Regional Planning for Extracorporeal Membrane Oxygenation Allocation During Coronavirus Disease 2019

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Health systems confronting the coronavirus disease 2019 (COVID-19) pandemic must plan for surges in ICU demand and equitably distribute resources to maximize benefit for critically ill patients and the public during periods of resource scarcity. For example, morbidity and mortality could be mitigated by a proactive regional plan for the triage of mechanical ventilators. Extracorporeal membrane oxygenation (ECMO), a resource-intensive and potentially life-saving modality in severe respiratory failure, has generally not been included in proactive disaster preparedness until recently. This paper explores underlying assumptions and triage principles that could guide the integration of ECMO resources into existing disaster planning. Drawing from a collaborative framework developed by one US metropolitan area with multiple adult and pediatric extracorporeal life support centers, this paper aims to inform decision-making around ECMO use during a pandemic such as COVID-19. It also addresses the ethical and practical aspects of not continuing to offer ECMO during a disaster.

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The coronavirus disease 2019 (COVID-19) pandemic has placed unprecedented pressure on ICUs in Asia and Europe to provide scalable respiratory critical care in hospitals already near their capacity.[1] Preparations at US hospitals for surges in ICU demand are well underway, with an overall goal of equitably distributing resources to maximize benefit during a period of resource scarcity. Existing critical care guidelines address crisis decision-making and the inevitable demand for ICU beds, ventilators, and medications.[2-4] To avoid ad hoc decision-making during a pandemic, guidelines emphasize the proactive development of operational plans and clinical recommendations for specific shortages.[5,6] This is especially important for triage decisions about high-intensity medical interventions, such as extracorporeal life

ABBREVIATIONS: COVID-19 = coronavirus disease 2019; ECMO = extracorporeal membrane oxygenation; SAT = Science Advisory Team

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support, which includes extracorporeal membrane oxygenation (ECMO).

ECMO can be a life-saving therapy for select patients with influenza- or coronavirus-associated pneumonia leading to severe ARDS.[7,8] Stimulated by improvements in ECMO safety and transportability, the volume of adult ECMO cases and ECMO-capable centers has increased dramatically in the wake of the 2009 influenza A (H1N1) pandemic.[9] Furthermore, the World Health Organization's interim clinical guidance for COVID-19 suggests that, in regions with access to ECMO expertise, patients with refractory hypoxemia despite lung protective ventilation strategies be considered for referral to an ECMO center.[10] ECMO is resource intensive compared with conventional critical care, its availability is inconsistent, and regional coordination is often lacking.[11,12] These challenges only amplify the vulnerability of ECMO to resource saturation during a pandemic; however, guidelines have neglected the thoughtful allocation of ECMO resources compared with other modalities for artificial support.

The Minnesota Department of Health Science Advisory Team (SAT) is an advisory body to the state health commissioner. It includes clinical, policy, ethics, and public health members who develop guidelines for clinical resource allocation during crises. The SAT has developed regional response plans for various scenarios.[13] These plans combine subject matter expertise from the SAT with policy and operational support from the local health-care coalition, a disaster planning and response group representing hospitals, public health, emergency medical services, and emergency management. Key principles assure the following:

- Clinical decision support tools are available in advance, and can be adapted to the incident,
- All participating hospitals have awareness of the situation via a coordination/consultation mechanism,
- Specialty resources are directed to those most likely to benefit, and
- Expert physicians are involved in the decision-making process.

Because of the significant potential for resource saturation during a viral pandemic, a similar regional construct was desired for ECMO.

Of the five ECMO centers in Minnesota (population 5.5 million), four are in the Minneapolis/St Paul metropolitan area (population 3.5 million). At peak capacity, these centers could theoretically support 55 patients on ECMO simultaneously. Sustainability depends on available personnel, supplies, and ICU space. Several referring hospitals can initiate ECMO but cannot provide ongoing management.

Our group identified six core assumptions that inform ECMO decision-making in crises. They are as follows:

1. ECMO is a limited-resource subject to saturation.
2. Some indications for ECMO are better characterized than others, allowing predictions about duration of support and patient outcome. For example, patients on ECMO with influenza A pneumonia and ARDS in 2009 received ECMO and mechanical ventilation for an average of 10 and 25 days, respectively, with acceptable outcomes.[7] Although several centers in the United States and abroad have experience with ECMO for patients infected with COVID-19, outcome data are not widely available.
3. For other causes of refractory cardiopulmonary failure, the role of ECMO and optimal management are still evolving. This raises several medical and ethical questions regarding resource distribution during crises.
4. ECMO requires a substantial investment of resources. It may be necessary to limit ECMO support to patients more likely to survive. These decisions—likely made at the physician or hospital level—ought to be based on a framework determined in advance with input from subject experts, ethics committees, health systems, and the community.
5. When demand for ECMO is high and prioritization by indication is necessary, preference should be given to conditions with historically better outcomes and shorter expected duration of support.
6. Epidemics may require further prioritization or novel strategies. A process must be in place to integrate public health and clinical expertise to address incident-specific challenges.

Operationalizing these concepts requires communication and consensus-building. Beginning in 2019, we leveraged an existing ECMO workgroup that includes two designees from each regional ECMO center—generally the ECMO medical director and program coordinator—who understand staffing, equipment, and ICU capacity at their institution. Members of this ECMO consortium have maintained regular communication around pandemic preparedness through semiannual meetings. Contact between centers has necessarily kept pace with the rapid spread of

COVID-19 infection in our community; we hold biweekly virtual meetings with more frequent operational updates as necessary. We have collaborated on tabletop exercises to simulate just-in-time triage of patients and ECMO equipment. The ECMO consortium developed an online surveillance tool which displays center-specific and aggregate census data for actual ICU, ventilator, and ECMO capacity at the four ECMO centers in our metropolitan area. This allows ECMO physicians and the larger health-care coalition to maintain situational awareness and hold each other accountable should scarce resource allocation become necessary in our region during the dynamic trajectory of the COVID-19 pandemic.

In our concept, when an ECMO center lacks resources to initiate or manage ECMO, or anticipates lacking these resources shortly, other centers will be contacted. If two or more regional centers are unable to assist, the requesting center will use an existing regional on-call disaster response coordinator to trigger an immediate conference call among regional ECMO directors. If, during a prolonged incident, demand has outstripped regional resources, the group will plan for incident-specific prognosis, plan for equipment shortages, and evaluate the feasibility of continuing to provide ECMO. The COVID-19 pandemic may require a centralized triage team, with rotating ECMO physician support, to evaluate transfer requests in real time from referring hospitals in our region using a toll-free number provided by the health-care coalition.

A surge in demand may trigger resource conservation measures, such as the discontinuation of extracorporeal CPR programs for patients suffering refractory out-of-hospital cardiac arrest, deferring elective procedures likely to require postoperative ECMO (eg, congenital heart disease repair), and an earlier return to high-intensity mechanical ventilation for patients already on veno-venous ECMO support.

Our work group agreed on a framework for ECMO decision-making in times of resource constraint (e-Appendix 1, Table 1). The timing of deployment of this ECMO allocation framework will need to be flexible, incident-specific, and synchronized with the larger regional health-care response, and likely will coincide

TABLE 1] Framework for Prioritizing Common ECMO Indications During a Disaster, by Predicted Survival and Duration of Support

Tier (Predicted Survival)	Short Duration ECMO Anticipated (≤ 5 d)	Long Duration ECMO Anticipated (> 5 d)
Tier 1 (> 60%)	Acute hypercarbic respiratory failure because of status asthmaticus	Acute respiratory failure because of infection (especially influenza or coronavirus) with single organ failure
	Cardiac arrest or cardiogenic shock because of severe accidental hypothermia (ie, extracorporeal rewarming)	Acute respiratory failure because of trauma (drowning, pulmonary contusion, etc) with single organ failure
	Pediatric pre- and postcardiotomy cardiogenic shock	Pediatric myocarditis
	Neonatal meconium aspiration syndrome	Other neonatal indications (including sepsis, congenital diaphragmatic hernia, and persistent pulmonary hypertension of the newborn)
Tier 2 (30%-60%)	Poisoning-induced cardiogenic shock	Acute respiratory failure from any cause with multiorgan failure (including kidney injury requiring dialysis or hypotension requiring vasopressor support)
	Massive pulmonary embolism	Pediatric/neonatal cardiac arrest from a cardiac etiology
Tier 3 (< 30%)	Adult postcardiotomy cardiogenic shock	Bridge to lung transplantation for irreversible respiratory failure
	Out-of-hospital, refractory cardiac arrest with favorable prognostic features (ie, extracorporeal CPR)	Acute respiratory failure and severe immunocompromise (eg, stem cell transplant < 240 d posttransplant)
	Cardiac arrest with nonshockable rhythm or unfavorable prognostic features (including most adults with in-hospital cardiac arrest)	Cardiovascular collapse refractory to vasopressors in the setting of multiorgan failure of any cause (eg, septic shock)

ECMO = extracorporeal membrane oxygenation.

with the appointment of an ECMO triage officer or team to advise the regional incident command system. Table 1 groups the most common indications for ECMO into three tiers based on expected outcome, with cut points at 30% and 60% approximate survival. These tiers are further divided into short or long expected duration of ECMO support, using a consensus cut point of 5 days. When determining a patient's eligibility and priority for ECMO during a public health emergency, the regional ECMO triage team—or in its absence, ECMO physicians at the hospital level—will assess the prognosis by ECMO indication, critical illness severity, the anticipated duration of use, and patient age (see e-Appendix 1 for our rationale and five-step method for ECMO allocation). Our consortium adapted this priority scoring system from a construct by White and Lo[14] describing the allocation of scarce critical care resources such as ventilators.[15] It is consistent with priorities for ECMO use in a consensus guideline concerning COVID-19.[16] There is ethical and practical value to a consensus-driven, common regional framework of decision support during the COVID-19 response, without discouraging physicians from considering their local context or patient factors.

ECMO should be considered a trial of support rather than an indefinite resource assignment. In our approach, patients and family members will be counseled that ECMO is a highly specialized resource that may be withdrawn depending on response to therapy. Patients may receive other available support modalities as appropriate if they are ineligible for ECMO.

One of the strengths of this framework is that the triage decision-making matrix is based on survival data, and as such the position of any given indication for ECMO in the matrix may be adjusted over time (Table 1). There are currently insufficient data to accurately predict survival of patients with COVID-19 supported with ECMO. Once a sufficient quantity and quality of data are available, it may be determined that more, or fewer, patients with COVID-19 should be offered this technology.

An important limitation of our ECMO allocation framework is that it does not evaluate the relative benefit of ECMO support compared with conventional support, which is a fundamentally different concept from the short-term prognosis associated with a certain indication for ECMO. For example, a patient with status asthmaticus and severe hypercarbic respiratory failure (a tier I indication with short anticipated duration of ECMO support per Table 1) has a favorable prognosis with ECMO support, but their prognosis has historically been favorable with mechanical ventilation as well; therefore, in certain cases, the relative benefit of ECMO over conventional support may be small. Many ECMO indications listed in Table 1 lack robust comparative effectiveness data; therefore, this prognostic framework should be viewed as a starting point for resource allocation. Especially during the health-care resource constraints of a global pandemic such as COVID-19, thoughtful patient selection remains vital to maximizing the relative benefit of ECMO for individual patients. An objective prioritization scheme used by an impartial ECMO triage officer should complement, rather than replace, nuanced clinical judgment by a group of experienced physicians at the bedside.

Proactive ECMO resource allocation has several advantages for existing medical disaster preparedness systems during the COVID-19 pandemic. ECMO centers can leverage response mechanisms maintained by regional health-care coalitions to manage interfacility alerts, notification, and coordination. This allows smooth integration into the incident management system. By including ECMO resources, operational leaders will have a more comprehensive accounting of finite ICU assets. A proactive approach to these events ensures that potentially difficult allocation decisions are as equitable and transparent as possible for the sickest patients.

ECMO has benefitted patients with severe respiratory failure who likely would have died without it.[17] The likelihood of difficult decisions around ECMO allocation during the COVID-19 response is real and pressing. The evidence base for ECMO in this pandemic is still evolving, but each step forward strengthens our collective efforts as stewards of finite resources. We encourage other health systems to partner with local disaster management experts to refine our framework and adopt a process for ECMO coordination. Continued integration of these plans into a unified critical care approach to surge capacity will maximize benefit for vulnerable patients with COVID-19 infection during periods of resource scarcity.

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Additional information: The e-Appendix can be found in the Supplemental Materials section of the online article.

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