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Echocardiography in Pandemic: Front-Line Perspective, Expanding Role of Ultrasound, and Ethics of Resource Allocation

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The grave clinical context of the coronavirus disease 2019 (COVID-19) pandemic must be understood. Italy is immersed in the COVID-19 pandemic. Most of the world will soon follow. The United States currently has the most documented cases of COVID-19 of any nation. Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2)–associated acute cardiomyopathy is common in critical care patients and is associated with a high mortality rate. Patients with COVID-19 frequently require mechanical support for adequate oxygenation. A severe shortfall of ventilators is predicted. Of equal concern is the projected shortage of trained professionals required to care for patients on mechanical ventilation. Ultrasonography is proving to be a valuable tool for identifying the pulmonary manifestations and progression of COVID-19. Lung ultrasound also facilitates successful weaning from mechanical ventilation. Ultrasonography of the lung, pleura, and diaphragm are easily mastered by experienced echocardiographers. Echocardiography has an established role for optimal fluid management and recognition of cardiac disease, including SARS-CoV-2-associated acute cardiomyopathy. Cardiologists, anesthesiologists, sonographers, and all providers should be prepared to commit their full spectrum of skills to mitigate the consequences of the pandemic. We should also be prepared to collaborate and cross-train to expand professional services as necessary. During a declared health care crisis, providers must be familiar with the ethical principles, organizational structure, practical application, and gravity of limited resource allocation. (J Am Soc Echocardiogr 2020;33:683-9.)

Keywords: Pandemics, Echocardiography, Ultrasonography, Ventilators, Mechanical, Resource allocation

Dr. Tedros Ghebreyesus, director general of the World Health Organization, declared coronavirus disease 2019 (COVID-19) as a pandemic on March 11, 2020. He stated that he was "deeply concerned by the alarming levels of spread and severity and the alarming levels of inaction."[1] COVID-19 is associated with more efficient transmission and a higher mortality rate than seasonal influenza.[2-5] The gravity of this pandemic must be understood. Action is required to slow disease transmission and mitigate the surge of critically ill patients into our health care systems. Action is also required to minimize additional life-years lost if critical care resources are overwhelmed. Professional commitment and informed resource allocation should reduce loss of life.

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NATIONAL PERSPECTIVES

The Italian Perspective on COVID-19

Italy is immersed in the COVID-19 pandemic.[6] Hospitals are under extraordinary pressure to meet the surge in demand. San Raffaele Hospital is a multispecialty university center in Milan and one of several institutions caring for patients with COVID-19 while still providing emergent cardiology and cardiothoracic surgery services. They have 52 intensive care unit (ICU) beds specifically for mechanically ventilated patients with COVID-19 and another 260 beds for symptomatic patients with COVID-19 on oxygen therapy. Fifteen beds are designated for cardiovascular care and seven for postoperative intensive care. Nearly all other Italian critical care facilities are allocated for COVID-19. Professor Alberto Zangrillo, head of the Department of Anesthesia and Intensive Care, stated, "Every hospital in this country has increased, doubled and, in our case, tripled the number of intensive care beds. The problem is that this virus is extremely contagious and in two or three weeks has brought to our ICUs the number of patients we used to see in an entire year. When these patients develop pneumonia, they have a form of exudative alveolitis that in a very short time makes them very dependent on positive end-expiratory pressure. It is a form of pneumonia that tends to resolve, but requires an ICU stay of more than 2 weeks." He has recommended the early adoption of containment to slow the contagion and an aggressive proactive approach to invasive ventilation. There are several regions where ventilators are in short supply.[6]

Abbreviations

ARDS = Acute respiratory distress syndrome

COVID-19 = Coronavirus disease 2019

ECMO = Extracorporeal membrane oxygenation

ICU = Intensive care unit

POCUS = Point-of-care ultrasound

PPE = Personal protective equipment

SARS-CoV-2 = Severe acute respiratory syndrome coronavirus-2

Although there are enough physicians, there are not enough physicians with appropriate skills.

Lung ultrasound is frequently performed at U Parini Hospital in Aosta and has demonstrated high diagnostic yield. It is effective for monitoring the progression of the disease in both ventilated and nonventilated patients. If typical COVID-19 lung ultrasound findings are found in patients with negative results on first polymerase chain reaction testing, retesting is performed. Often the second or third polymerase chain reaction test produces positive findings.

Echocardiography has been most useful for (1) initial assessment of patients with respiratory symptoms who are seen in the COVID-19 evaluation pathway but may have other etiologies for their symptoms; (2) assessment of cardiac function in critical care patients, among whom severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2)–associated cardiomyopathy is prevalent; and (3) volume assessment of patients with acute respiratory distress syndrome (ARDS), in whom sparing unnecessary fluids is mandatory. Volume assessment should include lung ultrasound. Cardiac involvement is common in patients with advanced disease. It is difficult to determine the exact role of SARS-CoV-2 cardiac infection, because these patients often have multiple acute comorbidities. The most common findings are pulmonary arterial hypertension, right ventricular dysfunction, regional wall motion abnormalities, and decreased ejection fraction. There is a significant incidence of pulmonary embolism.

Point-of-care ultrasound (POCUS) is the initial imaging study for nearly all patients. Transthoracic echocardiography is used if a definitive diagnosis cannot be made with POCUS. Transesophageal echocardiography is reserved for intubated patients with poor image quality on surface studies. Machines are segregated into COVID-19 and non-COVID-19 cohorts.

In Italy, as elsewhere, there is a shortage of personal protective equipment (PPE). Health care providers are getting sick and are also in short supply. The Italian government is hiring approximately 20,000 new health care providers, including 5,000 physicians and physicians in training. For clinicians with any critical care experience, the most frequently used skill is ventilator management. Non–critical care patients with COVID-19 are cared for by physicians from all specialties. All elective consultations and procedures have been cancelled. All face-to-face meetings and teaching are forbidden. All activity outside of the hospital is monitored by the police. Data from the World Health Organization suggest that the American surge may be similar.[7]

The American Perspective on COVID-19

The American Hospital Association estimates that 4.8 million patients will be hospitalized. Early reporting indicates that 12% of hospitalized with COVID-19 will have acute cardiomyopathies.[8] Nearly 2 million will be admitted to critical care units, and 960,000 will require mechanical ventilation.[9] There are approximately 65,000 ventilators in use in the United States.[9-11] The addition of the strategic national supply, anesthesia machines, and older ventilators not currently in use should bring the total ventilator capacity to 200,000. Perhaps of greater importance, the Society of Critical Care Medicine estimates that there are only 135,000 professionals trained in mechanical ventilation.[9] The US capacity for providing professional staffing for mechanical ventilation may be seriously challenged if the current transmission rate continues and 5% to 6% of infected patients require ventilation.[12,13] Cross-training and hierarchical management may be necessary for managing the high volume of pulmonary disease.[9]

Key Points on COVID-19

- COVID-19 is associated with more efficient transmission and a higher mortality rate than seasonal influenza.
- Estimates for the United States include the following:
  - 4.8 million patients will be hospitalized;
  - 600,000 patients will have acute cardiomyopathies;
  - 1.9 million patients will require intensive care;
  - 960,000 patients will require mechanical ventilation;
  - 65,000 ventilators are currently in use;
  - 200,000 ventilators are available, but many are not adequate for managing ARDS; and
  - 135,000 professionals are currently trained to provide mechanical ventilation.
- SARS-CoV-2-associated cardiomyopathy is common in the critically ill.
- Ventilators are a severely limited resource.
- The capacity to provide qualified staff members for mechanical ventilation may be seriously challenged.
- Professional cross-training will be required.

LUNG SONOGRAPHY AND ECHOCARDIOGRAPHY IN COVID-19

Ultrasound is a valuable resource in this pandemic. Lung ultrasound, especially POCUS, is a relatively new technology, and experience with COVID-19 is limited.[14,15] Reporting from China and Italy indicates that sonography of the lung can reliably identify and quantify COVID-19-associated pleural and interstitial disease.[14,15] Lung ultrasound is superior to conventional radiography for patients undergoing rapid evaluation for pneumonia and an attractive alternative in the ICU.[16,17] Lung ultrasound is routinely used to identify complications from pneumonia, ARDS, and mechanical ventilation, such as pulmonary consolidation, pleural effusions, and pneumothorax.[18] Ultrasonography effectively monitors the progression of pulmonary disease by detecting lung inhomogeneity, cyclic alveolar recruitment and derecruitment, and diaphragmatic injury from ventilator volume overload.[19] Wave elastography facilitates staging of interstitial lung disease, including identification of early pulmonary fibrosis.[20] Ultrasonography effectively predicts successful weaning and extubation from mechanical ventilation for patients with ARDS.[21-23]

POCUS plays an important role in the diagnosis and management of patients with COVID-19 (Figure 1). Cross-training of echocardiographers and other personnel in pulmonary ultrasonography is effective and has been validated.[17] Standards for lung ultrasound in COVID-19 have recently been proposed.[24] A properly trained echocardiographer or intensivist wearing maximum-coverage PPE may be able to consecutively study numerous patients and perform serial examinations on individual patients as needed. In this scenario, the echocardiographer must be provided with the highest level of PPE

HIGHLIGHTS

- The gravity of the COVID-19 pandemic must be understood.
- Professional staff shortages may supersede the limited supply of ventilators.
- Lung ultrasonography and echocardiography are essential tools during this pandemic.
- Collaboration and cross-training are required to expand professional resources.
- Limited resource allocation requires ethical guideline proficiency and planning.

and should be immersed in the COVID-19 environment for the minimum time necessary to complete the examinations. Consecutive shifts should be avoided. This will reduce the risk for delivering a high and potentially lethal viral load to the provider.[25] The studies should be transmitted to a remote reading area. Bedside nurses and physicians should not repeat POCUS examinations. This should reduce the number of individuals coming into contact with infected patients, reduce the need for radiologic studies, decrease the consumption of PPE, improve the reproducibility of examinations, and decrease transmission of disease. Lung ultrasonography performed by properly trained personnel is a useful strategy in the fight against this pandemic.[14,15,24]

Surface echocardiography effectively screens for coronary artery disease and is essential for the rapid recognition of SARS-CoV-2-associated acute cardiomyopathy.[26-29] Coronary artery disease is one of the most common comorbidities associated with increased mortality from COVID-19.[30,31] SARS-CoV-2-associated acute cardiomyopathy has been reported in 12% of hospitalized patients with COVID-19.[8] Fulminating myocarditis may be a result of direct viral infection or the SARS-CoV-2 cytokine storm.[32] Viral myocarditis is associated with 40% to 70% mortality. Early aggressive therapy, including mechanical support, may reduce mortality from SARS-CoV-2-associated acute cardiomyopathy.[32] Rapid diagnostic evaluation and guideline-directed therapy are recommended.[29]

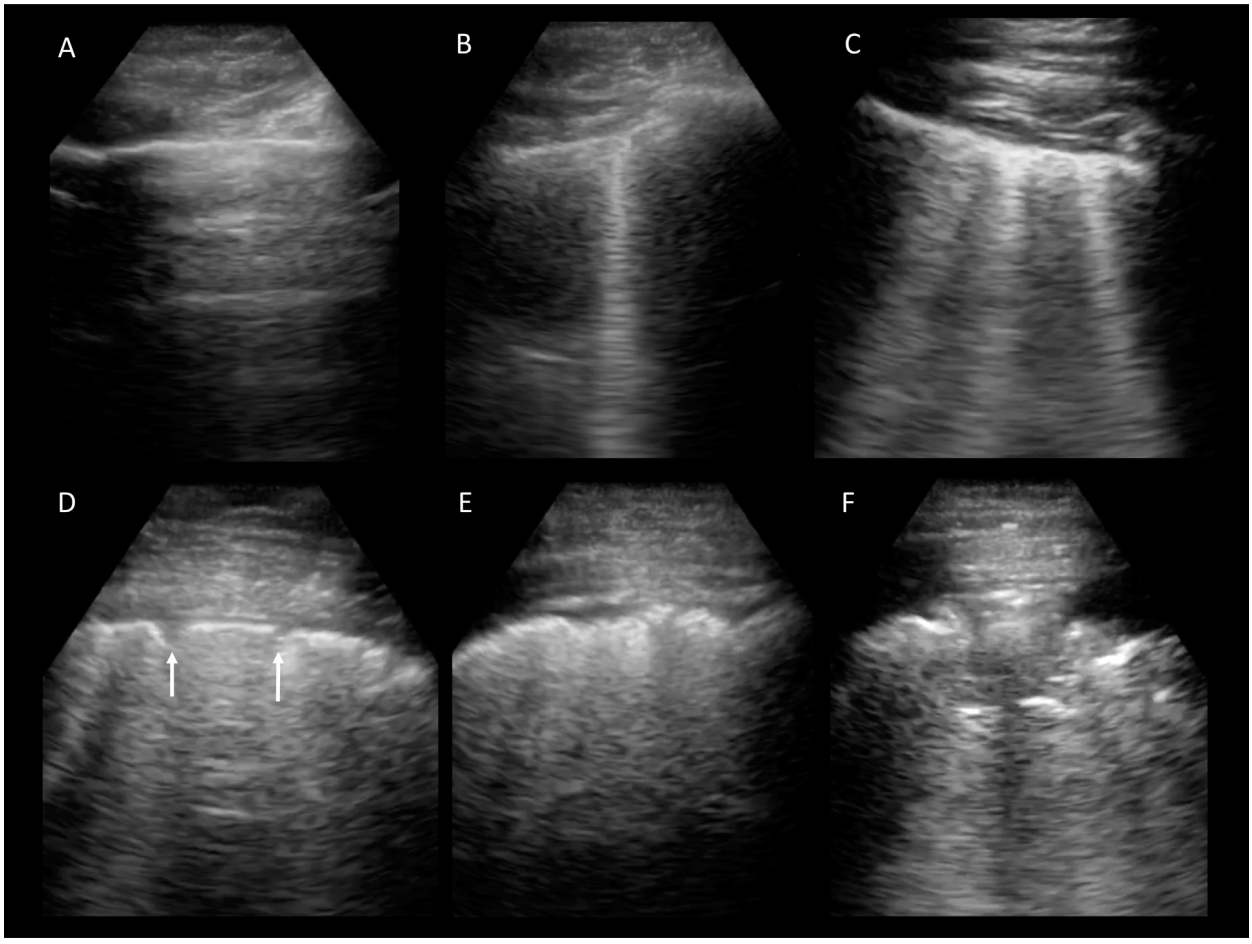

Figure 1 Lung POCUS in patients with COVID-19. Pulmonary involvement generally begins in the terminal alveoli, which are close to the pleura and easily visible on ultrasound. The basal lateral and posterior lung fields are most frequently involved. Images are acquired through intercostal windows on the anterior, lateral, and posterior chest. Typically, 12 to 14 brief video clips are obtained. **(A)** The upper bright horizontal line is normal pleura. Below is a normal lung demonstrating four horizontal A lines that are the result of reverberation artifact from normal tissue. **(B)** A single vertical B line is present. A few scattered nonconfluent B lines indicate a mild interstitial syndrome. **(C)** Multiple coalescing B lines indicate moderate to severe interstitial syndrome. **(D)** Skip lesions (*arrows*) are an early diagnostic feature of COVID-19. **(E)** More advanced skip lesions and subpulmonic consolidation are demonstrated. **(F)** Hyperechoic densities indicate complete consolidation in a patient with COVID-19 pneumonia.

Transthoracic echocardiography is essential for monitoring patients on extracorporeal membrane oxygenation (ECMO), and lung ultrasonography is a promising tool for daily interstitial assessment of patients with ARDS on ECMO.[33,34]

Echocardiography is portable and offers a clear advantage for reducing disease transmission by avoiding transporting patients through the hospital.[35] Mitigating transmission requires the appropriate use of PPE, meticulous equipment care, and limiting attendance to essential personnel during imaging. Compared with portable chest radiography, POCUS is less disruptive and may reduce direct patient contact. POCUS devices are smaller and easier to disinfect than portable chest radiographic machines. However, despite the higher risk for disease transmission, computed tomography may be required for more comprehensive evaluation of the chest.

Key Points on Sonography of the Lung, Pleura, Diaphragm, and Heart

- Early experience in China and Italy indicates that lung ultrasound can identify and quantify pulmonary complications of COVID-19.
- Lung ultrasound can routinely be used to identify pulmonary consolidation, effusions, pneumothorax, and interstitial disease, including pulmonary fibrosis.
- POCUS using handheld devices is effective for monitoring the progression of pulmonary disease, monitoring fluid status, early recognition of SARS-CoV-2-induced fulminating myocarditis, and identifying the presence and etiology of hemodynamic compromise.
- Ultrasonography is predictive of successful weaning from mechanical ventilation, effective for monitoring interstitial disease in patients on ECMO, and required for evaluation of line and cardiac status in patients on ECMO.
- POCUS is less disruptive and carries a lower risk for disease transmission, and the device is easier to clean than conventional radiographic equipment.
- Lung ultrasound is easily mastered by experienced echocardiographers.
- Computed tomography may be required for more detailed evaluation of the chest.

REQUIRED SKILLS, CROSS-TRAINING, AND CODE OF ETHICS

Cardiologists and anesthesiologists possess important skills that are required during a pandemic. These include mastery of cardiac imaging, assessment and triage of the critically ill, interventional risk-benefit analysis, airway management and intubation, invasive line procedures, ventilator and hemodynamic management, recognition of medically ineffective care, and familiarity with a high-pressure work environment. Echocardiographers expedite the identification and severity of common cardiac conditions as well as cardiac disease associated with COVID-19. All of these skills are required in communities hit hard by the pandemic.

Cross-training through a hierarchical tiered staffing strategy has been recommended to augment the professional services.[9] In this scenario, the first tier is staffed by two or three trained pulmonologists, intensivists, or anesthesiologists who are expert in critical care, including mechanical ventilation. Each of the first-tier physicians can reasonably advise several cardiologists, surgeons, and other physicians with at least some expertise in critical care. In turn, each of the second-tier physicians then works with several third-tier, midlevel providers and bedside nurses to supervise critical care. A similar hierarchical tiered approach may be used by hospitalists and emergency physicians to expand noncritical inpatient and emergency department care. Telemedicine technology greatly facilitates communication among tiers and with outside expertise.

The American Society of Echocardiography's code of ethics states "Patient welfare must be paramount in the practice of echocardiography and vascular ultrasound. Under no circumstances shall a member place his or her self-interest above patient welfare."[36] For physicians, the American Medical Association's code of ethics states that commitment to care for the sick requires physicians to provide urgent care during disasters, even in the face of risks to their own safety, health, or life.[37] The duty to treat is implicit in the social contract between physicians and the public.[38] The American College of Cardiology, American Society of Anesthesiologists, and Society of Thoracic Surgeons have similar codes.[39-41] However, the health care provider workforce is limited, especially during a pandemic. Physicians have an obligation to weigh the risks of caring for infected individuals against the need to be available to provide care in the future.[37] We must do our best to remain healthy to prevent spreading the disease to other patients, colleagues, and loved ones.

DEFINING A PUBLIC HEALTH CRISIS

The following discussion of a public health crisis is summarized from the Centers for Disease Control and Prevention's "Ethical Considerations for Decision Making Regarding Allocation of Mechanical Ventilators During a Severe Influenza Pandemic or Other Public Health Emergency,"[42] unless otherwise referenced.

Slowing and limiting disease transmission are mandatory for controlling the pandemic. Limiting disease transmission decreases the surge of critically ill patients into the health care system. Decreasing the surge reduces the demand on health care resources and decreases mortality.[43]

During a pandemic, the surge capacity of each hospital should be fully deployed. If a public health crisis is imminent, (1) severely limited resources should be identified and acquired (PPE, medications, ventilators); (2) severely limited infrastructure should be identified and acquired (professional and support staff members, isolation beds, critical care beds); (3) complete expansion of hospital capacity should occur, (4) all reasonable efforts to conserve, reuse, adapt, and substitute resources should be implemented; (5) requests for additional resources from local, regional, and state health officials should be completed; and (6) requests to use regional, state and federal resources or infrastructure should also be made (referral and transfer networks).[42] Only after all of these options have been completely exhausted should triage of limited resources be initiated.[44] Critical care should not be withheld or withdrawn without patient or surrogate consent until no other options exist and a health care crisis has been formally declared. The health care crisis should be continuously monitored.

Key Points for Defining a Public Health Crisis

- The surge capacity of each hospital should be fully deployed.
  - Hospital capacity is fully expanded.
  - Severely limited resources are identified and acquired.
  - Severely limited infrastructure is identified and acquired.
  - Efforts to conserve, reuse, adapt, and substitute limited resources are fully implemented.
  - Requests for additional resources from local, regional, state, and federal health officials are complete.
  - Requests to use regional, state, and federal resources and infrastructure have been made.

- Only after all options have been exhausted should a public health crisis be declared and triage of limited resources initiated.
- The health care crisis should be continuously monitored.
- Triage should immediately cease as limited resources become available.

PUBLIC HEALTH CRISIS TRIAGE

Critical Care Triage Committee

Health care providers should be familiar with the ethical principles and process of limited resource allocation. The decision to refuse or withdraw critical care because of limited resources should not be made in isolation. Before the public health crisis is imminent, a critical care triage committee should be created and its responsibilities defined.[42,45] The committee should provide multiple perspectives, facilitate broad communication, and optimize community support. The advisory committee to the Centers for Disease Control and Prevention recommends that the committee include senior leadership from the medical staff, intensive care nursing, respiratory care, and ethics if available.[44] Triage physicians should not concomitantly provide bedside care. This allows bedside clinicians to preserve the patient-physician relationship and continue to advocate on behalf of patients. Community commentary should be sought while developing public health crisis triage protocols, especially with regard to involuntary withholding or withdrawal of life support. These policies should be completely transparent, specifically identify the decision makers, and explicitly clarify the patient population to whom they apply. At a minimum, public health officials, city council members, and members of other governing organizations should be involved and provide support to the triage committee. The triage committee should be frequently updated on resource availability. Once limited resources become available, the triage committee should be immediately notified and triage should cease.

Limited Resource Allocation for Disease Prevention

Once a public health crisis is declared, rules that prioritize the overall benefit to society take precedence.[44] During the preventive phase, interventions that preserve a functional society may reasonably be given priority. Disease prevention includes the distribution of vaccines and antiviral medications to health care providers and others needed to maintain a functioning society.

Limited Resource Allocation for the Critically Ill

Critical care triage, including allocation of ventilators and ECMO, presents different ethical considerations. The critically ill can no longer contribute to the preservation of a functioning society. Recovery during and following ventilator dependence may be prolonged. Therefore, priority is given to those most likely to survive. If the probability of survival between two patients is the same, other factors such as years of life saved and resource consumption should be considered. Making the decision to withhold or withdraw life-sustaining resources from one patient who may survive for the purpose of giving those resources to a second patient who is more likely to survive is unprecedented for most physicians. These decisions are often complex and extremely difficult. They should be assigned to the triage committee. During a public health crisis, withholding or removal of ventilatory support or ECMO should not require consent from the patient or family. However, transparency is required, and the patient and family should be informed of the decision. Effective palliation of pain and suffering should be provided.

Numerous criteria have been proposed for the allocation of mechanical ventilation.[46] The sequential organ failure assessment scoring system is one of the most comprehensive.[47] Scoring systems are derived from retrospective analysis and have not been validated for prospective application. Although they can be useful, they should not be used exclusively for making individual patient decisions.[46]

Limited resource allocation requires proficiency with ethical guidelines and planning in advance. The following publications are highly recommended. The Centers for Disease Control and Prevention's "Ethical Considerations for Decision Making Regarding Allocation of Mechanical Ventilators During a Severe Influenza Pandemic or Other Public Health Emergency"[42] and the New York State Department of Health Task Force on Life and the Law's "Ventilator Allocation Guidelines"[48] detail the ethical considerations, organizational structure, and clinical context for developing regional policy and protocol. The clinical application and gravity of these circumstances are summarized in "The Toughest Triage—Allocating Ventilators in a Pandemic."[45]

In conclusion, during a declared public health crisis, the decision to withhold or withdraw critical care from a patient who might survive if critical care resources were available should be made by the triage committee using a fair process for each individual patient. Bedside providers should continue to advocate on behalf of their patients.

SUMMARY

Cardiologists, anesthesiologists, sonographers, and all providers should be prepared to commit their full spectrum of skills to mitigate the consequences of the present pandemic. We should be prepared to collaborate and cross-train to expand professional resources as necessary. In a true health care crisis, providers should understand the ethical principles, organizational structure, role of the triage committee, practical applications, and gravity of limited resource allocation. Professional commitment and informed resource allocation will reduce mortality and years of life lost.

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REFERENCES

1. Mahase E. Covid-19: WHO declares pandemic because of "alarming levels" of spread, severity, and inaction. BMJ 2020;368:m1036.
2. Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) in China. Zhonghua Liu Xing Bing Xue Za Zhi 2020;41:145-51.
3. Yee J, Unger L, Zadravecz F, Cariello P, Seibert A, Johnson MA, et al. Novel coronavirus 2019 (COVID-19): emergence and implications for emergency care. JACEP Open. Available at: https://onlinelibrary.wiley.com/doi/10.1002/emp2.12034. Accessed April 12, 2020.
4. Heymann DL, Shindo N. COVID-19: what is next for public health? Lancet 2020;395:542-5.

5. Centers for Disease Control and Prevention. Severe outcomes among patients with coronavirus disease 2019 (COVID-19)—United States, February 12–March 16, 2020. Available at: https://www.cdc.gov/mmwr/volumes/69/wr/mm6912e2.htm?s_cid=mm6912e2_w. Accessed March 23, 2020.
6. Mounk Y. The extraordinary decisions facing Italian doctors. Available at: https://www.theatlantic.com/ideas/archive/2020/03/who-gets-hospital-bed/607807/. Accessed March 22, 2020.
7. World Health Organization. Coronavirus disease 2019 (COVID-19) situation report – 53. Available at: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200313-sitrep-53-covid-19.pdf?sfvrsn=adb3f72_2. Accessed March 22, 2020.
8. Huang C, Wang Y, Li X, Ren L, Zhao J, Zhang L, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020;395:497-506.
9. Halpern N, Tan KS. SCCM Ventilator Taskforce 2020. U.S. ICU resource availability for COVID-19. Available at: https://sccm.org/Blog/March-2020/United-States-Resource-Availability-for-COVID-19?_zs=jxpjd1&_zl=w9pb6. Accessed March 13, 2020.
10. Johns Hopkins Center for Health Security. Ventilator stockpiling and availablility in the US. Available at: http://www.centerforhealthsecurity.org/resources/COVID-19/200214-VentilatorAvailability-factsheet.pdf. Accessed March 22, 2020.
11. Rubinson L, Vaughn F, Nelson S, Giordano S, Kallstrom T, Buckley T, et al. Mechanical ventilators in US acute care hospitals. Disaster Med Public Health Prep 2010;4:199-206.
12. Liew MF, Siow WT, MacLaren G, See KC. Preparing for COVID-19: early experience from an intensive care unit in Singapore. Crit Care 2020;24:83.
13. Ajao A, Nystrom SV, Koonin LM, Patel A, Howell DR, Baccam P, et al. Assessing the capacity of the US health care system to use additional mechanical ventilators during a large-scale public health emergency. Disaster Med Public Health Prep 2015;9:634-41.
14. Poggiali E, Dacrema A, Bastoni D, Tinelli V, Demichele E, Mateo Ramos P, et al. Can lung US help critical care clinicians in the early diagnosis of novel coronavirus (COVID-19) pneumonia? Radiology. Available at: https://pubs.rsna.org/doi/full/10.1148/radiol.2020200847. Accessed April 12, 2020.
15. Peng QY, Wang XT, Zhang LN. Findings of lung ultrasonography of novel corona virus pneumonia during the 2019–2020 epidemic. Intensive Care Med. Available at: https://link.springer.com/article/10.1007/s00134-020-05996-6. Accessed April 12, 2020.
16. Laursen CB, Sloth E, Lassen AT, Christensen RD, Lambrechtsen J, Madsen PH, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. Lancet Respir Med 2014;2:638-46.
17. Arbelot C, Dexheimer Neto FL, Gao Y, Brisson H, Chunyao W, Lv J, et al. Lung ultrasound in emergency and critically ill patients: number of supervised exams to reach basic competence. Anesthesiology 2020;132:899-907.
18. Mayo P. Bedside pleural ultrasonography: equipment, technique, and the identification of pleural effusion and pneumothorax. Available at: https://www.uptodate.com/contents/bedside-pleural-ultrasonography-equipment-technique-and-the-identification-of-pleural-effusion-and-pneumothorax. Accessed March 22, 2020.
19. Fan E, Brodie D, Slutsky AS. Acute respiratory distress syndrome: advances in diagnosis and treatment. JAMA 2018;319:698-710.
20. Zhou B, Bartholmai BJ, Kalra S, Osborn TG, Zhang X. Lung US surface wave elastography in interstitial lung disease staging. Radiology 2019;291:479-84.
21. Ferrari G, De Filippi G, Elia F, Panero F, Volpicelli G, Apra F. Diaphragm ultrasound as a new index of discontinuation from mechanical ventilation. Crit Ultrasound J 2014;6:8.
22. Farghaly S, Hasan AA. Diaphragm ultrasound as a new method to predict extubation outcome in mechanically ventilated patients. Aust Crit Care 2017;30:37-43.
23. Goligher EC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, et al. Mechanical ventilation-induced diaphragm atrophy strongly impacts clinical outcomes. Am J Respir Crit Care Med 2018;197:204-13.
24. Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Brigani DF, et al. Proposal for international standardization of the use of lung ultrasound for COVID-19 patients; a simple, quantitative, reproducible method. J Med Ultrasound. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/jum.15285. Accessed April 12, 2020.
25. Liu Y, Yan LM, Wan L, Xiang TX, Le A, Liu JM, et al. Viral dynamics in mild and severe cases of COVID-19. Lancet Infect Dis. Available at: https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30232-2/fulltext. Accessed April 12, 2020.
26. Kirkpatrick JN, Grimm R, Johri AM, Kimura BJ, Kort S, Labovitz AJ, et al. Recommendations for echocardiography laboratories participating in cardiac point of care cardiac ultrasound (POCUS) and critical care echocardiography training: report from the American Society of Echocardiography. J Am Soc Echocardiogr 2020;33:409-22.e4.
27. Doherty JU, Kort S, Mehran R, Schoenhagen P, Soman P. ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2019 appropriate use criteria for multimodality imaging in the assessment of cardiac structure and function in nonvalvular heart disease: a report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and the Society of Thoracic Surgeons. J Nucl Cardiol 2019;26:1392-413.
28. Hu H, Ma F, Wei X, Fang Y. Coronavirus fulminant myocarditis saved with glucocorticoid and human immunoglobulin. Eur Heart J. Available at: https://academic.oup.com/eurheartj/advance-article/doi/10.1093/eurheartj/ehaa190/5807656. Accessed April 12, 2020.
29. Kociol RD, Cooper LT, Fang JC, Moslehi JJ, Pang PS, Sabe MA, et al. Recognition and initial management of fulminant myocarditis: a scientific statement from the American Heart Association. Circulation 2020;141:e69-92.
30. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med. Available at: https://www.nejm.org/doi/full/10.1056/NEJMoa2002032. Accessed April 12, 2020.
31. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet. Available at: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30566-3/fulltext. Accessed April 12, 2020.
32. Chen C, Zhou Y, Wang DW. SARS-CoV-2: a potential novel etiology of fulminant myocarditis. Herz. Available at: https://link.springer.com/article/10.1007/s00059-020-04909-z. Accessed April 12, 2020.
33. Nanjayy VB. Ultrasound guidance for extra-corporeal membrane oxygenation general guidelines. Available at: https://www.elso.org/Portals/0/Files/elso_Ultrasoundguideance_ecmogeneral_guidelines_May2015.pdf. Accessed March 17, 2020.
34. Mongodi S, Pozzi M, Orlando A, Bouhemad B, Stella A, Tavazzi G, et al. Lung ultrasound for daily monitoring of ARDS patients on extracorporeal membrane oxygenation: preliminary experience. Intensive Care Med 2018;44:123-4.
35. Kirkpatrick JN, Mitchell C, Taub C, Kort S, Hung J, Swaminathan S. ASE statement on protection of patients and echocardiography service providers during the 2019 novel coronavirus outbreak. J Am Soc Echocardiogr 2020;33:648-53.
36. American Society of Echocardiography 2006. American Society of Echocardiography code of ethics. Available at: https://www.asecho.org/wp-content/uploads/2014/06/ASE-Code-of-Ethics-92506.pdf. Accessed March 22, 2020.
37. American Medical Association. Physicians' responsibilities in disaster response & preparedness code of medical ethics opinion 8.3. Available at:

https://www.ama-assn.org/delivering-care/ethics/physicians-responsibilities-disaster-response-preparedness. Accessed March 22, 2020.
38. Orentlicher D. The physician's duty to treat during pandemics. Am J Public Health 2018;108:1459-61.
39. American College of Cardiology. American College of Cardiology code of ethics. Available at: https://www.acc.org/about-acc/our-bylaws-and-code-of-ethics/code-of-ethics. Accessed March 22, 2020.
40. American Society of Anesthesiologists. Guidelines for the ethical practice of anesthesiology. Available at: https://www.asahq.org/~/media/sites/asahq/files/public/resources/standards-guidelines/guidelines-for-the-ethical-practice-of-anesthesiology.pdf?la=en. Accessed March 22, 2020.
41. Society of Thoracic Surgeons. Code of ethics. Available at: https://www.sts.org/about-sts/policies/code-ethics. Accessed March 22, 2020.
42. Centers for Disease Control and Prevention. Ethical considerations for decision making regarding allocation of mechanical ventilators during a severe influenza pandemic or other public health emergency. Available at: https://www.cdc.gov/about/advisory/pdf/VentDocument_Release.pdf. Accessed April 12, 2020.
43. Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72314 cases from the Chinese Center for Disease Control and Prevention. JAMA. Available at: https://jamanetwork.com/journals/jama/fullarticle/2762130. Accessed April 12, 2020.
44. Kinlaw K, Barrett DH, Levine RJ. Ethical guidelines in pandemic influenza: recommendations of the Ethics Subcommittee of the Advisory Committee of the Director, Centers for Disease Control and Prevention. Disaster Med Public Health Prep 2009;3(suppl 2):S185-92.
45. Truog RD, Mitchell C, Daley GQ. The toughest triage—allocating ventilators in a pandemic. N Engl J Med. Available at: https://www.nejm.org/doi/full/10.1056/NEJMp2005689. Accessed April 12, 2020.
46. Nates JL, Nunnally M, Kleinpell R, Blosser S, Goldner J, Birriel B, et al. ICU admission, discharge, and triage guidelines: a framework to enhance clinical operations, development of institutional policies, and further research. Crit Care Med 2016;44:1553-602.
47. Ferreira FL, Bota DP, Bross A, Melot C, Vincent JL. Serial evaluation of the SOFA score to predict outcome in critically ill patients. JAMA 2001;286:1754-8.
48. New York State Health Department Task Force on Life and the Law. Ventilator allocation guidelines. Available at: https://www.health.ny.gov/regulations/task_force/reports_publications/docs/ventilator_guidelines.pdf. Accessed March 22, 2020.