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British societies guideline on the management of emergencies in patients on extracorporeal membrane oxygenation

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Abstract

Extracorporeal membrane oxygenation (ECMO) is providing an increasingly important therapy for patients in severe heart and lung failure. Care of these patients is complex, with changes in circulation that mean standard advanced life support algorithms may not always be applicable. Through collaboration between all UK ECMO centres and eight national societies, we have assessed the current evidence base and, using a modified Delphi process, produced national guidelines on the management of emergencies on ECMO. The guidelines focus on the recognition of cardiac arrest, team prioritisation, and early ECMO troubleshooting for key life-saving interventions. The guidelines are applicable to all staff and types of ECMO performed in the UK and should be utilised in conjunction with appropriate training. In summary, the joint British societies and ECMO centres working group present the UK guideline for the management of emergencies in ECMO.

Keywords: ECMO, Cardiac arrest, Resuscitation, Mechanical circulatory support

Introduction

Extracorporeal membrane oxygenation (ECMO) has provided lifesaving organ support for an increasing number of our sickest patients [1]. ECMO, in the most basic terms, consists of a drainage and return cannula attached to a pump and blood oxygenator. Various configurations to support the lung, heart, or both are formed by the approach in which venous or arterial systems are accessed. The therapy can be delivered both through large peripheral vessels and centrally through an open chest.

The UK severe respiratory failure veno-venous ECMO (VV ECMO) has grown in strength since its inception in 2011, with a reported 74% survival to intensive care discharge [2]. During the COVID-19 pandemic, the service also rescued severely unwell patients, gaining national attention [3, 4]. Increasingly, veno-arterial ECMO (VA ECMO) is utilised in the management of patients in cardiogenic shock as well as cardiac arrest, termed extracorporeal cardiopulmonary resuscitation (ECPR) [5–7].

Decision making around patient selection and the cannulation is key. The care of patients on support is equally important, especially considering the high risk of serious complications. In VV ECMO, 40.2% of

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patients suffered a complication, with bleeding, intracranial haemorrhage, and mechanical complications (such as oxygenator or cannula failure) being the commonest [8, 9]. VA ECMO carries an even higher risk, particularly related to vascular complications such as limb ischaemia [10–12]. Early intervention in complications is key to preventing a vicious circle of decline into cardiac arrest [13].

In the UK, there are 13 centres that provide ECMO support, which consists of a mixture of severe respiratory failure, general, and transplant cardiothoracic centres. The teams who manage these patients will consist of round-the-clock cover from physicians and nurses with expertise in ECMO, clinical perfusionist scientists, and the wider intensive care multidisciplinary team. The experience level of resident staff, particularly out of hours, can be variable, and frontline healthcare staff need to be empowered with the tools they need to manage emergencies.

ECMO support introduces changes to the circulation which can make it difficult to utilise existing advanced life support algorithms. For example, in VA ECMO, there can often be no pulsatile blood flow and therefore no pulse detectable [14]. In fact, there may be no detectable heart rhythm or even ventricular fibrillation with a preserved circulation. In all types of ECMO, carbon dioxide removed by the oxygenator can lead to an artificially low end-tidal carbon dioxide measurement. The dependency of a patient with a failing heart or lungs on ECMO means device failure can be catastrophic, as the patient may have no physiological reserve to recover with standard advanced life support measures alone.

There have been several guidelines produced to aid staff in the management of emergencies on ECMO [15]. Each has its own strengths and weaknesses; however, few have taken the approach of broader advanced life support algorithms [16]. These algorithms excel in providing a structured approach, which can be used as a basis by staff of all disciplines and experience for resuscitation in emergencies. In advanced trauma life support, a primary survey identifies immediate life-saving problems prior to a more complete secondary and tertiary survey, which guide more definitive management [17]. This has recently been replicated in the UK for the management of emergencies in patients with implantable LVADs [18].

In this guideline, we utilised this approach to support hospital first responders in recognition of arrest and ECMO troubleshooting in the first few minutes of deterioration. We sought to provide the simplest possible advice to maximise the chances of surviving a life-threatening emergency regardless of ECMO configuration or underlying pathology. This approach minimises cognitive load by prioritising immediate resuscitation and deferring consideration of more definitive assessment and management.

Scope & methods

This guideline is designed for staff managing patients treated with ECMO support. It is focussed on cardiac arrest; however, many of the same principles apply to various emergency settings that may occur in patients supported with ECMO.

We developed this guideline by convening a national ECMO Emergency Algorithm Working Group comprising the 14 UK ECMO centres: Barts Health NHS Trust, London; Bristol Royal Infirmary, Bristol; Freeman Hospital, Newcastle; Golden Jubilee National Hospital, Glasgow; Guy's & St Thomas' NHS Foundation Trust, London; Hammersmith Hospital, London; Harefield Hospital, London; King's College Hospital, London; Glenfield Hospital, Leicester; Royal Brompton Hospital, London; Royal Papworth Hospital, Cambridge; St George's University Hospital, London; University Hospitals Birmingham NHS Foundation Trust, Birmingham; and Wythenshawe Hospital, Manchester. The process was supported by eight national organisations: Association of Cardiothoracic Anaesthesia and Critical Care, British Association of Critical Care Nurses, British Cardiovascular Society, British Society of Heart Failure, Intensive Care Society, Faculty of Intensive Care Medicine, Resuscitation Council UK, and the Society for Cardiothoracic Surgery in Great Britain & Ireland. A patient representative from the Faculty of Intensive Care Medicine was a core member throughout the process.

Service leads were contacted at all UK ECMO centres and relevant national societies and asked to nominate relevant team members to participate in the process. Terms of reference were developed during the initial online meeting and agreed by consensus. Multidisciplinary and multispecialty input was mandated along with oversight from a patient representative (Online Appendix 2). All conflicts of interest (COI) were identified and declared; the chair was required to have no direct COI. Any member with a direct financial COI was not eligible to decide on recommendations relating to the COI.

A systematic literature search was conducted using the PubMed database via the NCBI interface to identify studies relevant to the use of ECMO in the context of cardiac arrest and resuscitation. The search included all articles published up to 1 May 2024. The search terms included "ECMO" and "cardiac arrest" and one of the following: "cardiac arrest," "resuscitation," "CPR," "emergencies," "algorithm," "alarms," "ventricular arrhythmias," "access insufficiency," "bleeding," "signs of life," "capnography," "basic life support," and "advanced life support." Boolean operators were applied appropriately to structure the search. Studies were included if they were conducted in human subjects, focussed on adult populations (age ≥ 18), published in English, and contained relevant content related to ECMO and cardiac arrest or resuscitation using the specified keywords. The initial search returned 1,257 articles. After duplicate removal and preliminary title and abstract screening, full-text articles were assessed for eligibility. A total of 15 studies were identified and included in the final evidence review. The quality and certainty of evidence for each included study were assessed taking into account domains such as risk of bias, consistency, directness, precision, and potential publication bias [19, 20]. Findings were synthesised and summarised in evidence tables, which were reviewed by an expert panel to inform the development of recommendations (see Online Appendix 1).

The European Society of Cardiology framework for guidelines was used to determine the class of recommendation and level of evidence [21]. This details a standard process for membership formation and declaration of COI. A quorate 75% agreement was required for a level of recommendation. The class of recommendation is as follows: I is recommended, IIa should be considered, IIb may be considered, III is not recommended. The level of evidence is as follows: A refers to multiple randomised trials, B to a single randomised trial, C to observational data and expert consensus.

The working group employed a modified Delphi process to reach consensus, defined as at least 75% agreement amongst voting members. Each ECMO centre and national society was allocated one vote, with the consortium chair casting the deciding vote in the event of a tie. A quorum was established as participation by more than 50% of voting members. The consultation process was initiated in April 2024 with the formation of the working group in June 2024. Through electronic communications, virtual meetings, and after five modified Delphi rounds (Online Appendix 2), the following guideline was finalised in June 2025.

UK ECMO Emergency algorithm development

We have detailed below the key issues identified and recommendations placed in the generation of the emergency algorithm (Fig. 1). This is applicable to all configurations of ECMO, whether this be for respiratory or cardiac failure.

A core principle described below is division into a patient and device team with an overall team leader. During a cardiac arrest, the team leader should use the algorithm as a checklist to guide management. Institutions will need to determine the optimal composition of the resuscitation team to implement this model effectively. This should include both patient care and ECMO-related expertise, along with a designated individual capable of assuming overall team leadership.

A regular clinical familiarity with ECMO is essential, and the guideline is intended to be complementary and implemented through the provision of structured training [22].

Recommendation	Class	Level
Emergency responders to patients deteriorating and in cardiac arrest with ECMO should have dedicated resuscitation training using a structured algorithm	IIa	C

Initial response

Recognition of cardiac arrest on ECMO can be difficult. As with all advanced life support algorithms, we have placed a starting clinical parameter of a patient who is unresponsive and/or is not breathing normally [23]. Though ECMO patients can be sedated and mandatory ventilated, increasingly many ECMO patients are managed fully awake. This clinical parameter is combined with one measured value for confirmation of cardiac arrest, a mean arterial pressure (MAP) of < 30 mmHg. There is no evidence for a set MAP to define compatibility with life; however, consensus was that below this, no adult patient on ECMO would have an adequate circulation. The term “confirmed” was placed preceding this to emphasise the need to check that the transducer is functioning and levelled appropriately.

The MAP was deemed to be the fundamental criterion for diagnosing cardiac arrest in this setting. There are also other variables that can be supportive for the recognition of cardiac arrest, especially if any uncertainty remains with the accuracy of MAP. This includes a sudden unexpected drop in endotracheal end-tidal carbon dioxide ($ETCO_2$) and no flow on the ECMO. Though ETCO2 has some evidence in resuscitation decision making, its use in ECMO is complicated by the presence of the membrane oxygenator, which removes carbon dioxide from the blood and the bypassing of lung circulation in peripheral VA ECMO [24]. Both can lead to abnormally low $ETCO_2$ [25]. Absence of ECMO flow is immediately life-threatening for a patient who is dependent and can lead to circulatory arrest. However, if the patient has started to recover and is ready for weaning, the patient might be minimally affected by a sudden loss of ECMO flow.

Activation of the cardiac arrest team varies across the UK; however, all hospitals utilise the 2222 emergency number, which has been incorporated into the algorithm. Each institution will need to adapt the exact phrase to be reported to their switchboard, such as alerting additional

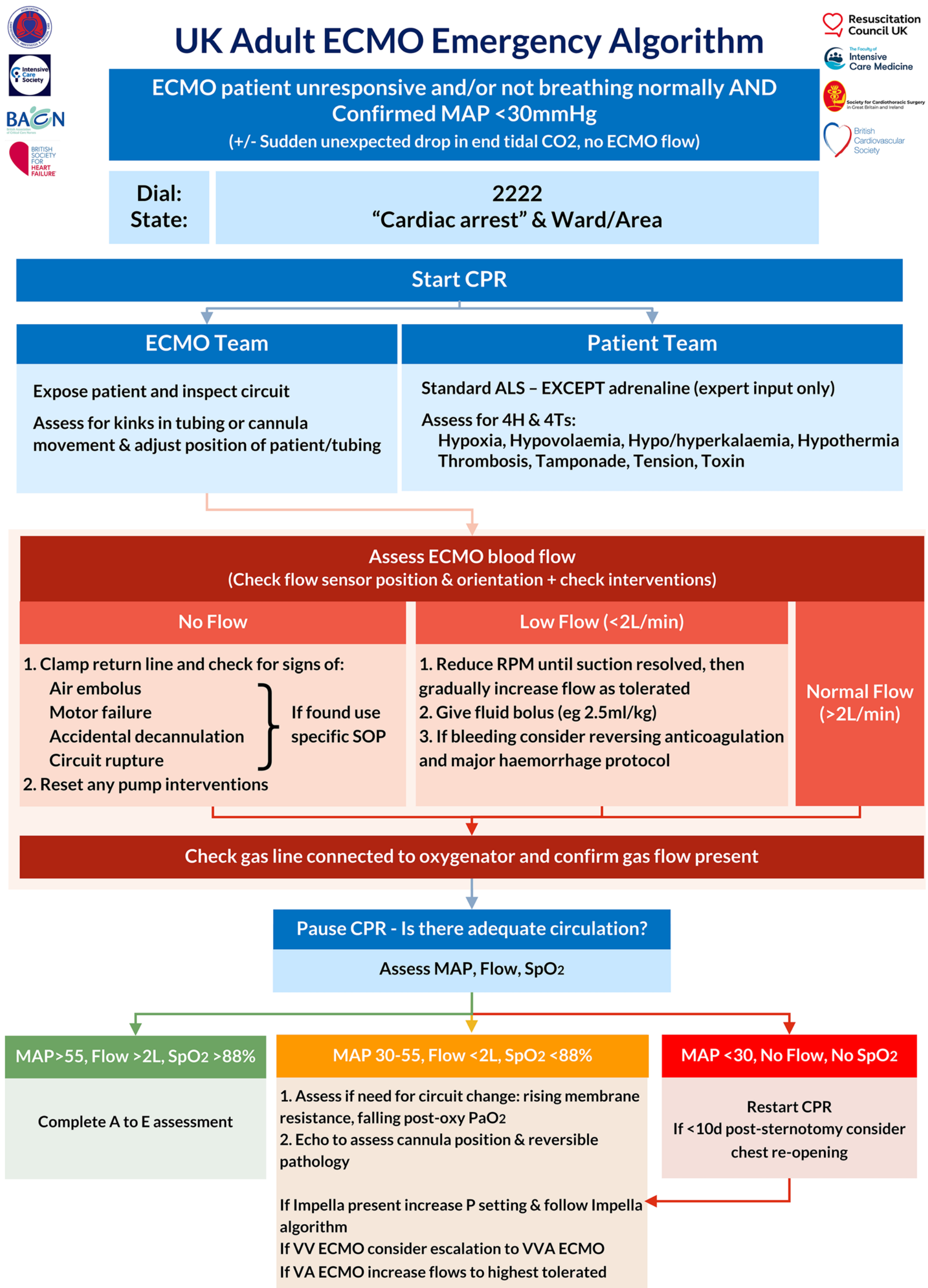

Fig. 1 UK adult ECMO emergency algorithm. *ECMO* extracorporeal membrane oxygenation, *MAP* mean arterial pressure, *CPR* cardiopulmonary resuscitation, *ALS* advanced life support, *SOP* standard operating procedure, *RPM* revolutions per minute, *SpO*$_2$ oxygenation saturations, *OXY* oxygenator, *VV* veno-venous, *VVA* veno-venous-arterial, *VA* veno-arterial

specialist teams in mechanical support when an emergency occurs in an ECMO patient. Some specialist teams are always present on the unit, and thus only an emergency buzzer needs to be activated.

Recommendation	Class	Level
In the event of a patient who is unresponsive or not breathing normally a confirmed mean arterial pressure < 30 mmHg should be an indication to initiate CPR. Additional supportive features for cardiac arrest include a sudden unexpected drop in endotracheal end tidal carbon dioxide and no ECMO flow	IIa	C

Initial and secondary responder

Once cardiopulmonary resuscitation (CPR) has been initiated, the responders will need to split into two teams: one to focus on the ECMO and the other on the patient. These two teams should be overseen by a team leader who will follow the overall algorithm and patient management. In a patient who is dependent on ECMO, the priority in cardiac arrest should be to restore circulation by resolving any device dysfunction caused by either mechanical failure or physiological problems.

Cardiac arrest or "patient" teams are well defined in hospital systems and should follow standardised advanced life support algorithms. The only consideration for deviation in this situation is in the use of cardiac arrest bolus dose adrenaline. In cases where device troubleshooting may restore device flow quickly, the patient may suffer further organ injury from adrenaline-induced hypertension impeding adequate device support. Use of adrenaline, however, may well still be indicated, especially if device troubleshooting has failed. The decision-making should be made by an "expert" who should have a good understanding of the device and resuscitation efforts. When doses are given, reduced dosing or infusions may be preferable to cardiac arrest dosing. The patient team should exclude any reversible causes, notably bleeding, which can occur with increased frequency in ECMO patients due to haemolysis, anticoagulation, and underlying disease processes [26].

The "ECMO" team will need to be defined by each institution, but typically will include a doctor, nurse, and perfusion specialist in ECMO. The focus of this team should start with fully exposing the patient and inspecting the circuit, noting colour change between drainage and return tubes. Any kinks in the tubing should be straightened, and cannulas should be assessed for position changes. Adjusting the bed and patient to a supine position can help resolve any unseen kinking of the cannulas.

Recommendation	Class	Level
The recommended priority in cardiac arrest in ECMO patients is to restore circulation by resolving device dysfunction caused by mechanical failure or physiological problems	I	C

ECMO troubleshooting

ECMO troubleshooting can involve an array of interventions from resolving a simple kink in the tubing to catastrophic circuit disruption.

Initial actions by the ECMO team should be focussed on ensuring adequate ECMO blood flow. It is important to ensure the flow sensor is correctly oriented and that any programmed interventions on the ECMO have been appropriately reset.

If ECMO flow is greater than 2L/min, then the team should proceed to the next step of troubleshooting. It is important to remember this may be an inadequate level of support for many clinical contexts. However, the flow is sufficient to indicate the device is functioning and allow progression to other stages of troubleshooting.

In low flow defined as ECMO flow < 2 L/min, it is likely there is access insufficiency occurring, and the first step will be to reduce the revolutions per minute (RPM) until suction is resolved. The RPMs should then be gradually increased to the highest flow tolerated. An intravenous fluid bolus, for example, 2.5 ml/kg of crystalloid, can be given to improve drainage, and the RPMs further adjusted. Causes of low flow and suction should be assessed in conjunction with the patient team. A common cause is bleeding, and consideration should be given to a major haemorrhage protocol and reversal of anticoagulation if needed. Echocardiography can be useful to identify cannula position, tamponade, cardiac dysfunction, and the need for vasoactive medications to improve pulmonary and systemic circulation.

No flow is a critical issue, and the return ECMO line to the patient must be clamped immediately. There are four serious problems that may have arisen, and each will have its own manufacturer and centre-specific standard operating procedure (SOP) to resolve. An air embolus requires de-airing of the device utilising in-built side ports and physically manipulating air within the circuit. Both teams should identify any source of air, such as an open port on a central line or malposition of the cannulae. In motor failure, the ECMO oxygenator will need to be transitioned to a new pump/console. In some cases, a hand crank can be utilised till a replacement pump is available. In accidental decannulation or circuit rupture, there will need to be local systems in place, such as ECPR, for rapid recannulation or circuit change if this is deemed to be appropriate. On resolution of the issue, ensure the pump interventions are reset on the console to re-initiate flow.

After troubleshooting ECMO flow, it is important to determine there is gas flow present to the oxygenator with a visible colour change between the drainage and return tubes. Repeated errors have been reported across institutions, such as a transport cylinder that has depleted after a transfer, with failure to transition to walled oxygen [22]. Many ECMO devices have no inbuilt alarm system to detect a loss of gas flow, making manual checking of the gas line throughout the entire flow path mandatory, ensuring connection at both the flow metre and oxygenator, and confirming flow is present.

Recommendation	Class	Level
In an acutely unwell patient with low ECMO flow, expose the patient and circuit to assess for tubing kinks or cannula movement and adjust patient and tubing position if needed. Reduce the revolutions per minute until suction resolved and consider a fluid bolus (e.g. 2.5 ml/kg) to manage suction	I	C
In an acutely unwell patient with no ECMO flow, expose the patient and circuit to assess for tubing kinks or cannula movement and adjust patient and tubing position if needed. If flow not improved clamp the return line to the patient and follow standardised operating procedures for air embolus, motor failure, circuit rupture or accident decannulation if present	IIa	C
In an acutely unwell patient on ECMO ensure the gas line is connected to the oxygenator and confirm gas flow is present	I	C

Determination of adequacy of circulation

The above described ECMO troubleshooting should be completed within a few minutes. At this point, reassessment of circulation can be determined utilising a combination of the MAP, ECMO flow, and patient oxygenation saturations. We pragmatically decided on an intermediate category between the defined cardiac arrest variables and clinical parameters associated with a normal circulation based on consensus agreement.

Adequate circulation is confirmed by a MAP > 55 mmHg, ECMO flow > 2 L/min, and oxygenation saturations > 88%. At this stage, the team should complete an Airway, Breathing, Circulation, Disability, and Exposure (A to E) assessment.

If there is intermediate circulation with a MAP 30–55 mmHg, ECMO flow < 2 L/min and/or saturations < 88%, then an assessment should be made whether an ECMO circuit change is required. This can be indicated by rising transmembrane resistance prior to arrest and falling post-oxygenator oxygen partial pressure. Emergency echocardiogram must be performed to assess for reversible pathology such as pericardial tamponade and ensure appropriate cannulae position. If available, this step should ideally be performed as early as possible during patient resuscitation. However, due to practical delays such as the time required to power up echocardiography machines and the availability of appropriately skilled personnel, it has been positioned at this stage of the algorithm. If an Impella is present in an ECPELLA (ECMO and Impella) arrangement, then increase the P setting if able and follow an Impella specific algorithm [27]. If the patient is on VV ECMO and remains with inadequate circulation or is in cardiac arrest, then consideration for escalation to VVA ECMO should be considered. If the patient is on VA ECMO, the flows should be maximised to the highest tolerated level till circulation is improved.

If inadequate circulation remains with a MAP < 30 mmHg, no ECMO flow, and no recordable saturations, then CPR should be restarted. If the patient is less than 10 days post sternotomy, then emergent re-sternotomy should be considered [28].

There is no evidence of the safety of using mechanical cardiac compression devices in patients with mechanical circulatory support. Pragmatically, their use will be required to facilitate ECPR; however, outside of this context, no recommendation has been made.

There is no evidence to suggest that CPR is harmful to patients on ECMO who have an inadequate circulation. The vast majority of ECMO therapy is performed in patients percutaneously; however, there is a significant portion who receive centrally inserted ECMO [1]. These patients can also vary in whether the chest remains fully or partially open post sternotomy on the intensive care unit. As such, a CPR decision, whether external or internal, will need to be made by the clinical teams on a patient-specific basis. In a patient with a closed chest on central VA ECMO, there should not be any deviation needed from the initial troubleshooting set out in this algorithm.

Recommendation	Class	Level
Assessment of adequate circulation should be made utilising a number of physiological parameters including mean arterial pressure, saturations and ECMO flow	IIa	C
CPR can be performed safely in ECMO and should be considered in patients with inadequate circulation	IIa	C
In the presence of inadequate circulation in an ECMO patient less than 10 days post cardiotomy, emergent chest re-opening should be considered if initial measures have failed	IIa	C

Holistic care

Though this algorithm is focussed on an active resuscitation approach to patients who have suffered a life-threatening emergency on ECMO, it is important to recognise that this may not be the appropriate course of action for all patients. It is important that decision-making about the appropriateness of different resuscitative strategies is made early during a patient's journey and communicated effectively to the whole team.

During resuscitative efforts, consideration must be given to allowing relatives or companions to be present. An experienced member of staff who can explain what is going on should be delegated to stay with them and liaise with the team on their behalf.

Conclusion

We present the UK ECMO emergency algorithm to be used by staff managing patients on ECMO support. This guideline has been endorsed by all UK ECMO centres and eight national societies. The guideline outlines a pragmatic advanced life support approach to the management of emergencies on ECMO by frontline healthcare staff in the first few minutes of a patient's deterioration.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s00134-025-08142-2.

Abbreviations

A to E: Airway, breathing, circulation, disability and exposure; CPR: Cardiopulmonary resuscitation; ECPR: Extracorporeal cardiopulmonary resuscitation; ECMO: Extracorporeal membrane oxygenation; ETCO2: End-tidal carbon dioxide; MAP: Mean arterial pressure; RPM: Revolutions per minute; SOP: Standard operating procedure; VA ECMO: Veno-arterial extracorporeal membrane oxygenation; VV ECMO: Veno-venous extracorporeal membrane oxygenation.

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Data availability

Not applicable.

Declarations

Conflicts of interest

Waqas Akhtar has received educational grants to institution from Abiomed, Abbott, Chalice, Medtronic, Takeda, and Resuscitec, and speaker honoraria from Abiomed. Alex Rosenberg received educational grants and speaker honoraria from Getinge, Resuscitec, and Abiomed. Sofia Pinto received speaker honoraria from Abiomed. Brijesh Patel received speaker honoraria from Johnson & Johnson, Medtronic, and participates on a Novartis board. Marlies Ostermann received research funding to institution from Baxter and Biomerieux. Matt Govier has received speaker honoraria from Abiomed. Roy Gardner has received speaker honoraria from Abbott, Alnylam, AstraZeneca, Boehringer Ingelheim, Boston Scientific, Novartis, Pfizer, and Roche Diagnostics.

Ethical approval

No ethical approval was required.

PPI

Patient representation was present throughout the process.

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