doi: 10.1111/nicc.12265

An international survey: the role of specialist nurses in adult respiratory extracorporeal membrane oxygenation

Kathleen JR Daly, Luigi Camporota and Nicholas A Barrett

ABSTRACT

BACKGROUND: The last decade has seen an increase in the number of centres able to provide venovenous extracorporeal membrane oxygenation (VV-ECMO) internationally across different health care systems. To support this growth, a variety of staffing arrangements have been adopted depending on local need and availability of resources, both in terms of manpower and finances to safely meet the complex needs of the patient and circuit management.

AIM: The aim of the survey was to describe current staffing arrangements of care provision for adult patients on VV-ECMO, with a focus on understanding the professional roles and responsibilities of staff managing the circuit in order to inform further discussion around different approaches to staffing.

METHODS: We conducted a cross-sectional international survey using an electronic questionnaire emailed to 177 worldwide ECMO centres treating adult patients with acute respiratory failure. The survey questions were generated through an internal and external iterative process and assessed for clarity, content and face validity.

RESULTS: The response rate was 82%. Respondents managed extracorporeal oxygenation for adult respiratory alone (75%) or in combination with adult cardiac (67%), paediatric respiratory (62%) and paediatric cardiac (58%). The specialist nurse to patient ratio was 1:1 in 59% of centres, with 24-h/day presence in 74%. Overall, the specialist nurse provided the 24-h/day management of the circuit, including interventions. Perfusionists were responsible for the technical aspects of circuit management.

CONCLUSIONS: A specialist nurse with perfusion backup is the staffing arrangement implemented by most centres and likely reflects the most efficient use of the professional competences available.

RELEVANCE TO CLINICAL PRACTICE: Staffing for adult respiratory extracorporeal support has important implications for the planning of workforce, training and education, quality of service and the number of ECMO beds available.

Key words: Adult intensive care • Advanced practice/nurse specialist roles • Inter-professional collaboration • Respiratory therapies • Service organization/delivery

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is a supportive therapy for patients with severe cardiorespiratory failure refractory to conventional management (Marasco *et al.*, 2008; Brodie and Bacchetta, 2011). ECMO is derived from cardiopulmonary bypass and miniaturized to allow longer-term support within an intensive care environment. Venovenous ECMO (VV-ECMO) provides support for isolated respiratory failure and requires the cannulation of the venous circulation. Venous blood is drained from the superior and/or inferior vena cava and pumped through the membrane oxygenator and returned into the right atrium fully oxygenated. The patient's own heart then pumps the oxygenated blood around the body. Venoarterial ECMO (VA-ECMO) provides support for cardiac failure and requires the cannulation of both venous and arterial circulations. Venous blood is drained from the superior and/or inferior vena cava and pumped through the membrane oxygenator back into the arterial circulation through the ascending aorta (central ECMO) or the femoral artery (peripheral ECMO). Modern ECMO circuits use centrifugal pumps and low-resistance polymethylpentene gas exchange membrane with heparin-bonded tubing and percutaneously inserted cannulae. The gas exchange membrane allows the addition of oxygen and removal of carbon dioxide directly from the blood. To provide adequate systemic arterial oxygenation, blood flows of 4–6 L/min need to be achieved.

ECMO has been provided for critically ill adults since the 1970s (Hill *et al.*, 1972); however, early randomized controlled trials did not support the technique (Zapol *et al.*, 1979; Morris *et al.*, 1994). The Conventional

Authors: Kathleen JR Daly, RN, PhD, Consultant Nurse, Critical Care, Division of Asthma, Allergy and Lung Biology, King's College London, London, UK; Department of Adult Critical Care, Guy's and St Thomas' NHS Foundation Trust, King's Health Partners, London UK; St Thomas' Hospital, 1st Floor East Wing, Westminster Bridge Road, London SE1 7EH, UK; Luigi Camporota, FFICM, Consultant, Critical Care, Division of Asthma, Allergy and Lung Biology, King's College London, London, UK; Department of Adult Critical Care, Guy's and St Thomas' NHS Foundation Trust, King's Health Partners, London UK; St Thomas' Hospital, 1st Floor East Wing, Westminster Bridge Road, London SE1 7EH, UK; Nicholas A Barrett, FCICM, Consultant, Critical Care, Division of Asthma, Allergy and Lung Biology, King's College London, London, UK; Department of Adult Critical Care, Guy's and St Thomas' NHS Foundation Trust, King's Health Partners, London, UK; St Thomas' Hospital, 1st Floor East Wing, Westminster Bridge Road, London SE1 7EH, UK

Address for correspondence: Kathleen JR Daly, Division of Asthma, Allergy and Lung Biology, King's College London, London, UK; Department of Adult Critical Care, Guy's and St Thomas' NHS Foundation Trust, King's Health Partners, London, UK; St Thomas' Hospital, 1st Floor East Wing, Westminster Bridge Road, London SE1 7EH, UK

E-mail: Kathleen.daly@gstt.nhs.uk

BACCN Nursing in Critical Care

Ventilation or ECMO for Severe Respiratory Failure (CESAR) trial demonstrated a significant benefit for patients with severe respiratory failure when transferred to an ECMO-capable intensive care unit (ICU) for consideration of ECMO (Peek *et al.*, 2009). Subsequently, during the Influenza A H1N1 pandemic in 2009–2011, observational data showed surprisingly good outcomes for patients commenced on ECMO (Davies *et al.*, 2009; Noah *et al.*, 2011, Pham *et al.*, 2013). The results of CESAR and the Influenza A (H1N1) pandemic led to accelerated uptake of adult VV-ECMO for severe acute respiratory failure (MacLaren *et al.*, 2012; Abrams and Brodie, 2013; Paden *et al.*, 2013; Munshi *et al.*, 2014). Miniaturised, transportable ECMO pumps have been developed with centrifugal pumps, and polymethylpentene hollow fibre gas exchange membranes which have improved biocompatability, greater efficacy and cause less 'blood trauma' than earlier generations of ECMO devices (Mendler *et al.*, 1995; Khoshbin *et al.*, 2005).

Respiratory ECMO is most commonly indicated in adults with severe, potentially reversible, acute respiratory failure refractory to conventional ventilation (Bartlett, 2000; Hemmila *et al.*, 2004; Cordell-Smith *et al.*, 2006; Maggio *et al.*, 2007; Mikkelsen *et al.*, 2009; Turner and Cheifetz, 2013). Relative contraindications include contraindications to even minimal anticoagulation and prolonged duration of potentially injurious mechanical ventilation. There is only one widely accepted absolute contraindication to ECMO, and that is multi-organ failure secondary to viral haemorrhagic fever (Ebola).

The Extracorporeal Life Support Organisation (ELSO) is an international body representing practitioners of ECMO. In addition to forming the largest registry of ECMO cases worldwide, ELSO has produced guidelines pertaining to the ideal institutional requirements for an ECMO centre in terms of organizational structure, staffing, physical facilities, equipment, staff training, continuing education and ongoing programme evaluation. These guidelines recommend that ECMO centres (ICUs caring for patients on ECMO) should be located in tertiary hospitals receiving referrals from geographic areas that can support a minimum of six ECMO patients per year; however, any centre, regardless of number of ECMO patients per year, can register with ELSO (ELSO, 2013).

In England, the Department of Health's response to the H1N1 pandemic and the CESAR study was to commission a dedicated regionalized VV-ECMO service through the National Specialised Commissioning Team. A tiered model of advanced respiratory care was created, with the development of a system of referral from local hospitals through to regional, high-volume tertiary ICUs. These services deliver specialist consultant-led and delivered retrieval, assessment, acceptance, and treatment of patients fulfilling the clinical criteria for respiratory ECMO. Centres plan for and manage seasonal variation in activity and respond on a national basis to unanticipated surges in demand. In our centre, for the last 5 years, the VV-ECMO survival was 79·7%, ICU survival was 75%, and 6-month survival was 73·6%. These are similar to results reported by the other UK ECMO centres (N Barrett, personal communication), all of whom have an ECMO specialist nurse managing patients 24/7.

According to ELSO, the ECMO specialist is 'the technical specialist trained to manage the ECMO system and clinical needs of the patient on ECMO under the direction and supervision of an ECMO trained physician' (ELSO, 2013). Internationally, specialists come from a range of professional backgrounds, including perfusion, nursing, physiotherapy and medicine. In the UK, the staffing arrangement for the provision for adult VV-ECMO adopted by the five commissioned centres is the ECMO specialist nurse, an ICU nurse with additional specialist training. Currently, both nationally and internationally, there are no agreed standards of practice or certification process for ECMO specialists, with each hospital credentialing staff to an internally developed standard. However, concomitantly, with the clinical and technological changes in ECMO, the role of the ECMO specialist has evolved to manage the patient–circuit interaction, the clinical needs of the patient and to ensure the safety of the ECMO circuit through continuous surveillance, assessment and troubleshooting as well as preventing and managing circuit emergencies. Each ECMO centre, depending on local need and the availability of resources, both in terms of manpower and finances, has developed its own local specialist role, training programme and staffing arrangements. There are also no internationally agreed frameworks of service provision or defined competencies for ECMO specialists and the specific roles within the multidisciplinary clinical team.

AIM

The aim of the survey was to identify ECMO specialist staffing arrangements for the provision for adult VV-ECMO patients, with a focus on understanding professional roles and responsibilities of staff providing the management of the ECMO circuit in order to inform future discussion around models of care provision.

METHODS

We conducted a cross-sectional international survey using an electronic questionnaire emailed to 177 worldwide ECMO centres treating adult patients with acute respiratory failure. Centres were located in Africa (South Africa, Israel, Saudi Arabia), Asia (China, India, Japan, Singapore, South Korea, Taiwan), Europe (Austria, Belgium, Croatia, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Netherlands, Norway, Poland, Portugal, Russia, Sweden, United Kingdom), North America (Canada, USA), South America (Chile) and Oceania (Australia). An invitation to participate in this study was sent to the local co-ordinators of the 177 ECMO centres. Email addresses were retrieved from publicly available database sources and from personal contacts of the authors. Exclusive paediatric and cardiac ECMO centres were excluded because we wanted to determine how the staffing arrangements for the provision for adult VV-ECMO adopted in the five UK adult centres compared with international practice.

Development and administration of the online questionnaire

Using an iterative process, the survey questionnaire was developed by three authors (K. D., N. B., L. C.). This was followed by internal pilot testing amongst clinicians within our institution, including consultants, perfusionists, ECMO specialist nurses and physiotherapists. The pilot was followed by further retesting using an ECMO co-ordinator from one of the other four UK centres to refine and finalize question stems, response formats and to assess face validity and clarity. Confidentiality was maintained through the survey software, which did not identify individual responses.

The survey consisted of 10 questions arranged in two domains: (1) demographic data and background of each ECMO centre and (2) ECMO circuit management, roles and responsibilities. The survey was self-administered using a commercially available, subscription-based service (Smart Survey™; Smart Survey Ltd, Basepoint Business Centre, Oakfield Close, Tewkesbury, UK, http://www.smart-survey.co.uk).

In the first domain, participants answered questions about staffing and case load: structured responses were provided to questions regarding the training background of the senior critical care physicians, the patient population treated, the number of ECMO patients treated in the previous year (2013) and the total number of years of experience in providing ECMO.

The second domain concerned responsibility for circuit management. Participants reported which specialist was responsible for all aspects of circuit management.

The questionnaire was answered online in one session that occurred in 2014. Participants were required to select all answers applicable to their institution from a series of predetermined options (>1 specialist per question likely).

Participants were initially contacted by email. The ECMO co-ordinator for each ECMO centre was contacted to participate in the survey. ECMO co-ordinators, depending on the centre, are nurses, perfusionists, respiratory specialists or doctors. The email included a cover letter explaining the purpose of the survey and a link to the web-based Smart Survey tool and a request for the ECMO co-ordinator to contribute information on behalf of their centre. Two follow-up reminders were sent in the first and third month following the initial email. Participation was voluntary, and no incentives were provided for responding to the survey. The institutional research and development department approved the study and waived the need for ethical approval and consent (authorization RJ114/N353).

Analysis of data

Descriptive analyses and frequencies were calculated for demographic and qualitative data. We include '*non verbatim*' statements provided by each respondent as free text to support the rationale for the selected response. Free-text responses were examined to provide clarification to the answers respondents provided. Data analysis was carried out using Prism 6·0 software (GraphPad Software, Inc., USA).

RESULTS

Survey respondents

Of the 177 ECMO centres contacted, 146 centres responded (82%). Respondents had the choice to respond to all the questions or skip a question ('I do not know'). In addition, for some questions, more than one answer was possible. This will affect the total number of responses for each question (i.e. the denominator will vary, and the total can amount to > 100% of the respondents).

Demographics

Respondents were asked questions relating to the type of ECMO provided by their centre, the professional background of the senior clinician leading their ECMO service and the number of years their centre had been providing respiratory ECMO. Respondents managed adult respiratory (109 centres), adult cardiac (98 centres), paediatric respiratory (91 centres) and paediatric cardiac ECMO (85 centres). The professional background of the senior clinicians primarily responsible for the management of ECMO patients was intensivists (116 centres), surgeons (61 centres), anaesthetists (30 centres) and physicians (25 centres). The majority of respondents had provided ECMO for severe respiratory failure for >10 years (72 centres), with the remaining centres reporting 6–10 years (19), 3–5 years (36) and 0–2 years (19), respectively. The number of adult respiratory patients each centre, respectively, placed on ECMO in 2013 was 1–10 patients (74 centres), 11–20 patients (26 centres), 21–30 patients (15 centres), 31–40 patients (8 centres) and > 40 patients (18 centres) (Table 1).

Responsibility for the bedside management of the ECMO circuit

The specialist primarily responsible for the bedside management of the circuit was a combination of the ECMO specialist nurse in 86 of 146 (59%) of centres, the ECMO specialist perfusionist in 44 of 146 (30%) of centres, the ECMO specialist respiratory therapist in 33 of 146 (23%) of centres and the ECMO specialist doctor in 14 of 146 (9%) of centres. A further 21 centres (14%) that did not have bedside ECMO specialists reported a combination of either the bedside nurse with remote perfusion or medical backup cover in 16 of 146 (11%) of centres or the bedside doctor with remote specialist perfusion cover in 5 of 146 (3%) of centres. The ratio of ECMO specialists to patients was 1:1 in 94 of 144 (65%) of centres, 1:2 in 20 of 144 (14%) of centres, 1:3 in 8 of 144 (6%) of centres, 1:4 in 2 of 144 (1%) of centres and less than 1:4 in 7 of 144 (5%) of centres. A further 8 of 144 (5%) of centres reported a specialist to

Table 1 ECMO centres' background, case-volume, experience and staffing model

Domain	Frequency
Training background of the senior clinicians	
Anaesthetists	30
Intensivists	116
Physicians	25
Surgeons	61
ECMO patient population	
Adult respiratory	109
Adult cardiac	98
Paediatric respiratory	91
Paediatric cardiac	85
Adult respiratory failure patients treated (patients/year)	
0–10	74
11–20	26
21–30	15
31–40	8
>40	18
Experience with ECMO for acute respiratory failure (years)	
0–2	19
3–5	36
6–10	19
>10	72
Responsibility for the bedside management of the ECMO circuit	
ECMO specialist nurse	59%
ECMO specialist perfusionist	30%
ECMO specialist respiratory therapist	23%
ECMO specialist doctor	9%
No ECMO specialist (general ICU nurse with remote backup)	11%
No ECMO specialist (general ICU doctor with remote backup)	3%
Ratio of ECMO specialists to patients	
2:1 or 2:3	3%
1:1	65%
1:2	14%
1:3	6%
1:4	1%
<1:4	5%

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

patient ratio of 2:1 or 2:3 patients, whilst 5 of 144 (3%) reported an 'other' ratio. The amount of time the specialist spent at the patient's bedside varied between centres. In 74% of the centres, the ECMO specialist provided 24-h bedside presence; in 12% of centres, the ECMO specialist was on site but not at the bedside; in 6% of centres, the specialist was off site but was available on site in less than 15 min; in 5% of centres, the specialist was off site but available on site in less than 30 min; and in one site, the specialist was off site but was available on site in longer than 60 min. In 120 of 143 (84%) of responding centres, there was a bedside nurse who was responsible for patient management in addition to the ECMO specialist. The bedside nurse to ECMO patient ratio was 1:1 in 123 of 144 (85%), 1:2 in 25 of 144 (17%), 1:3 in 1 of 144 (less than 1%) and 2:1 in 7 of 144 (5%) of respondents (Figure 1).

In 59% of centres, the ECMO specialist nurse was the specialist primarily responsible for the bedside management of the ECMO circuit, including titration of sweep gas, blood flow and anticoagulation. They were also responsible for the connection of renal replacement therapy and anticoagulation to the ECMO circuit in centres where this was the practice and for performing routine tasks, including taking pre- and post-oxygenator blood gases. In addition, the ECMO specialist nurse was responsible for ensuring the safe management of the ECMO circuit during any patient movement.

Responsibility for the technical aspects of circuit management, including priming the circuit prior to cannulation, changing circuit components as required (e.g. pigtails), performing emergency circuit changes and the connection/disconnection of the ECMO circuit during cannulation/decannulation, were primarily performed by the perfusionist. The perfusionist was also mainly responsible for the safe management of the circuit during intra-hospital transfers.

DISCUSSION

The aim of this cross-sectional international survey was to describe the role, responsibilities and professional background of the ECMO specialist in the management of the ECMO circuit; compare the UK staffing approach with staffing arrangements adopted internationally; and inform the discussion around the staffing arrangements to implement and provide a safe, effective ECMO service. We also wanted to understand how the UK approach, an ECMO specialist from a nursing background providing 24/7 care, compared with international practice. The survey had a very high response rate, with 146 of 177 (82%) of centres responding. The main finding was that the staffing arrangement implemented by most centres (59%) was the ECMO specialist nurse providing 24-h care supported by perfusion backup for the technical aspects of circuit management. This finding is in keeping with previously published surveys, which reported an incidence of between 73% and 89% of programmes employing a registered nurse with ICU experience and additional specialist training as the ECMO specialist to provide the management of the ECMO circuit (Allison *et al.*, 1990; Odell *et al.*, 1992; Lawson *et al.*, 2008; Sutton *et al.*, 2009). The

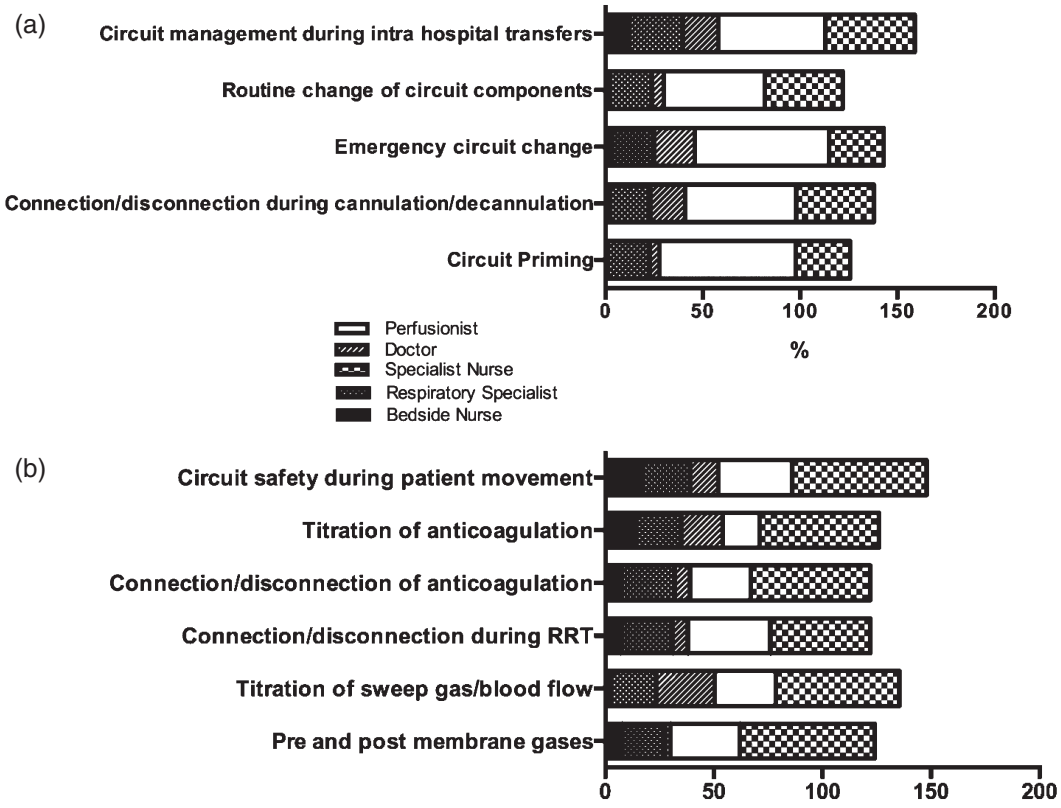

Figure 1 (a) Responsibility for the bedside aspect of extracorporeal membrane oxygenation (ECMO) circuit management. (b) Responsibility for the technical aspect of ECMO circuit management.

other main finding is that in the majority of centres (65%), a staffing of 1:1 ECMO specialist per ECMO patient is used in addition to the bedside nurse.

ECMO is a highly complex, high-cost intervention that requires specialist training and expertise to ensure the safe management of the patient and circuit. Whilst there is some guidance, both nationally and internationally, for centres wanting to develop an ECMO service (NICE, 2011; ELSO, 2013), the implementation of the guidance is subject to local interpretation. Currently, there are no internationally agreed frameworks of service provision or defined competencies for ECMO clinicians; however, it is generally acknowledged that ECMO should only be provided in centres where the multidisciplinary clinical team have specific training and expertise in its management.

It is interesting that despite variation in international health care funding, there are remarkable similarities in practice, particularly pertaining to ECMO's roles and responsibilities. Our survey determined that not only was the ECMO specialist nurse the staffing arrangement adopted by most centres but also the ECMO specialist/patient ratio was high, with 65% of centres reporting a 1:1 ratio. Furthermore, in 84% of centres, there was a bedside nurse in addition to the ECMO specialist nurse, providing 1:1 care. This 'two carers' approach to staffing is manpower-intensive with two nurses, the ECMO specialist nurse and the bedside nurse, working collaboratively to ensure the safe co-ordination and management of a critically ill patient with a wide range of complex care needs, including multi-organ system support and complex haematological, fluid and sedation management. In addition to meeting the complex needs of the patient, the ECMO specialist nurse is also responsible for ensuring the safe management of the ECMO circuit, including continuous surveillance, assessment and troubleshooting as well as preventing and responding to any circuit emergencies. Understanding the management of both patient and circuit and the potential patient-circuit interaction is essential. Given the inherent expense of this approach, it appears reasonable to assume that the majority of centres have found that this approach provides a high quality of care for patients. However, given its expense, this approach also has major implications for resource utilization, especially given the unpredictability of ECMO activity, with seasonal peaks and troughs in demand. The challenge for nursing is how to balance the opposing needs for a streamlined, cost-effective service whilst maintaining high-quality, safe, 24/7 care. An alternative approach that some centres have adopted is that of the 'single care' provider (McCoach *et al.*, 2010; Freeman *et al.*, 2012; Cavarocchi *et al.*, 2015), with the ECMO specialist nurse providing both clinical care of the patient and management of the ECMO circuit. In our survey, only 16% of respondents reported adopting the 'single care' approach. In 84% (120/143) of centres, regardless of the profession of the ECMO specialist, a 'two carers' approach was adopted, with the bedside nurse providing direct patient care in addition to the ECMO specialist. In 12% (17/146) of centres, there was a requirement for backup cover from perfusion as a non-ECMO-trained specialist was providing direct bedside management of the ECMO circuit. Whilst the 'single care' approach to staffing may reduce nursing costs, it is important to ensure that quality and safety of care is maintained.

As the results of this survey demonstrated, whilst other professionals have the educational background and technical skills to function in the role of ECMO specialist, the advantage of an ECMO specialist from a nursing background is the ability to provide 24-h care managing all aspects of patient care, including administration of medication, and to have the technical skills and knowledge to safely manage the ECMO circuit with perfusion backup for the more complicated aspects of circuit management. Further discussion is required to understand the risks and benefits of these different approaches to staffing.

Limitations and strengths of the survey

The strength of this study is in the breadth of questions involving some of the most important day-to-day aspects of the management of ECMO, the large number of international centres surveyed and the high response rate (82%). The key limitation of surveys is that they represent what clinicians think they 'do' and may not accurately reflect 'what they actually do' (Brunkhorst *et al.*, 2008). Nevertheless, the response to similar domains covered in recent surveys may indirectly indicate that the results presented in this survey are reproducible and may reflect real practice. Another limitation is that because of the anonymity of the survey, we do not know which geographical region the centres came from.

IMPLICATIONS FOR PRACTICE

The results of this survey clearly demonstrate that there is heterogeneity of ECMO specialist roles and professional backgrounds across international ECMO centres. It is likely that many of these differences relate to differences inherent to the varying health care systems. The results of this survey can readily be used to inform discussion about roles and professional backgrounds within the regulatory, financial and educational environment each centre operates in. Within the UK, the development of the ECMO specialist nurse in either the 'single care' or 'two carers' approach has major implications for nurse training and education. Since the commissioning of five adult respiratory ECMO services in 2011, each of the five designated centres must comply with national standards of practice, which include guidance on the expertise and training requirements of staff, including the ECMO specialist. ELSO is the only organization that has produced guidelines in an attempt to define the skills and knowledge required by an ECMO specialist (Extracorporeal Life Support Organisation, 2010). Unlike medicine, where the requirement for ECMO training has been recognized by the Faculty of Intensive Care Medicine (Faculty of Intensive Care Medicine, 2015) and also appears in the curriculum of the Royal College of Anaesthetists for advanced level (cardiothoracic training) (Royal College of Anaesthetists, 2010), this is not the case for nursing. Currently, there are no agreed national frameworks for nursing roles/responsibilities and training/education specifically for ECMO; as a result, local multidisciplinary ECMO courses have been set up to provide specialist training, with the development of local competency assessments. It is possible that in the future, as the use of VV-ECMO grows, nationally defined competencies for ECMO nurse training will be incorporated into the national competency framework for adult critical care nurses' three-step approach, either as a 'bolt on' to step 3, which defines the skills, knowledge, attitudes, values and technical abilities required at an advanced level, or alternatively, contained within a new step 4 stage for senior critical care

nurses with specialist skills and knowledge (Critical Care Networks, 2014).

CONCLUSIONS

We found that despite variation in funding and practice, the staffing arrangement implemented by most centres responding to this survey was the ECMO specialist nurse providing 24/7 ECMO care supported by perfusionist backup for the technical aspects of circuit management. This has major implications for future nurse funding and training as demand for VV-ECMO is likely to increase over the next 5–10 years. The challenge for nursing is how to meet this demand.

SUPPORTING INFORMATION

The following Supporting information is available for this article:

Figure S1. (a) Femoral vein-Femoral-vein configuration for venovenous extracorporeal membrane oxygenation (VV-ECMO). (b) Femoral vein-Internal Jugular vein configuration for VV-ECMO. (c) Dual-lumen cannula into Internal Jugular vein for VV-ECMO.

Additional Supporting Information may be found in the online version of this article:

WHAT IS KNOWN ABOUT THIS TOPIC

- The use of VV-ECMO for the management of patients with acute, reversible lung failure has increased significantly over the past 10 years.
- Advances in ECMO technology have resulted in the development of simpler, safer circuits, which are associated with fewer complications.
- ECMO is a highly complex, resource-intensive intervention and requires specialist training to ensure the safe management of both the patient and the circuit.

WHAT THIS PAPER ADDS

- Our findings confirm that the staffing arrangement implemented by the most international centres is the ECMO specialist nurse with backup from perfusion.
- Most ECMO centres, regardless of the profession of the ECMO specialist, adopt a 'two carers' bedside staffing arrangement, with the bedside nurse providing direct patient care in addition to the ECMO specialist.
- Investment in future nurse training and education is required if this staffing arrangement is implemented to ensure sustainability of the specialist nurse role.

REFERENCES

Abrams D, Brodie D. (2013). Emerging indications for extracorporeal membrane oxygenation in adults with respiratory failure. *Annals of the American Thoracic Society*; **10**: 371–377.

Allison PL, Kurusz M, Graves DF, Zwischenberger JB. (1990). Devices and monitoring during neonatal ECMO: survey results. *Perfusion*; **5**: 193–201.

Bartlett RH. (2000). Extracorporeal life support in the management of severe respiratory failure. *Clinics in Chest Medicine*; **21**: 555–561.

Brodie D, Bacchetta M. (2011). Extracorporeal membrane oxygenation for ARDS in adults. *The New England Journal of Medicine*; **365**: 1905–1914.

Brunkhorst FM, Engel C, Ragaller M, Welte T, Rossaint R, Gerlach H, Mayer K, John S, Stuber F, Weiler N, Oppert M, Moerer O, Bogatsch H, Reinhart K, Loeffler M, Hartog C, German Sepsis Competence N. (2008). Practice and perception – a nationwide survey of therapy habits in sepsis. *Critical Care Medicine*; **36**: 2719–2725.

Cavarocchi NC, Wallace S, Hong EY, Tropea A, Byrne J, Pitcher HT, Hirose H. (2015). A cost-reducing extracorporeal membrane oxygenation (ECMO) program model: a single institution experience. *Perfusion*; **30**: 148–153. https://www.elso.org/Portals/0/IGD/Archive/FileManager/97000963d6cusersshyerdocumentselsoguidelinesfortrainingandcontinuingeducationofecmospecialists.pdf

Cordell-Smith JA, Roberts N, Peek GJ, Firmin RK. (2006). Traumatic lung injury treated by extracorporeal membrane oxygenation (ECMO). *Injury*; **37**: 29–32.

Critical Care Networks. 2014. National Nurse Leads. National Standards for Critical Care Nurse Education. A framework to improve educational outcomes and quality of care 2012 [Online]. http://www.cc3n.org.uk/education-training/4577977309 [accessed 04/05/16].

Davies A, Jones D, Bailey M, Beca J, Bellomo R, Blackwell N, Forrest P, Gattas D, Granger E, Herkes R, Jackson A, Mcguinness S, Nair P, Pellegrino V, Pettila V, Plunkett B, Pye R, Torzillo P, Webb S, Wilson M, Ziegenfuss M. (2009). Extracorporeal membrane oxygenation for 2009 influenza A(H1N1) acute respiratory distress syndrome. *JAMA*; **302**: 1888–1895.

ELSO. 2013. ELSO guidelines for ECMO centers [Online]. ELSO. http://www.elso.org/Portals/0/IGD/Archive/FileManager/faf3f6a3c7cusersshyerdocumentselsoguidelinesecmocentersv1.8.pdf (accessed 04/05/16).

Extracorporeal Life Support Organisation. 2010. ELSO guidelines for training and continuing education for ECMO specialists [Online]. (accessed 04/05/16).

Faculty of Intensive Care Medicine. 2015. Faculty of intensive care medicine. The CCT in intensive care medicine [Online]. http://www.ficm.ac.uk/sites/default/files/CCT in ICM Part III - Syllabus %28Aug2015 v2.1%29.pdf (accessed 04/05/16).

Freeman R, Nault C, Mowry J, Baldridge P. (2012). Expanded resources through utilization of a primary care giver extracorporeal membrane oxygenation model. *Critical Care Nursing Quarterly*; **35**: 39–49.

Hemmila MR, Rowe SA, Boules TN, Miskulin J, Mcgillicuddy JW, Schuerer DJ, Haft JW, Swaniker F, Arbabi S, Hirschl RB, Bartlett RH. (2004). Extracorporeal life support for severe acute respiratory distress syndrome in adults. *Annals of Surgery*; **240**: 595–605; discussion 605-7.

Hill JD, O'brien TG, Murray JJ, Dontigny L, Bramson ML, Osborn JJ, Gerbode F. (1972). Prolonged extracorporeal oxygenation for acute post-traumatic respiratory failure (shock-lung syndrome). Use of the Bramson membrane lung. *New England Journal of Medicine*; **286**: 629–634.

Khoshbin E, Roberts N, Harvey C, Machin D, Killer H, Peek GJ, Sosnowski AW, Firmin RK. (2005). Poly-methyl pentene oxygenators have improved gas exchange capability and reduced transfusion requirements in adult extracorporeal membrane oxygenation. *ASAIO Journal*; **51**: 281–287.

Lawson DS, Lawson AF, Walczak R, Mcrobb C, Mcdermott P, Shearer IR, Lodge A, Jaggers J. (2008). North American neonatal extracorporeal membrane oxygenation

(ECMO) devices and team roles: 2008 survey results of Extracorporeal Life Support Organization (ELSO) centers. *The Journal of Extra-Corporeal Technology*; **40**: 166–174.

Maclaren G, Combes A, Bartlett RH. (2012). Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. *Intensive Care Medicine*; **38**: 210–220.

Maggio P, Hemmila M, Haft J, Bartlett R. (2007). Extracorporeal life support for massive pulmonary embolism. *Journal of Trauma*; **62**: 570–576.

Marasco SF, Lukas G, McDonald M, McMillan J, Ihle B. (2008). Review of ECMO (extracorporeal membrane oxygenation) support in critically ill adult patients. *Heart, Lung & Circulation*; **17**: S41–S47.

Mccoach RM, Baer LD, Wise RK, Woitas KR, Palanzo DA, Pae WE Jr, El Banayosy A. (2010). The new role of the perfusionist in adult extracorporeal life support. *Perfusion*; **25**: 21–24.

Mendler N, Podechtl F, Feil G, Hiltmann P, Sebening F. (1995). Seal-less centrifugal blood pump with magnetically suspended rotor: rot-a-flot. *Artificial Organs*; **19**: 620–624.

Mikkelsen ME, Woo YJ, Sager JS, Fuchs BD, Christie JD. (2009). Outcomes using extracorporeal life support for adult respiratory failure due to status asthmaticus. *ASAIO Journal*; **55**: 47–52.

Morris AH, Wallace CJ, Menlove RL, Clemmer TP, Orme JF Jr, Weaver LK, Dean NC, Thomas F, East TD, Pace NL, Suchyta MR, Beck E, Bombino M, Sittig DF, Bohm S, Hoffmann B, Becks H, Butler S, Pearl J, Rasmusson B. (1994). Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO_2 removal for adult respiratory distress syndrome. *American Journal of Respiratory and Critical Care Medicine*; **149**: 295–305.

Munshi L, Telesnicki T, Walkey A, Fan E. (2014). Extracorporeal life support for acute respiratory failure. A systematic review and metaanalysis. *Annals of the American Thoracic Society*; **11**: 802–810.

NICE. 2011. Extracorporeal membrane oxygenation for severe acute respiratory failure in adults [Online]. https://www.nice.org.uk/guidance/ipg391 (accessed 04/05/15).

Noah MA, Peek GJ, Finney SJ, Griffiths MJ, Harrison DA, Grieve R, Sadique MZ, Sekhon JS, Mcauley DF, Firmin RK, Harvey C, Cordingley JJ, Price S, Vuylsteke A, Jenkins DP, Noble DW, Bloomfield R, Walsh TS, Perkins GD, Menon D, Taylor BL, Rowan KM. (2011). Referral to an extracorporeal membrane oxygenation center and mortality among patients with severe 2009 influenza A(H1N1). *JAMA*; **306**: 1659–1668.

Odell RM, Erickson R, Mcewan RM. (1992). Identification and certification of extracorporeal membrane oxygenation specialists in the United States. *ASAIO Journal*; **38**: 858–861.

Paden ML, Conrad SA, Rycus PT, Thiagarajan RR, Registry E. (2013). Extracorporeal life support organization registry report 2012. *ASAIO Journal*; **59**: 202–210.

Peek GJ, Mugford M, Tiruvoipati R, Wilson A, Allen E, Thalanany MM, Hibbert CL, Truesdale A, Clemens F, Cooper N, Firmin RK, Elbourne D, Collaboration CT. (2009). Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial. *Lancet*; **374**: 1351–1363.

Pham T, Combes A, Roze H, Chevret S, Mercat A, Roch A, Mourvillier B, Ara-Somohano C, Bastien O, Zogheib E, Clavel M, Constan A, Marie Richard JC, Brun-Buisson C, Brochard L, Network RR. (2013). Extracorporeal membrane oxygenation for pandemic influenza A(H1N1)-induced acute respiratory distress syndrome: a cohort study and propensity-matched analysis. *American Journal of Respiratory and Critical Care Medicine*; **187**: 276–285.

Royal College of Anaesthetists. 2010. The CTT in anaesthetics-advanced level training (Annex E) [Online]. http://www.rcoa.ac.uk/system/files/TRG-CCT-ANNEXE_0.pdf (accessed 04/05/16).

Sutton RG, Salatich A, Jegier B, Chabot D. (2009). A 2007 survey of extracorporeal life support members: personnel and equipment. *The Journal of Extra-Corporeal Technology*; **41**: 172–179.

Turner DA, Cheifetz IM. (2013). Extracorporeal membrane oxygenation for adult respiratory failure. *Respiratory Care*; **58**: 1038–1052.

Zapol WM, Snider MT, Hill JD, Fallat RJ, Bartlett RH, Edmunds LH, Morris AH, Peirce EC 2nd, Thomas AN, Proctor HJ, Drinker PA, Pratt PC, Bagniewski A, Miller RG Jr. (1979). Extracorporeal membrane oxygenation in severe acute respiratory failure. A randomized prospective study. *JAMA*; **242**: 2193–2196.