Evolving Role of Anesthesiology Intensivists in Cardiothoracic Critical Care

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THE American Board of Anesthesiology first offered a certification of special competence in critical care in 1986.[1] The role of anesthesiologists in critical care was reviewed in Anesthesiology by Hanson *et al.* in 2001,[2] documenting the skills, tasks, and challenges at that time. The COVID-19 pandemic offers an opportunity to review the changes that have occurred at our institution, Massachusetts General Hospital (Boston, Massachusetts), as well as nationally and internationally, and how the successful use of extracorporeal membrane oxygenation has created a large demand for expertise in cardiothoracic critical care.

We will review the current roles of cardiothoracic anesthesiology intensivists in cardiogenic shock and extracorporeal membrane oxygenation at Massachusetts General Hospital to document an example of a successful multidisciplinary team that has been established in an institution with strong departmental interests. Then, a brief history of extracorporeal membrane oxygenation will document the past role of critical care anesthesiologists and their current role with both venovenous and venoarterial extracorporeal membrane oxygenation. This review will emphasize how the investigation of both cardiac and lung function in these critically ill patients now is essential. Finally, the review will evaluate the early data regarding extracorporeal membrane oxygenation in the COVID-19 crisis.

"Code Blue" and Shock Calls for the Cardiothoracic Intensivist

Our cardiothoracic anesthesiology intensivists manage a 34-bed heart center intensive care unit in a multidisciplinary and cross-specialty model (combined medical and surgical cardiac critical care). The cardiothoracic intensivist is now the first call for cardiogenic shock consults in the hospital.[3] Given that there is an approximate 30-min window to decide on extracorporeal life support cannulation during a cardiac arrest, a cardiac intensivist is in-house for these decisions 24/7. At Massachusetts General Hospital, bedside providers are encouraged to use our mobile app (application software; fig. 1) for cardiogenic shock consults for patients who may rapidly require escalation of care and possible mechanical circulatory support. Our cardiothoracic intensivists are then readily accessible through the app for acute airway support, placement of invasive monitors, point-of-care echocardiography/ultrasonography, initiation of a medical management plan (inotropic and vasopressor support), and ultimately a team discussion about extracorporeal life support if necessary. The cardiothoracic intensivist can also initiate the cannulation process (table 1).

Cardiothoracic anesthesiology intensivists have become experts in both transthoracic and transesophageal echocardiography.[4,5] Within critical care, we now have over 10 yr of experience developing protocols/algorithms/guidelines.[5] The National Board of Echocardiography now offers a new examination of special competence as well as diplomate status for any physician with subspecialty training in critical care medicine meeting specific criteria. There are also opportunities to sit for the examination of special competence in adult echocardiography and for the examination of special competence in advanced or basic perioperative transesophageal echocardiography (in addition to recertification examinations). These opportunities are important to maintain expertise and certification in echocardiography for the cardiothoracic anesthesiology intensivist. The ability to rapidly and safely use ultrasonography/echocardiography to support the clinical exam and make a diagnosis in the hemodynamically unstable patient has forced medical directors and fellowship directors to make this a key part of the clinical curriculum.[6]

The range of consults for cardiogenic shock is quite broad. The successful management of young women in the obstetrical suite during cardiac arrests now involves the cardiothoracic intensivist.[3] Similarly, as patients with ventricular assist devices require other procedures, the cardiothoracic intensivist may be called for consultations anywhere in the hospital from endoscopy to the interventional radiology suite. Heart, lung, and liver transplant patients now may also require extracorporeal life support for successful transplant surgery (pre- and postsurgery) and transesophageal echocardiography support during transplant operations.[7]

Echocardiography is now frequently used for extracorporeal membrane oxygenation cannulations to identify any contraindications to placement and guide cannula placement, and is part of standardized weaning protocols for extracorporeal membrane oxygenation/mechanical circulatory support.[8] Echocardiography is also used for the management

This article is featured in "This Month in Anesthesiology," page 1A.

Submitted for publication March 31, 2020. Accepted for publication May 13, 2020. Published online first on June 3, 2020. From Massachusetts General Hospital, Boston, Massachusetts.

 Anesthesiology 2020; 133:1120–6. DOI: 10.1097/ALN.0000000000003407

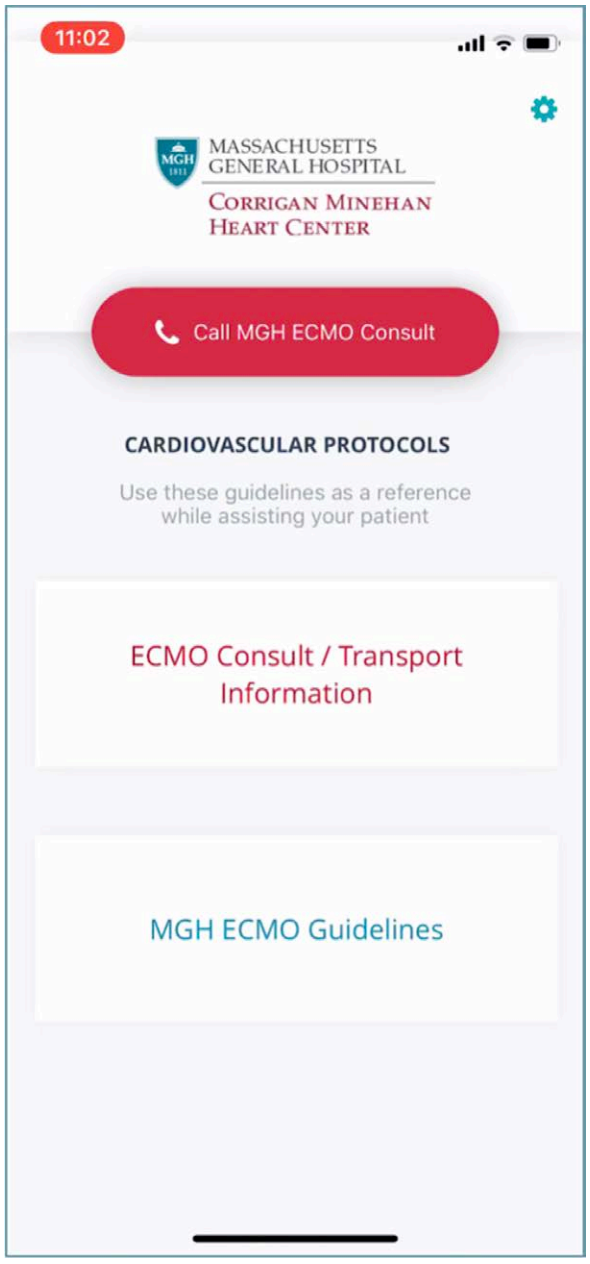

Fig. 1. Massachusetts General Hospital extracorporeal membrane oxygenation consult application.

of percutaneous ventricular assist devices such as right- and left-side Impella (Abiomed Inc., USA) support in addition to the dual lumen cardiac support Protek Duo (Tandem Life, LivaNova, USA) device. Correct positioning and management of ventricular assist devices are obviously important for the cardiothoracic intensivist and require point-of-care ultrasonography.[8] The use of echocardiography in following the progression of disease in the COVID-19 patients has not been defined, but clearly there will be a role.

Table 1. Role of the Cardiothoracic Anesthesiology Intensivists (24/7 Care Model)

Receives all cardiac shock consultations at Massachusetts General Hospital
Initiates a multidisciplinary discussion to decide on candidacy for extracorporeal membrane oxygenation
Initiates with the larger team venovenous and venoarterial extracorporeal cannulation
Initiates a medical management plan (inotropic and vasopressor support)
Available for acute airway support across our 34-bed heart center intensive care unit
Available for placement of invasive monitors
Available for point-of-care echocardiography/ultrasonography

Evolution of Treatments for Heart Failure and Shock

Just as new medications and interventions have caused an evolution in medical care, we have witnessed the need for even more expertise in anesthesiology critical care practitioners.[9] In our program at Massachusetts General Hospital, cardiothoracic anesthesiology intensivists in a cross-specialty model also serve as the attending of record for medical cardiology critical care patients. Advances in patient care have led to survival of sicker patients and the need for more sophisticated physician expertise. Cardiac disease is a syndrome of the elderly, and we expect those over the age of 65 yr to double by 2030.[10] Cardiac disease still makes up one third of deaths in the United States.[11] In a recent multicentered study by Bohula *et al.*, 41.3% of patients admitted to a cardiac intensive care unit had heart failure listed as part of their presentation. In fact, the primary admission indication to a current cardiac intensive care unit is now respiratory failure and shock in patients with heart failure.[12] Septic shock, acute kidney injury, and respiratory failure are just a few of the growing noncardiac diagnoses in "cardiac" patients in the cardiac intensive care unit in a study by Sinha *et al.* reviewing Medicare data from 2000 to 2013.[13]

The understanding and management of downstream organ insufficiency therefore are now part of routine cardiac critical care. The mortality is now also driven by the overlay of these noncardiac conditions with mortality rates exceeding 20% in patients with respiratory failure (24%) and renal replacement therapy (35%).[12] This truly challenges the previous cardiac critical care model divided by department/division along clinical service lines and forces a new model of patient- and family-centered care requiring exemplary collaboration and communication. It relies on experts with an understanding of neurophysiology, critical illness myopathy/polyneuropathy, respiratory failure, and renal failure. The evolution of cardiac critical care has therefore continued and become even more significant in terms of specialization needs based on the American Heart Association Scientific Statement of 2012.[14] Approximately 34% of patients in a multicenter network of tertiary cardiac

intensive care units in North America are now managed with a mechanical device during their intensive care unit stay.[15]

Brief History of the Use of Extracorporeal Membrane Oxygenation

The "mechanical heart and lung apparatus" was created in 1951 to provide life support for patients with acute cardiac and respiratory failure, but these "direct contact" oxygenators caused trauma to blood and "rarely could be used for more than a few hours" before creating severe complications.[16–18] Membrane oxygenators were tested in animals, and by the mid to late 1960s, there were materials and devices that could be used for "days rather than hours."[19–21] Physicians using a Bramson membrane heart-lung machine provided partial venoarterial and venovenous extracorporeal membrane oxygenation to adults with cardiogenic shock and to patients who were hypoxemic on 100% fraction of inspired oxygen for respiratory failure.[22,23] The first survivor of venoarterial extracorporeal membrane oxygenation was a young trauma victim described in 1972.[24] Subsequently, partial venoarterial extracorporeal membrane oxygenation was used to support a 2-yr-old boy with cardiogenic shock postcongenital heart surgery[25] and was used for neonatal respiratory failure.[26] Finally, venoarterial extracorporeal membrane oxygenation with conventional ventilation was compared to conventional ventilation alone in patients with severe acute respiratory failure in the late 1970s; survival rates were very poor in both groups.[27] These poor results led to a decrease in research utilizing extracorporeal membrane oxygenation; research did not really resume for another decade.[18]

Since 2009, enthusiasm and the use of venovenous extracorporeal membrane oxygenation for acute respiratory failure has grown for multiple reasons, but particularly due to data from a large randomized controlled trial, to a *post hoc* analysis of the extracorporeal membrane oxygenation for severe acute respiratory distress syndrome trial and its utility in the pandemic of influenza A virus subtype hemagglutinin 1 neuraminidase 1.[28–30] Venovenous extracorporeal membrane oxygenation has become an important treatment for acute respiratory failure, a bridge to lung transplant, and an aide in managing pulmonary vascular disease and is thus increasingly utilized in major centers worldwide.[31]

Extracorporeal Membrane Oxygenation by Anesthesiology Cardiothoracic Critical Care Specialists

In a previous era, the cannulation, management, and weaning of mechanical circulatory support rested solely on the cardiac surgery team. We have now seen a shift toward a more collaborative team based critical care approach to management.[32] In at least five major centers in the United States (Emory University, Atlanta, Georgia; University of Pennsylvania, Philadelphia, Pennsylvania; Massachusetts General Hospital, Boston, Massachusetts; Vanderbilt University, Nashville, Tennessee; and University of Pittsburgh, Pittsburgh, Pennsylvania), critical care cardiothoracic anesthesiologists play a major role in placement of the extracorporeal membrane oxygenation cannula as well as management of these patients. Currently, bedside cannulation is performed with echocardiography guidance for wire and catheter placement for venoarterial and venovenous extracorporeal membrane oxygenation. Critical care cardiothoracic anesthesiologists at our institution have now started to participate in percutaneous venoarterial and venovenous extracorporeal membrane oxygenation cannulation. Venovenous extracorporeal membrane oxygenation decannulation is currently performed by the critical care team, but venoarterial extracorporeal membrane oxygenation decannulation is currently performed by either a cardiac or vascular surgeon at our institution.

Mechanical Ventilation during Venovenous Extracorporeal Membrane Oxygenation

While managing mechanical ventilation has always been an important role for all intensivists, ventilation during extracorporeal membrane oxygenation may be unique and is now being studied in terms of what optimal mechanical ventilation is during extracorporeal membrane oxygenation.[33] The use of low tidal volumes during lung protective ventilation can lead to respiratory acidosis, which is treated with either respiratory rates up to 30 per minute in some centers or extracorporeal carbon dioxide removal by venovenous extracorporeal membrane oxygenation.[33] The use of venovenous extracorporeal membrane oxygenation in acute respiratory distress syndrome has documented the ability to achieve lower tidal volumes, lower driving pressures, and lower plateau pressures. The extracorporeal membrane oxygenation for a severe acute respiratory distress syndrome trial documented the largest reduction in mortality for patients enrolled who had respiratory acidosis and excessive ventilatory pressures but *not* those who were most hypoxemic.[28] However, the optimal "lung protective" settings during venovenous extracorporeal membrane oxygenation are not known and need to be tested.

The optimal ventilator settings and weaning criteria for the COVID-19 patients is not known. The increased prevalence of patients with obesity in the COVID-19 respiratory failure cohort suggests that esophageal manometry and/or electrical impedance tomography may be helpful in determining optimal positive end-expiratory pressure and for documenting the work of breathing during weaning.[34] The utility of extracorporeal membrane oxygenation in this pandemic is just beginning to be explored. The early, preliminary findings regarding venovenous extracorporeal

membrane oxygenation in COVID-19 patients are discussed below.

Venovenous Extracorporeal Membrane Oxygenation in COVID-19 Patients

The use and success of venovenous extracorporeal membrane oxygenation in COVID-19 patients will most likely depend on the preparedness of the healthcare system where the patients reside.[35] A recent review of extracorporeal membrane oxygenation preparedness for this outbreak suggests key variables are a multidisciplinary team who are trained in the care of extracorporeal membrane oxygenation patients, adequate supplies, clustering of patients with COVID-19 requiring extracorporeal membrane oxygenation, protocols for weaning and decannulation, staff support, ethical consideration, quality assurance, and collaborative research.[36] Given the necessary provider expertise and overall resources required for this patient population, it has become quite apparent that it is advantageous to have high-volume COVID-19 critical care regional centers that offer extracorporeal membrane oxygenation to support smaller community programs. Cardiothoracic critical care anesthesiologists sit on review panels helping to decide which patients should be triaged to centers of excellence that offer advanced medical and mechanical therapies like inhaled nitric oxide and extracorporeal membrane oxygenation. Point-of-care ultrasound is recommended to place the cannula but is also recommended for daily surveillance of the lungs, right and left heart, abdomen, and extremities.[4,5] The first successfully treated venovenous extracorporeal membrane oxygenation patient with COVID-19 in Washington was published as a case report recently, and authors included pulmonologists, anesthesiologists, infectious disease physicians, hematologists, cardiologists, and cardiac surgeons, suggesting the breadth of organ dysfunction in these patients. The patient required 160 h of extracorporeal membrane oxygenation support and was successfully extubated to room air.[37]

COVID-19 and Venoarterial Extracorporeal Membrane Oxygenation

As noted in several very recent publications, patients with underlying cardiovascular disease tend to have a higher mortality,[38] and mortality was significantly higher in patients with elevated troponin levels, who also were older and had higher rates of comorbidities.[39] A COVID-19–positive patient with myocarditis who does not have the typical respiratory disease may require venoarterial extracorporeal membrane oxygenation, just as we have seen with influenza as well as with parvovirus B-19 infections.[40,41] Other manifestations of this infection appear to be acute coronary syndromes, arrhythmias, and exacerbation of heart failure.[42] While the focus of this disease has clearly been on acute respiratory distress syndrome, we are now starting to understand that there are significant cardiovascular complications as well. The initiation of inotropic support and venoarterial extracorporeal membrane oxygenation in our program has been based largely on serial echocardiography examinations and invasive cardiac monitoring by the intensivist team. Finally, it is important to remember that more patients die of cardiovascular causes than respiratory failure in influenza epidemics,[43] and this may be true for the COVID-19 pandemic.

As more data are collected, the role for venoarterial extracorporeal membrane oxygenation and other mechanical devices will become clearer. Our current cardiothoracic intensivists are part of every respiratory or cardiac hospital shock call for possible extracorporeal membrane oxygenation in patients with COVID-19 (prearrest). As a team, we made the decision not to offer extracorporeal cardiopulmonary resuscitation for this current patient population. In addition to deciding on options for advanced mechanical devices, we also support the other critical care teams (including our general anesthesiology intensivists) with cardiogenic shock management, transthoracic echocardiography/transesophageal echocardiography support if needed, and initiation of extracorporeal membrane oxygenation if warranted. All patients who are placed on venoarterial extracorporeal membrane oxygenation are then managed in our heart center intensive care unit with our specialized cardiothoracic intensivists.

Speculation Regarding Future Roles

The current pandemic leads us to speculate which roles for the cardiothoracic critical care anesthesiologists will grow after the surge. A core group of cardiothoracic critical care anesthesiologists should be utilized to remotely monitor all community hospitals in a network and selectively triage patients who may benefit from the growing field of mechanical assist devices. Cardiothoracic critical care anesthesiologists would be part of the intensive care teams but also the echocardiography teams utilized in hospitals, providing day and night consultations in the operating rooms, in intensive care units, and before discharge. We also expect these experts to offer physical care outside of their primary hospital in the form of mobile shock teams in the future. Cardiothoracic critical care anesthesiologists at the University of Pennsylvania have taken a leading role in this arena by offering a mobile venovenous extracorporeal membrane oxygenation service.[44,45] This model will likely continue to expand into larger mobile shock teams as well to care for patients in cardiogenic shock. If venovenous extracorporeal membrane oxygenation is improved and requires less sedation and allows more mobility, it may become the preferred treatment for respiratory failure, rather than mechanical ventilation. There could be a significant increased need for cardiothoracic critical care anesthesiologists for cannulation, oversight, and weaning of respiratory failure patients.

Conclusions

Anesthesiologists involved in cardiothoracic critical care have embraced this new role as experts in the management of cardiogenic shock and extracorporeal membrane oxygenation. The current pandemic highlights that respiratory failure is just one manifestation of the multiorgan failure system commonly seen in today's critically ill patients. Optimal treatment involves expanding our knowledge and involvement in innovations. The barriers that anesthesiologists face in critical care mentioned by Hanson *et al.* in 2001 in Anesthesiology still exist.[2] Compensation differences for anesthesiologists in the operating room *versus* those in the intensive care unit, lower representation in critical care medicine as a specialty, and the requirement for continuous night and weekend coverage for patient care in high-intensity critical care programs continue to persist. However, we have made tremendous progress as a specialty, particularly in cardiothoracic critical care as the interest and exposure to this new field of intensive care medicine expands for our programs. Finally, it is imperative that we bring our residents and fellows into this exciting field of cardiothoracic critical care. Currently, both our cardiac anesthesiology and critical care fellows rotate in the heart center intensive care unit during their fellowships. With an attending physician, they respond to all hospital shock calls. Anesthesiology residents are now receiving more exposure to this field than ever before.

Research Support

Support was provided solely from institutional and/or departmental sources.

Competing Interests

The authors declare no competing interests.

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