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Mobile Extracorporeal Membrane Oxygenation Teams: The North American Versus the European Experience

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Abstract

Objective—To evaluate differences in the inclusion of anesthesiologists in mobile extracorporeal membrane oxygenation (ECMO) teams between North American and European centers.

Design—A retrospective review of North American versus European mobile ECMO teams. The search terms used to identify relevant articles were the following: “extracorporeal membrane transport,” “mobile ECMO,” and “interhospital transport.”

Setting—MEDLINE review of articles.

Participants—None.

Interventions—None.

Results—Between 1986 and 2015, 25 articles were published that reported the personnel makeup of mobile ECMO teams in North America and Europe: 6 from North American centers and 19 from European centers. The included articles reported a total of 1,329 cases: 389 (29%) adult-only cohorts and 940 (71%) mixed-age cohorts. Among North American studies, 0 of 6 (0%) reported the presence of an anesthesiologist on the mobile ECMO team in contrast to European studies, in which 10 of 19 (53%) reported the inclusion of an anesthesiologist (Fisher exact p for difference = 0.05). In terms of number of cases, this discrepancy translated to 543 total cases in North America (all without an anesthesiologist) and 499 cases in Europe (37%) including an anesthesiologist on the team (Fisher exact p for difference <0.001).

Conclusions—This study demonstrated significant geographic discrepancies in the inclusion of anesthesiologists on mobile ECMO teams, with European centers more likely to incorporate an anesthesiologist into the mobile ECMO process compared with North American centers.

Keywords

extracorporeal membrane oxygenation; *anesthesiology*; *mobile ECMO*

EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO) is a potentially lifesaving modality used in critically ill patients who experience severe cardiac and/or pulmonary failure, and its use has increased over the past 2 decades.[1,2] Along with the rise in ECMO utilization, the ability to provide interhospital transfer to tertiary care centers with the

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assistance of ECMO support has led to the emergence of critical questions regarding the appropriate timing and execution of such transfers. Transport ECMO was first reported by Cornish et al in 1986,[3] but standardization of this complex undertaking remains a potentially important quality improvement opportunity worthy of investigation.

Despite a relative paucity of data regarding transport ECMO, increasing numbers of primary and secondary care facilities are using mobile ECMO for interhospital transfer of critically ill patients to tertiary care centers.[4] Appropriately equipped hospitals and other healthcare facilities around the world have put ECMO teams in place to carry out these transfers, but the makeup of these teams is not standardized across centers. Thus far, the largest systematic review of the mobile ECMO literature did not focus on the makeup of these teams across institutions or geographic regions.[5]

Accordingly, for this study, the authors analyzed differences in the personnel used during transport ECMO, with a particular focus on the inclusion of anesthesiologists in mobile ECMO teams as it differs between North American and European centers. Secondarily, the authors sought to perform a qualitative review of the complications encountered during the mobile ECMO experience between North American and European centers.

METHODS

Search Criteria

The authors conducted a PubMed database search to identify literature that reported experiences with interhospital transfer of patients undergoing ECMO. The search terms used for identification of relevant articles were the following: “extracorporeal membrane transport,” “mobile ECMO,” and “interhospital transport.”

Analytic Plan

After gathering descriptive statistics on mobile ECMO teams between North American and European centers, the authors compared the proportion of studies from each continent that reported the inclusion of anesthesiologists in its mobile ECMO teams and the number of cases these studies represented. This difference was analyzed using Fisher exact test, with a 2-sided p value of <0.05 considered significant. The types of complications encountered among transport ECMO teams also were examined. Because these data were not standardized and frequently omitted across the studies analyzed, the authors did not attempt to perform a quantitative analysis of the incidence of complications. Complications were grouped by type in accordance with the descriptions contained in the relevant references. The type of ECMO used (ie, venoarterial [VA] *v* venovenous [VV]) also was reported (Table 1[4–28]). Finally, data on transport distance were gathered and are summarized herein as ranges. Because many studies did not include full descriptions of the distributions of distance traveled, only ranges are reported because weighted means, which would have accounted for each study's sample size, were not possible to calculate.

RESULTS

A total of 317 articles were identified for screening using the aforementioned search terms in PubMed. Identified articles were published between 1986 and 2015, of which 54 were specifically about mobile ECMO (see Fig 1). Of these 54 articles, the following were excluded: pumpless extracorporeal lung-assist cases (3), single-case reports (3), articles not available in the English language (5), articles not specifying an ECMO team (2), articles from institutions outside of Europe and North America (5), and articles that included overlapping, duplicate data from the same institution (11), leaving a total of 25 included articles for this analysis (see Fig 1)—6 from North American centers and 19 from European centers. In sum, the included articles reported a total of 1,329 cases: 389 (29%) adult-only cohorts and 940 (71%) mixed-age cohorts.

Contrasting North American with European practice, a notable discrepancy was found in the proportion of studies that included an anesthesiologist on the ECMO transport team. Among North American studies, 0 of 6 (0%) reported the presence of an anesthesiologist on the mobile ECMO team in contrast to 10 of 19 (53%) studies from Europe reporting the inclusion of an anesthesiologist on the transport team. (Fisher exact p for difference between proportions by studies was 0.05). In terms of the number of cases, this discrepancy translated to 543 total cases in North America (all without an anesthesiologist) and 499 cases in Europe (37%) incorporating an anesthesiologist on the team (Fisher exact p for difference between proportions by cases was <0.001 [see Table 1]). The inclusions of surgeons, nurses, and perfusionists on the transport team were similar between centers on the 2 continents; they were all reported in 50% or more of the studies. A few studies reported intensivists, but their specialties were unspecified. A complete list of mobile ECMO team members by study is listed in Table 2[4–28].

Other notable characteristics between the North American and European experience included similar ranges of transport distance (4–12,070 km for North American *v* 1–13,447 km for European cohorts). There was nearly 100% survival during the transport process, with only 1 reported death en route.

In relation to the type of ECMO used in the transported patients, North American studies reported 189 cases of VA ECMO versus 315 cases of VV ECMO, whereas the European studies reported 389 and 94 cases, respectively. It is notable that one of the biggest studies performed in Europe did not report the type of ECMO used in its transported patients.[5]

Regarding complications, due to inconsistent reporting between and within studies, a quantitative representation of the incidence of complications was not possible. This was exemplified by some overlapping studies that reported mutually inconsistent complications. Nevertheless, it still was informative to review the types of complications reported as a qualitative representation of the range of issues encountered during transport ECMO. Although reporting was inconsistent, complications included death, cardiac arrest, arrhythmia, cardiac stun, bleeding, loss of tidal volume, hypothermia, hypotension, bradycardia, equipment malfunction/failure, overinfusion of intravenous drugs, and transportation mishaps such as an airplane landing at the wrong airport (see Table 1).

Interestingly, just as critical care patient complications were, as expected, a dominant theme within this qualitative review, electrical and mechanical malfunctions also were highly prevalent among those reported.

DISCUSSION

This study demonstrated significant geographic discrepancies in the inclusion of anesthesiologists in mobile ECMO teams, with European centers much more likely to incorporate an anesthesiologist in the mobile ECMO process compared with centers in North America.

Patients with critical, life-threatening cardiopulmonary conditions refractory to medical therapy require specialized assistance by a team of clinicians in a multispecialty environment.[29] Particularly relevant to this analysis, several of the complications reported in the literature are ones that commonly are encountered in the perioperative environment and for which anesthesiologists are trained to provide lifesaving interventions, including the treatment of hypotension, hypothermia, arrhythmias, tidal volume/airway management, pressor support, equipment failure, and appropriate sedation.

Limitations

The difference in historic practice patterns may not have any relationship to outcomes and simply may reflect the differing role of anesthesiologists between these areas, with the role of anesthesiologist-intensivists much more prominent historically in Europe than in North America.[30] This difference in the role of anesthesiologist-intensivists was reflected in a 2000 study by Angus et al, in which it was reported that anesthesiologist-intensivists in the United States made up 6% of the critical care workforce, and the supply for these specialty-trained individuals was expected to remain stagnant.[31]

Even though some studies in the review presented here reported the experiences in relation to the type of ECMO used, the specificity of reporting was insufficient to determine the related complications stratified by type of ECMO.[20] In addition, the reasons as to why VA versus VV ECMO use differed in proportion between the 2 continents are worthy of further investigation. Furthermore, due to the limitations in this study, whether or not an anesthesiologist should be included to improve patient outcomes is a subject that warrants further prospective studies. The authors hope that future studies of transport ECMO will report these findings in detail to get a better idea of what role ECMO personnel may play in improving patient outcomes.

Despite the limitations posed by a lack of uniformity among ECMO transport teams, the need for an anesthesiologist may be warranted. For example, according to Day et al, “transport teams should be thoroughly familiar with the pathophysiology of cardiac and respiratory failure. They should be equipped to continue the monitoring and treatment initiated at the referring center, to maintain that level of care during transfer, and to treat complications of the diseases or of the therapy itself.”[32] Studies showed that significant life-threatening cardiopulmonary changes can occur during patient transport, and cardiac or critical-care-trained anesthesiologists deal with these issues as a part of their daily clinical responsibility.[4] Thus, it may be prudent to use their expertise during interhospital transport of ECMO patients. The second aspect of this qualitative review of complications worthy of note was the variety of equipment malfunctions that were described. From electrical failures to loss of equipment, these failures were present across studies and may indicate that a key avenue for quality improvement going forward will include checklists designed to ensure that equipment is functioning properly, that critical backup equipment is immediately available (including battery supplies and surplus oxygen), and that ECMO transport teams are trained in how to recognize and respond to common equipment failures. Such checklists also might serve to prevent logistics-related complications like the complication experienced by one unfortunate patient whose plane landed at the wrong airport.

A final consideration worthy of further study is the costs associated with mobile ECMO.[33] Although mobile ECMO provides crucial support to hemodynamically unstable patients during inter-hospital transfers, Coppola et al have reported costs for mobile ECMO of up to $160,000.[8,13,34] In contrast to the authors' suggestions regarding the role of anesthesiologists in mobile ECMO, Schwartz et al referenced costs in concluding that the role of a physician is better used for clinical decisions than on-the-scene responses.[35]

In addition to the aforementioned practical limitations, the study presented here was, by necessity, only able to include transport ECMO experience that was included in peer-reviewed articles indexed in MEDLINE. There may be more variation in practice among centers that have not published their experience, and the literature may be skewed toward centers with limited complications. This publication bias naturally would bias these results to make transport ECMO appear to be more feasible and safer than it actually may be. Despite these limitations, this analysis of the literature documents what is likely to be an important difference in practice between North American and European centers.

In conclusion, as opposed to the North American experience, most European ECMO teams have recruited anesthesiologists to provide critical treatment during transfers. Whether recruiting anesthesiologists to North American ECMO transport teams may lead to better outcomes during and after transport is a subject worthy of further investigation. If improvements in outcome are demonstrated, the workforce and economic considerations may be paramount in enabling such a change in North American practice.

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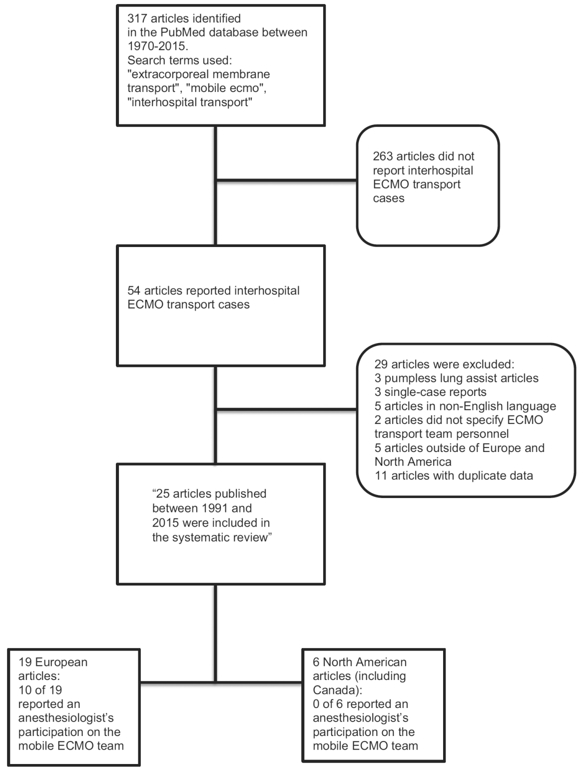

Fig 1.

Diagram of article selection and analysis.

Table 1

A Systematic Review of Articles Reporting Interhospital Transport of Patients on ECMO

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (n = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type: VV	VA	VVA	VV-VA	VA-VV
North America												
Biscotti et al[6]	—	No	—	100	Adult	4–1,1400	NR	79	19	2		
Bryner et al[5]	1990–2012	No	Critical care surgeon and fellow	221	Neo/Ped/Adult	—	Patient related (9): arterial catheter rupture, cardiac arrest, death Missing item (23): specific cannula sizes, stretcher, sterile water bath Electrical/ mechanical problem (39): ambulance battery outage, portable laboratory device not working, battery loss requiring hand-cranking of pump, water heater failure Transportation mishap (8): landing at wrong airport, ambulance engine failure Circuit issue (20): circuit depriming, oxygenator clotting	107	114			
Clement et al[7]	1990–2008	No	Intensivecare physician, not specified	112	Neo/Ped	—	NR	1	111			

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (n = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type				
								VV	VA	VVA	VV-VA	VA-VV
Coppola et al[8]	1985–2007	No	—	68	Neo/Ped	13–12,070	Patient related (2): mild hypothermia Circuit issue (2): membrane oxygenator failure thrombosis Electrical/ mechanical problem (4): power supply failure, blood warmer leakage, roller pump failure with subsequent circuit tubing rupture while hand-cranking pump	1	67			
Gebremichael et al[9]	1994–1996	No	Intensive care physician, not specified	36	Ped/Adult	4.83–740.3	Patient related (2): transient hypotension (1 died while being moved from the sending hospital bed to the transport gurney; the death was sudden and believed to be consistent with an acute pulmonary embolus)	—	—	—	—	—
Horne et al[10]	2004–2009	No	—	6	Neo/Ped	—	Patient related (2): cannula site bleeding, infection Circuit issue (1): cannula site thrombosis	1	4		1	

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (n = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type				
								VV	VA	VVA	VV-VA	VA-VV
Europe												
Broman et al[4]	2010–2013	Yes		322	Neo/Ped/Adult	6.9–13,447	Patient related (66): loss of tidal volume, flooding of the lung, bleeding, hypovolemia, hypothermia, bradycardia, loss of arterial line, thrombocytosis, cardiac stun, electrolyte imbalance, arousal, leg ischemia, vasovagal reflex/ secretions, circulatory instability, cannulation problems Equipment/ technical (18): clotting of ECMO system, cannula clot, oxygenator clot, broken laboratory device, syringe pump failure, broken heater/ hose, broken oxygen hose, broken ventilator hose, loss of power supply to pump; ECMO system forgotten, pump head forgotten Transportation mishap (7): wrong	—	—	—	—	—

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (n = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type				
								VV	VA	VVA	VV-VA	VA-VV
							ambulance, ambulance traffic accident, colliding with wildlife, no electricity, change in destination, no transport after delivery					
Chenaitia et al[11]	2009–2010	Yes		43	Adult	7–135	NR	11	32			
Ciapetti et al[12]	1998–2004	No	Intensive care physician, not specified	4	Adult	35–520	NR	4				
D'Ancona et al[13]	2009–2010	Yes		8	Adult	—	Electrical/ mechanical problem (1): pump arrest secondary to an electrical failure of the pump battery	7	—	—	—	—
Delnoij et al[14]	2009–2013	No	Intensive care physician, not specified	10	Adult	27–126	NR	10				
Gariboldi et al[15]	2006–2008	Yes		38	Ped/Adult	1–230	NR	6	32			
Haneya et al[16]	2001–2008	Yes		9	Adult		Equipment (1): oxygen supply was insufficient	9				
Isgrò et al[17]	2004–2009	No	Intensive care physician, not specified	12	Ped/Adult	—	Electrical/ mechanical (3): battery pack was unable to maintain the charge and the ventilator switched off during ICU ambulance transfer, touch screen malfunctioned, magnetic decoupling of the centrifugal pump head due	12				

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (*n* = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type				
								VV	VA	VVA	VV-VA	VA-VV
							to street roughness					
Linden et al[18]	1996–2000	No	—	29	Neo/Ped/Adult	4–1,500	Transportation (1): ambulance malfunctioned, disabling shock absorbers Electrical (2): electric supply circuits went down	—	—	—	—	—
Lucchini et al[19]	2004–2012	No	Intensive care physician, not specified	29	Ped/Adult	9–1,044	Electrical (1): battery failure of ventilator during transport from the ICU to the ambulance Circuit issue (1): difficulty in obtaining an acceptable extracorporeal flow due to the patient's position	28	1			
Lunz et al[20]	—	Yes		6	Adult	66–178	NR	6				
Philipp et al[21]	2010–2010	Yes		6	Adult	80–5,850	Patient related (1): systemic pressure drop	5	1			
Raspé et al[22]	2010–2013	Yes		36	Ped/Adult		NR	36				
Roch et al[23]	2009–2013	No	Intensive care physician, not specified	85	Adult	—	NR	77	8			
Roncon-Albuquerque et al[24]	2009–2011	No	Intensive care physician, not specified	10	Adult	116–133	Patient related (2): unexplained respiratory deterioration	9			1	
Rossaint et al[25]	1993–1995	Yes		8	Ped/Adult	—	Mechanical (1): breakage of a stopcock on top	8				

Reference	Year Ranges	Anesthesiologist on ECMO Transport Tea	Non-anesthesiologist Intensivist on Team	No. of Patients Transported (n = 1,329)	Patient Population	Distance Range or Percent (km)	En-Route Complications (No. of Incidents Reported)	ECMO Type				
								VV	VA	VVA	VV-VA	VA-VV
							of membrane lung					
Starck et al[26]	2009–2011	No	–	6	Adult	12–55	NR	6				
Vaja et al[27]	2010–2014	No	Intensive care physician, not specified	102	Adult	3.6–980	Patient related (1): ventricular tachycardia	95	7			
Wagner et al[28]	1992–2008	Yes		23	Neo/Ped/Adult	—	NR	6	13		3	1

Abbreviations: ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit; Neo, neonatal; NR, none reported; Ped, pediatric; VA, venoarterial; VV, venovenous; VVA, veno-veno-arterial.

Table 2

Detailed List of ECMO Transport Personnel by Study

Reference	ECMO Team Personnel
North America	
Biscotti et al[6]	2 perfusionists, 2 critical care paramedics, 1 cardiothoracic surgeon, and, since 2013, 1 surgical fellow
Bryner et al[5]	2 medical flight nurses, 2 ECMO specialists, 1 critical care surgeon, 1 critical care fellow
Clement et al[7]	1 ECMO coordinator, 1 pediatric cardiac surgeon, 1 surgical assistant, 1 intensive care physician
Coppola et al[8]	1 pediatric cardiologist, 1 surgeon, 2 circuit/child nurse, 1 respiratory therapist, 1 ECMO director, 1 ECMO coordinator, technicians and trainees
Gebremichael et al[9]	1 critical care physician, 1 practicing critical care nurse, 1 respiratory therapist
Horne et al[10]	Adult cardiac surgeon/pediatric general surgeon/pediatric cardiologist and perfusionists
Europe	
Broman et al[4]	1 ECMO physician (anesthesiologist and transport team leader), 1 ECMO specialist (ICU nurse), 1 cannulating surgeon
Chenaitia et al[11]	1 cardiac surgeon, 1 resident surgeon, 1 perfusionist, 1 anesthesiologist
Ciapetti et al[12]	Intensivist, cardiac surgeon, cardiologist, perfusionist, and nurses
D'Ancona et al[13]	1 anesthesiologist, 1 cardiac surgeon, 1 perfusionist
Delnoij et al[14]	2 intensivists, 1 intensive care nurse, 1 perfusionist
Gariboldi et al[15]	1 cardiac surgeon, 1 anesthesiologist, 1 perfusionist
Haneya et al[16]	1 anesthesiologist experienced in cardiopulmonary bypass, 1 perfusionist, 1 nurse or paramedic, 1 cardiac surgeon
Isgrò et al[17]	2 ICU physicians, 1 ICU nurse, and 1 ECMO specialist, plus trainees (1 ICU physician and 1 ICU nurse)
Linden et al[18]	1 ECMO physician, 1 ECMO coordinator, 1 cannulating surgeon
Lucchini et al[19]	2 intensivists, 1 ICU nurse, 1 perfusionist
Lunz et al[20]	1 cardiac anesthesiologist, 1 clinical perfusionist
Philipp et al[21]	1 cardiac anesthesiologist, 1 cardiac surgeon, 1 pump technician
Raspé et al[22]	1 cardiac anesthesiologist, 1 cardiac surgeon, 1 clinical perfusionist
Roch et al[23]	1 ICU physician, 1 cardiac surgeon, 1 perfusionist
Roncon-Albuquerque et al[24]	2 intensive care physicians, 1 nurse, 1 perfusionist
Rossaint et al[25]	2 anesthesiologists, 1 nurse
Starck et al[26]	1 cardiac surgeon, 1 perfusionist
Vaja et al[27]	Someone trained in cannulation for ECMO, transport and intensive care, perfusion, and the ECMO circuit; and an ECMO specialist nurse
Wagner et al[28]	1 cardiothoracic surgeon, 1 anesthesiologist, 1 perfusionist, 1 ICU nurse

Abbreviations: ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit.