Dalhousie University and Nova Scotia Health.

Survey questions were created by the study team based on their experience using ECMO in burn patients.[13] The initial survey instrument was tested by a number of intensivists and researchers at the author's institution and was revised based on their feedback. A copy of the final survey instrument is available as Supplementary Material 1. Contact information for burn unit directors was obtained from the ABA member's portal[17] and via the CBA. An email invitation to participate in the survey was sent to burn unit directors in fall 2020, followed by two reminders in the following weeks. This email reviewed the background and purpose of the study and contained a link to the web-based survey. The survey opened with an electronic consent form that had to be completed before proceeding to data collection and included built-in logic to identify any centers that only treated pediatric burn patients. A combination of multiple-choice and open-ended questions was employed, and responses were tracked using the built-in cloud data collection feature of REDCap. Data collection lasted approximately 6 weeks, and all data were de-identified before analysis.

Study Outcomes

The primary outcome measure was the current use of ECMO at burn centers for the treatment of severely burned adult patients with ARDS or respiratory failure. Secondary outcomes were burn center directors who responded "yes" to ECMO use in this patient population were then directed to further questions regarding ECMO use at their institution. Follow-up questions involved the frequency of ECMO use, indications for use (open-ended), use of dedicated teams/protocols, and use of anticoagulants. If a center answered "yes" to the use of anticoagulants, they were directed to additional questions regarding the specific agent used (open-ended), titration methods used (open-ended), and whether surgery would be considered for a patient on anticoagulation. Directors who responded "no" to ECMO use in adult severe burn patients with ARDS or respiratory failure were asked if they would consider using ECMO to treat these patients if it were available at their institution. Participants who answered "yes" were then asked to identify any perceived barriers to the use of ECMO at their institution, while participants who responded "no" were asked to provide reasons for not using ECMO.

Statistical Analysis

Descriptive statistics including frequencies and proportions were used to analyze the data. We grouped burn centers as academic or community centers. The answers to the open-ended questions were analyzed thematically with a grouping of similar answers. The remaining data were aggregated and presented using descriptive methods. All analyses were performed using Microsoft Excel.

RESULTS

According to the ABA and CBA registries, there were 139 burn centers in the United States and 7 in Canada at the time of survey administration (Figure 1). Of these, 13 centers exclusively treated pediatric patients and were excluded from the study. The survey was sent to burn center directors at the remaining 133 centers. Responses were received from 43 burn center directors (response rate of 32%). Four of these respondents indicated their center did not treat adult burn patients and were excluded, leaving a total of 39 burn centers for analysis (30 academic centers and 9 community centers).

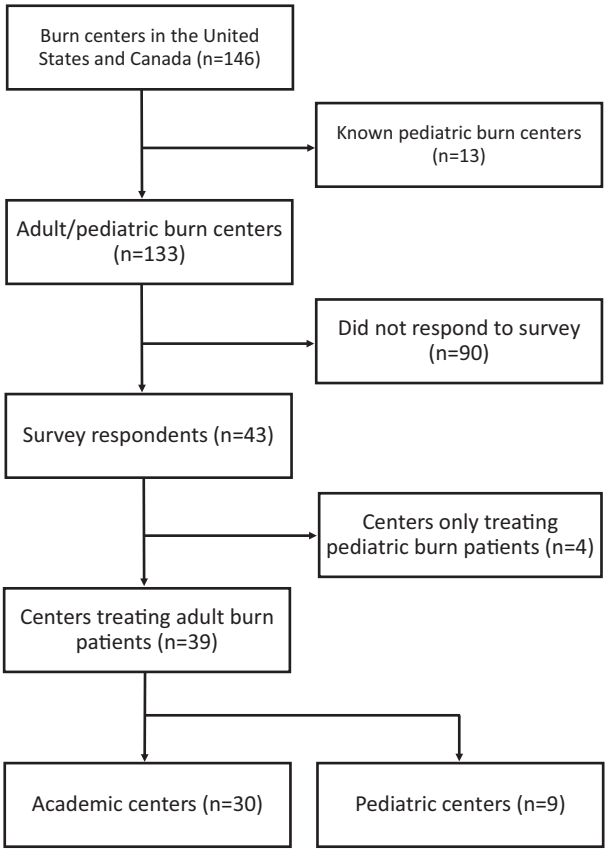

Figure 1. North American burn center inclusion in the survey process.

Table 1 displays the characteristics of burn centers included in the study. The majority of centers treated both adult and pediatric burn patients (66.7%; 26/39); the remaining 13 centers treated adult burn patients exclusively. Institutions with burn centers (79.5%) reported using ECMO in some capacity (eg, intensive care unit, trauma), with a similar proportion for academic centers (80.0%) and community centers (77.8%). Of the 31 centers using ECMO, 64.5% used ECMO to manage severe burn patients with ARDS or respiratory failure. This included 17 academic centers and 3 community centers. Among the eight centers not using ECMO in any capacity, 87.5% of directors indicated they would consider using ECMO for ARDS or respiratory failure if it were available, while 12.5% responded they were uncertain.

Characteristics of centers that used ECMO in severe burn patients are given in Table 2. Directors reported infrequent use of EMCO in burn patients, with 50% using it less than once per year and 30% using ECMO in approximately one burn patient per year. There were three respondents who used ECMO in two to three burn cases per year and one center used it in four to five burn cases per year. No participants used ECMO in more than five burn patients per year. Of note, the center with the highest number of burn cases involving ECMO was a community center. A majority of respondents using ECMO in burn patients (13/20) had a dedicated team for ECMO, with a similar distribution between academic (64.7%) and community centers (66.7%). Specific protocols for the use of ECMO in severe burns were reported at 40% of centers. Only 30% of centers had both a dedicated ECMO team and specific protocols in place.

Table 1. Characteristics of burn centers included in survey

Characteristic	Academic Centers (n = 30)	Community Centers (n = 9)	Overall (n = 39)
Patient population			
Adults/pediatrics	19 (63.4%)	7 (77.7%)	26 (66.7%)
Adult	11 (36.6%)	2 (22.3%)	13 (33.3%)
ECMO use in any capacity	24 (80.0%)	7 (77.8%)	31 (79.5%)
ECMO use in burn patients with ARDS or respiratory failure	17 (56.7%)	3 (33.3%)	20 (51.3%)

ECMO, extracorporeal membrane oxygenation; *ARDS*, acute respiratory distress syndrome.
Data are reported as n (%).

Table 2. Characteristics of centers using ECMO in burn patients with respiratory failure

Characteristic	Academic Centers (n = 17)	Community Centers (n = 3)	Overall (n = 20)
Number of cases per year			
<1	9 (52.9)	1 (33.3)	10 (50.0)
1	5 (29.5)	1 (33.3)	6 (30.0)
2–3	3 (17.6)	0 (0.00)	3 (15.0)
4–5	0 (0.00)	1 (33.3)	1 (5.0)
Dedicated ECMO team	11 (64.7)	2 (66.7)	13 (65.0)
Protocols for use of ECMO in burn patients	7 (41.1)	1 (33.3)	8 (40.0)
Use of therapeutic anticoagulants during ECMO	13 (76.5)	2 (66.7)	15 (75.0)

ECMO, extracorporeal membrane oxygenation; *ARDS*, acute respiratory distress syndrome.
Data are reported as n (%).

Table 3. Perceived barriers to using ECMO in burn patients at centers where ECMO was available or unavailable

Barrier	ECMO Available, Not Used in Burn Patients (n = 11)	ECMO Unavailable, Would Use in Burn Patients (n = 7)
Lack of burn care team expertise caring for ECMO patients (nursing staff, respiratory therapists, etc.)	5 (45.5)	7 (100.0)
Lack of physician/surgeon expertise caring for ECMO patients	2 (18.2)	7 (100.0)
Lack of institutional support	4 (36.4)	5 (71.4)
Insufficient evidence to support its efficacy/safety in burn care	4 (36.4)	4 (57.1)
Financial concerns	2 (18.2)	5 (71.4)
Lack of access to required equipment	2 (18.2)	5 (71.4)
Safety concerns regarding perioperative bleeding (major bleeding during/after wound debridement or grafting)	1 (9.1)	5 (71.4)
Safety concerns regarding non-perioperative bleeding (IV cannula site bleeding, need for therapeutic anticoagulation, bleeding during dressing changes, etc.)	0 (0.0)	3 (42.9)
Other	6 (54.5)	0 (0.0)

ECMO, extracorporeal membrane oxygenation.
Data are reported as n (%).

The use of therapeutic anticoagulants was reported by 15 of 20 centers using ECMO in burn patients. Among these 15 centers, 12 reported using some form of heparin for anticoagulation, 1 reported using a mix of heparin and argatroban, and 2 reported that they follow the recommendations of their local ECMO team. For titration of anticoagulants, most centers followed the patients' partial thromboplastin time (PTT) (40.0%), while four centers (26.7%) used the activated clotting time. The remaining centers used a combination of tests. Of the 15 centers using anticoagulation in severe burn patients on ECMO, 7 had operated on patients actively being treated with ECMO, 6 (40%) reported that they defer surgery while on ECMO, and 2 were unsure. At those centers that do operate on patients receiving anticoagulation while on ECMO therapy, there was a wide range of protocols regarding how long to hold anticoagulation preoperatively, ranging from not stopping the anticoagulant at all perioperatively to holding it for 4 hours.

Table 3 reports perceived barriers to ECMO use in burn patients at institutions where ECMO was available, as well as perceived barriers to using ECMO in burn patients at centers where ECMO was not available. Among the 11 centers where ECMO was available but not used for burn care, the two leading barriers identified were lack of burn care team expertise caring for ECMO patients (45.5%) and lack of patient volume (45.5%), followed closely by a lack of institutional support (36.4%). Interestingly, safety concerns around perioperative bleeding were only selected by one director. Of note, none of the directors selected concerns around non-perioperative bleeding (cannula site bleeding, intracerebral hemorrhage, etc.). About 64% of directors indicated they would consider ECMO if there was a more robust body of literature supporting its use in burn patients. Among the seven centers that did not have institutional access to ECMO but whose directors indicated they would use it for burn care if available, all responded that a lack of expertise among the burn care team and the physicians/surgeons was a barrier to using ECMO in burn patients. Lack of financial or institutional support, lack of access to equipment, and lack of evidence were also commonly cited barriers to ECMO use in severely injured burn patients.

DISCUSSION

Among the respondents to our survey, the use of ECMO in institutions with a burn center was high (79%). Since burn centers provide highly specialized care, it is not a surprise to find them co-located at centers that also provide complex therapy like ECMO. Institutional access to ECMO did not ensure that it was used in burn care, as only 65% of centers used it in the management of severe burn patients. Importantly, some burn center directors commented that both academic and community centers in smaller hospitals tend to use less ECMO in the care of severe burn patients, as they are able to transfer these challenging patients to more experienced centers.

While there is strong physiologic rationale for the use of ECMO in ARDS, the ECMO literature has not reached a consensus to date.[18,19] The CESAR trial in the United Kingdom demonstrated a significant reduction in mortality when patients were transferred to an ECMO center.[16] However, as explained in the study itself and later by Chen et al,[18] it is not clear whether this decrease in mortality was due to the use of ECMO or the transfer of patients to a more specialized or higher-volume center.[8] It has therefore been hypothesized that the main reduction in mortality would be attributable to the center, rather than the ECMO intervention per se.[18,19] The EOLIA trial attempted to investigate this hypothesis and concluded that ECMO did not lead to a significant reduction in mortality compared to patients receiving conventional ventilation therapy.[20] Similarly, differentiating between the benefit of the center and ECMO itself will prove to be a challenge in burn care. So far, limited case review studies have found that there was no increase in mortality between burn patients on ECMO and the general ECMO population.[3,21] More studies are needed to better understand the specific effects of ECMO on mortality in burn patients.

Although more centers than we expected used ECMO in their burn units, most participants (80%) treated less than one burn patient with ECMO per year, with no center reporting more than five patients per year. This low volume of ECMO use likely explains the lack of existing protocols

in the majority of centers (60%). Directors at centers with no specific protocols mentioned in the comment section of the survey that the anticoagulation agent and perioperative management were dependent on the case or team preference. Given the high stakes involved in managing a burn patient perioperatively while on ECMO, moving beyond physician preference on a case-by-case basis to developed protocols created by consensus can only help to improve our practice and patient outcomes.

In existing critical care literature, the implementation of comprehensive anticoagulation and transfusion protocols for ECMO patients has been shown to have positive outcomes, such as a reduced need for blood transfusions.[22] In their meta-analysis of the literature on anticoagulation therapy, Sklar et al[23] found that protocols targeting lower activated PTT (aPTT) seemed more efficient in limiting hemorrhagic episodes and have a slight improvement in mortality. The drawback of those lower aPTT targets was an increase in thrombosis episodes, mainly in the circuit.[21,23] With the evolution of ECMO technology, shorter and heparin-bound circuits have been associated with a decrease in the need for anticoagulation therapy.[24] As these technologies continue to evolve and there is a decreased need for anticoagulation therapy to maintain the circuit's integrity, we can speculate that the use of ECMO may increase in the care of trauma patients, including burn patients.[25] The lack of consensus found in our survey is in line with the lack of consistent evidence in the literature for a specific anticoagulation protocol and highlights the need for better evidence investigating anticoagulation therapy in ECMO patients.

In the centers where ECMO was available but not used in burns, the main concerns seem to stem from the lack of patient volume, coupled with the lack of burn care team expertise. Directors at several centers commented that they would use ECMO, but had not yet had a suitable patient. Among the centers where ECMO was not available, all burn unit directors expressed interest in using ECMO. Interestingly, all of these centers reported a lack of physician/surgeon expertise in caring for ECMO patients, a lack of burn care team expertise caring for ECMO patients, and a lack of access to required equipment as barriers. This is somewhat expected since these institutions do not use ECMO in any capacity so the centers would not be able to draw on other departments' knowledge or resources. There seems to be a larger concern with anticoagulation therapy since 71.4% reported this as a major barrier, compared to 9.1% of directors at burn centers with access to ECMO. This may be explained by cross-education within departments and a better understanding of ECMO in institutions already using it for nonburn patients.

One concern not explored by our survey is the potentially increased rate of infection for burn patients on ECMO compared to the general ECMO population, as noted by Marcus et al.[26] As this study mostly focused on the perioperative decision to use ECMO, we did not specifically include increased infection rates as one of the preidentified concerns and no respondent specifically raised it as a concern. With the evolving recommendations for the use of prophylactic antibiotics and antimicrobials in the general ECMO population, it would be interesting to analyze the current practices of infection control for burn patients on ECMO in future studies.[27,28]

Limitations of this study are related to the nature of an anonymized online survey. The email was written in English with no translation available and sent to centers where English predominates as a first language, with the exception of two centers in the primarily French-speaking province of Quebec. Additionally, individual centers were not targeted as part of the survey; hence, response rates were lower than might have been achieved with targeted recruitment. There could also be a self-selecting bias where centers interested in ECMO were more likely to answer the survey. Multiple centers reported transferring the sickest patients to more specialized facilities. Due to the anonymization of data and our relatively low response rate, we do not know if the centers most specialized in the use of ECMO in severe burns participated in this survey. Finally, differences in definitions for terms such as "severe burn" may have led to an underreporting phenomenon.

Despite these limitations, our study has demonstrated clear themes. First, all burn center directors were receptive to the use of ECMO in severe burn patients if the technology was available to them. Second, lack of patient volume and lack of evidence seem to be the two most significant barriers to the use of ECMO in severe burn patients. These are important factors to highlight, because this general lack of experience has hindered the development of ECMO protocols for burn patients, which in turn may prevent centers from using ECMO and acquiring the necessary experience. To achieve eventual standardization and more widespread uptake, it will be necessary for burn care providers with ECMO experience, in conjunction with intensivists, perfusionists, critical care, and burn nurses to work together to generate consensus guidelines and recommendations on best practices. The level of practice variation we have documented would support the addition of a burn module to the ELSO registry data forms, which will include data regarding burn severity, perioperative management, and morbidity/mortality. This information would enable us to gather a more substantial dataset and better understand the effect of ECMO on burn patients. This could allow for targeted future studies to help standardize practice and improve ECMO outcomes and enable the development of an ECMO guideline for severe burn patients. Given that ECMO may offer life-saving therapy for severe burn patients with respiratory failure who have failed more conventional therapies, the development of such guidelines is of critical importance.

CONCLUSIONS

Approximately half of the burn centers in North America use ECMO to treat severely burned adult patients with ARDS or respiratory failure. Limited evidence for ECMO use in burn patients, low volumes of suitable patients, and lack of experience were the most commonly reported barriers to more widespread uptake of ECMO in the care of severe burn patients. Enhanced collaboration and communication are required to standardize practices, drive further research, and improve patient outcomes.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Burn Care & Research* online.

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