ECMO Resource Planning in the Setting of Pandemic Respiratory Illness

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The emergence of a novel coronavirus (SARS-CoV-2) causing respiratory disease rapidly led to a global pandemic threatening to overwhelm healthcare infrastructure and require rationing of existing resources. Following its identification in China in December 2019, this new coronavirus, causing a disease termed COVID-19, spread to other countries in the region before creating a worldwide health crisis. By early March 2020, more than 100,000 people had tested positive with nearly 4000 dead (1). Per initial reports, the virus causes a spectrum of symptoms ranging from intermittent fevers and cough to profound respiratory failure and cardiogenic shock. The early clinical experience with this emerging pathogen indicates that approximately 15-30% of hospitalized patients develop acute respiratory distress syndrome (ARDS). According to one study, 12% of admitted patients progress to requiring mechanical ventilation with 3% needing extracorporeal membrane oxygenation (ECMO) support (2).

There is no vaccine or targeted anti-viral therapy currently available to reduce the burden of disease for infected COVID-19 patients. Care for these patients remains largely supportive with a therapeutic goal of maintaining homeostasis and reducing complications from mechanical ventilation. For patients with refractory hypoxemia, the WHO guidelines recommend transferring patients to an ECMO center for consideration of advanced support (3). ECMO has previously been used successfully during pandemics of severe respiratory illness and may play an important role as salvage therapy in the COVID-19 pandemic (4, 5).

Based on current practice patterns, the role for ECMO in supporting patients during a pandemic depends on the severity of the pandemic. In a mild pandemic, hospitals may see a surge of 20% over usual volume. In a severe pandemic the role of ECMO becomes vanishingly small, as the burden of disease vastly surpasses available resources. At this juncture, the focus

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of patient care transitions from patient-centric to population-centric. The overarching goal of population-centric care is to limit total mortality to achieve "the greatest good for the greatest number (6)." In the scenario of a severe pandemic, in which resources are limited and staff is overburdened, intensive critical care services, such as ECMO, may be de-prioritized to redirect care towards numerous patients with a higher likelihood of survival.

ECMO is a resource intensive therapy requiring consideration prior to its deployment. In the setting of a severe pandemic, with strain on both personnel and material resources, use of ECMO demands additional deliberation. Based on the existing clinical experience, the specific role of ECMO in the COVID-19 pandemic is unclear. As case numbers increase, so too will the number with severe disease with an anticipated increase in the call for use of ECMO to support patients with COVID-19-associated ARDS. Despite the fact that ECMO use in severe ARDS continues to grow, (7) there are no ECMO specific guidelines or references for centers on preparation for pandemics of severe respiratory illness. We suggest the following framework for ECMO centers to consider during a natural disaster/pandemic.

Guidelines for ECMO Initiation

During a pandemic, criteria for initiating ECMO support must be clearly defined to reduce the burden on ECMO services and enable bedside clinicians to appropriately guide expectations and patient management. Consensus guidelines regarding critical care during pandemics recommend having a priori derived criteria for critical care procedures that are objectively and universally applied, rather than clinical judgement applied on an individual basis (6). Preparing

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guidelines in advance eliminates subjectivity and inconsistency between individual providers making allocation of intensive therapies more equitable and ethical. It is common practice for ECMO centers to institute specific guidelines and criteria for ECMO implementation. Guidelines should stress the importance of performing all other evidence-based interventions, such as lung-protective ventilation and prone positioning, prior to the consideration of ECMO. During emergency crisis situations, these criteria must be revised and adapted to triage current patient demand and prepare for anticipated needs. Given heightened demand for limited capacity, this policy must clearly define criteria for cessation of support to reduce futile care and enable allocation of limited resources. Patients on support require regular re-evaluations to ensure recovery remains viable and to guide appropriate goals of care. During situations of mass critical care, it may be ethically permissible to withdraw ECMO to reallocate support to patients with higher likelihood of benefit (6). Figure 1 details an example of ECMO guidelines for COVID-19. These protocols are subject to change as more information about the disease is obtained.

Allocation of Scarce Resources

We recommend that ECMO be incorporated into hospital plans for allocation of scarce resources during crisis standards of care. The group that convenes to develop this framework should be multidisciplinary and include institutional experts in the following areas: emergency preparedness, disaster management, critical care medicine, palliative care medicine, ethics, and risk management. Once crisis standards of care are invoked, the allocation of scarce resources plan will be activated. At this time the decision to provide ECMO should be made by the triage

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team designated by the Hospital Incident Command System in conjunction with the ECMO service. The triage team will have a process of allocating resources that is based on ethical principles grounded in the following: attention to fairness, openness, transparency, and accountability in allocation of resources, and protection of the rights of individuals with respect to privacy, confidentiality, and imposition of limitations on personal freedom (8). In particular, with ECMO the goal will be to reserve this limited resource for those who would achieve the greatest benefit and limit prolonged runs in patients without recovery.

Equipment

During the hospital response preparation phase to a pandemic it is important to determine present inventory and stockpile important equipment while recognizing that demand will be increased universally. Unlike other critical care equipment, such as mechanical ventilators, there is no regional or national stockpile of ECMO equipment available to assist hospitals in the face of a pandemic. Therefore, it is reasonable to plan for a 20 to 200% increase in ECMO equipment from par level (9). In the presence of a slow-onset pandemic, equipment targets can be made based on data-driven projected increase in patients. It is incumbent on each ECMO center to maintain essential equipment necessary for extracorporeal support including vascular cannula, circuit tubing, pumpheads, and oxygenators. Advanced integrated systems would be anticipated to be costly and difficult to obtain in a pandemic but more cost-effective approaches, such as implementing simple pump and oxygenator-only systems, can be

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considered. Pre-emptively expanding the number of ECMO circuits in the early phases of a pandemic is worthwhile as a means of expanding total capacity.

At the onset of a pandemic, programs typically will use equipment as per pre-existing guidelines and practice patterns. ECMO coordinators should do daily inventory and order replacements to maintain adequate supplies and in anticipation of increasing demand. As the pandemic progresses or becomes more severe, ECMO protocols should be altered to be more selective in an effort to increase the likelihood to obtain maximal benefit.

Capacity

Maximum capacity per center should be defined a-priori. There are three main factors that usually determine the ECMO capacity of a hospital: ICU bed availability, RN/ECMO specialist staffing, and number of ECMO circuits. During a crisis scenario, ICU bed and staffing models should be optimized to care for the largest number of patients possible. This may require a change to usual staffing models. An example may be to cohort all ECMO patients in a single geographical space to enable a higher patient to ECMO specialist/RN ratio. Another option is to create critical surge staffing protocols (10). In these protocols, staffing can be adjusted based on level of acuity such that stable ECMO patients can be supported by fewer providers than usual. The number of ECMO circuits available is the ultimate limiting factor in determining total patient support capacity. Device improvisation is an option to increase number of ECMO machines available for use. Splicing an oxygenator to percutaneous VADs is a viable option to

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provide oxygenation and ventilation support (11, 12). Depending on expertise and equipment available at individual centers, this may be a viable option for increasing ECMO capacity.

Collaboration with Other Local/Regional ECMO Centers

Data have shown that outcomes are better when severe ARDS patients are transferred to ECMO centers (13). During a pandemic, ECMO centers maybe inundated with severe ARDS patients transferred from community centers lacking these capabilities. In order to ensure access to ECMO centers for severe ARDS patients from community centers, establishing a regional system to manage the surge in ECMO referral volume is vital. In the UK, the NHS has a standard operating procedure (SOP) dedicated to this exact scenario(14). There are several phases to this plan, including a pre-surge, surge, escalation, and recovery phase. At the crux of this protocol is regular teleconferences and communication between ECMO centers emphasizing capacity and an escalation/de-escalation plan. A similar concept can be instituted in non-nationalized health care settings as well. ECMO centers in geographical proximity should establish an SOP for ECMO during the pandemic. Important elements of this SOP include standardized criteria for ECMO initiation, real-time reporting structure for ECMO capacity and volume at each center, and a system to facilitate transfers from the community to the available centers with capacity. Another important function of this collaboration can be to advise local community hospitals in implementing advanced respiratory failure interventions (including prone positioning) prior to consideration for transfer for ECMO to avoid unnecessary transfers and conserve capacity.

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Summary

ECMO will be increasingly used as a vital support modality during pandemics of severe respiratory illness. Whether COVID-19 or another novel virus causing severe disease, hospitals will need to have a formal plan to rapidly respond to expanding need for a limited resource. The plan will need to be scaled to the magnitude of the pandemic. Our suggested framework for ECMO use in pandemics has been largely adapted from the guidelines and consensus statements of provision of mass critical care (Table 1). The overarching goals of ECMO utilization during a pandemic is to reduce mortality in patients with profound failure. Additional provisions must be made for the possibility of abandoning resource intensive critical care therapies, such as ECMO, in the setting severe pandemics to focus care on less resource dependent therapies that may provide greater benefit to a greater number of patients. Establishing these guidelines and practice patterns is vital to support the overall mission of preserving the highest number of quality life years for the population as a whole while ensuring equitable care.

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References

1. Coronavirus disease 2019 (COVID-19) Situation Report – 49 2020 [cited 2020 March,9].Available from: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200309-sitrep-49-covid-19.pdf?sfvrsn=70dabe61_4.
2. Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, et al. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA. 2020. Epub 2020/02/08. doi: 10.1001/jama.2020.1585. PubMed PMID: 32031570.
3. Clinical management of severe acute respiratory infection when Novel coronavirus (2019-nCoV) infection is suspected: Interim Guidance 2020 [cited 2020 March 7]. Available from: https://www.who.int/docs/default-source/coronaviruse/clinical-management-of-novel-cov.pdf.
4. Australia, New Zealand Extracorporeal Membrane Oxygenation Influenza I, Davies A, Jones D, Bailey M, Beca J, et al. Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome. JAMA. 2009;302(17):1888-95. Epub 2009/10/14. doi: 10.1001/jama.2009.1535. PubMed PMID: 19822628.
5. Al-Dorzi HM, Aldawood AS, Khan R, Baharoon S, Alchin JD, Matroud AA, et al. The critical care response to a hospital outbreak of Middle East respiratory syndrome coronavirus (MERS-CoV) infection: an observational study. Ann Intensive Care. 2016;6(1):101. Epub 2016/10/26. doi: 10.1186/s13613-016-0203-z. PubMed PMID: 27778310; PubMed Central PMCID: PMCPMC5078123.
6. Biddison LD, Berkowitz KA, Courtney B, De Jong CM, Devereaux AV, Kissoon N, et al. Ethical considerations: care of the critically ill and injured during pandemics and disasters: CHEST consensus statement. Chest. 2014;146(4 Suppl):e145S-55S. Epub 2014/08/22. doi: 10.1378/chest.14-0742. PubMed PMID: 25144262.
7. Rush B, Wiskar K, Berger L, Griesdale D. Trends in Extracorporeal Membrane Oxygenation for the Treatment of Acute Respiratory Distress Syndrome in the United States. J Intensive Care Med. 2017;32(9):535-9. Epub 2016/02/20. doi: 10.1177/0885066616631956. PubMed PMID: 26893318.
8. Leider JP, DeBruin D, Reynolds N, Koch A, Seaberg J. Ethical Guidance for Disaster Response, Specifically Around Crisis Standards of Care: A Systematic Review. Am J Public Health. 2017;107(9):e1-e9. Epub 2017/07/21. doi: 10.2105/AJPH.2017.303882. PubMed PMID: 28727521; PubMed Central PMCID: PMCPMC5551597.
9. Hick JL, Einav S, Hanfling D, Kissoon N, Dichter JR, Devereaux AV, et al. Surge capacity principles: care of the critically ill and injured during pandemics and disasters: CHEST consensus statement. Chest. 2014;146(4 Suppl):e1S-e16S. Epub 2014/08/22. doi: 10.1378/chest.14-0733. PubMed PMID: 25144334.
10. Salna M, Chicotka S, Biscotti M, 3rd, Agerstrand C, Liou P, Ginsburg M, et al. Management of Surge in Extracorporeal Membrane Oxygenation Transport. Ann Thorac Surg.

ANNALSATS Articles in Press. Published April 15, 2020 as 10.1513/AnnalsATS.202003-233PS

2018;105(2):528-34. Epub 2017/11/28. doi: 10.1016/j.athoracsur.2017.07.019. PubMed PMID: 29174776.

11. Herlihy JP, Loyalka P, Jayaraman G, Kar B, Gregoric ID. Extracorporeal membrane oxygenation using the TandemHeart System's catheters. Tex Heart Inst J. 2009;36(4):337-41. Epub 2009/08/21. PubMed PMID: 19693311; PubMed Central PMCID: PMCPMC2720287.
12. Betit P, Matte GS, Howe R, Iudiciani P, Barrett C, Thiagarajan R, et al. The addition of a membrane oxygenator to a ventricular assist device in a patient with acute respiratory distress syndrome. J Extra Corpor Technol. 2011;43(4):264-6. Epub 2012/03/16. PubMed PMID: 22416609; PubMed Central PMCID: PMCPMC4557432.
13. Peek GJ, Mugford M, Tiruvoipati R, Wilson A, Allen E, Thalanany MM, et al. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial. Lancet. 2009;374(9698):1351-63. Epub 2009/09/19. doi: 10.1016/S0140-6736(09)61069-2. PubMed PMID: 19762075.
14. Management of surge and escalation in critical care services: standard operating procedure for adult respiratory extra corporeal membrane oxygenation 2017 [cited 2020 March, 7]. Available from: https://www.england.nhs.uk/publication/management-of-surge-and-escalation-in-critical-care-services-standard-operating-procedure-for-adult-respiratory-extra-corporeal-membrane-oxygenation/.

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Table 1. Tiered approach to ECMO response during a pandemic
Mild surge - Focus is on increasing capacity
Develop criteria specific to pandemic for initiation and cessation of ECMO.
Stockpile necessary equipment.
Collocation/regionalization of ECMO patients.
Staffing protocols that allow for ECMO specialist/RN to care for more patients based on acuity.
Increase capacity by acquisition of more pumps, and or device improvisation with percutaneous VADs with oxygenators.
Collaboration with other local/regional ECMO centers: • Establish real-time reporting structure for ECMO capacity and volume between local ECMO centers in the Boston/New England area. • Develop a system to facilitate transfers from the community or between centers to centers with capacity.
Moderate surge - Focus on allocation of scarce resources
Incorporate ECMO initiation decision into HICS framework for allocation of scarce resources.
Major surge - Scarce resources may not be offered
National or regional guidance may mandate that ECMO no longer be offered, to focus the care on less resource intensive therapies that can provide a greater benefit to a greater number of patients.

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Figure Legend:

Figure 1. Proposed indications and contraindications for ECMO support during COVID-19 pandemic.

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Proposed Guidelines for ECMO Support in COVID-19 Pandemic

Indications for Venovenous ECMO:

- PaO_2:FIO_2 ratio < 80 mm Hg for more than 6 hours, despite optimal management listed below:
    - Optimized PEEP (Best PEEP trial, esophageal balloon, PV tool)
    - Neuromuscular blockade
    - Inhaled pulmonary artery vasodilator
    - Prone positioning
        - only contraindication to proning is spinal cord instability (elevated BMI is not a contraindication)
- P_{pl} > 30 cm H_20 on lung protective ventilation
- pH < 7.15
- No trend towards improvement or other rapidly intervenable pathology (such as pulmonary edema)

Absolute contraindications:

- Active solid or liquid malignancy
- Age > 65
- High grade shock (norepinephrine dose > 0.2 mcg/kg/min)
- Multiorgan failure
- Inability to tolerate anticoagulation for initiation of therapy (active hemorrhage)
- Receipt of mechanical ventilation for 7 days or longer
- Irreversible neurologic injury
- Expected life expectancy < 6 months

Relative contraindications:

- Thrombocytopenia (Platelets < 50000)
- Neutropenia (ANC < 500)
- BMI > 40
- Total body weight > 180 kg
- Long-term chronic respiratory insufficiency treated with oxygen therapy
- Unable to perform ADL's at baseline

Figure 1: Proposed indications and contraindications for ECMO support during COVID-19 pandemic

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