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Evolution of extracorporeal membrane oxygenation trigger criteria in COVID-19 acute respiratory distress syndrome

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ABSTRACT

Objective: To understand the implications of a tiered extracorporeal membrane oxygenation (ECMO) criteria framework and the outcomes of patients with COVID-19 acute respiratory distress syndrome who we were consulted on for ECMO but ultimately declined.

Methods: All patients declined for ECMO support by a large regional health care system between March 2020 and July 2021 were included. Restrictive selection criteria were enacted midway through the study stratifying the cohort into 2 groups. Primary outcomes included 30-day mortality. Secondary outcomes included reasons for declining ECMO and survival stratified by phase.

Results: One hundred ninety-three patients with COVID-19 acute respiratory distress syndrome were declined for ECMO within the study period out of 260 ECMO consults. At the time of consult, 71.0% (n = 137) were mechanically ventilated and 38% (n = 74) were proned and chemically paralyzed. Thirty-day mortality was 66% (n = 117), which increased from 53% to 73% (P = .010) when restrictive criteria were enacted. Patients with multisystem organ failure, prolonged ventilator time, and advanced age had respectively an 11-fold (odds ratio, 10.6; 95% CI, 1.7-65.2), 4-fold (odds ratio, 3.5; 95% CI, 1.1-12.0), and 4-fold (odds ratio, 4.4; 95% CI, 1.9-10.2) increase in the odds of mortality.

Conclusions: Patients with COVID-19 acute respiratory distress syndrome declined for ECMO represent a critically ill cohort. We observed an increase in the severity of disease and 30-day mortality in consults in the latter phase of our study period. These findings may reflect our use of tiered selection criteria coupled with ongoing education and communication with referring centers, sparing both patients likely to respond to medical therapy and those who were unsalvageable by ECMO. (J Thorac Cardiovasc Surg 2022; 17:111)

Given successes in extracorporeal membrane oxygenation (ECMO) in critically ill patients with acute respiratory distress syndrome (ARDS) 1,2 during prior respiratory viral outbreaks, its utility in COVID-19 has been widely investigated. Although initial reporting showed variable success, 3-6 later Extracorporeal Life Support Organization Registry data and meta-analyses demonstrated that ECMO is a reasonable intervention in critically ill COVID-19 patients with mortality rates comparable to other indications. 7,8 The overwhelming strain of COVID-19 on health care systems in the United States during the first year of the pandemic resulted in many patients without access to all available interventions. Much is still to be determined on the best way to stratify and designate patients who will most greatly benefit from ECMO during these
times. The outcomes of patients evaluated by a large ECMO center but then ultimately declined using a system of tiered predetermined criteria have not yet been reported. This study evaluates patients with COVID-19 ARDS pneumonia who were consulted for but ultimately declined for ECMO candidacy using a proactive tiered approach.

METHODS

All patients who were considered for ECMO at a regional health care system with a multistate catchment area between March 2020 and July 2021 were included. Initial phase criteria took effect from March 2020 until late November 2020 at which time enhanced selection criteria were utilized for the remainder of the study period. The initial phase was referred to as the green phase and later phase as the yellow phase. All patient data that were provided and available at the time of the initial consult were included. Hospital course and 30-day outcomes were obtained via retrospective review of public records and electronic health record.

Background of the Hospital System and ECMO Program

The University of Pittsburgh Medical Center is a large regional health system in Western Pennsylvania with a multistate catchment area. Across its multiple locations it maintains a capacity of 8700 beds. At the onset of the pandemic, as in hospitals all around the country, specific inpatient floors and medical intensive care units (ICUs) were designated for COVID-19 patients. Part of the cardiothoracic ICU at the flagship hospital was transformed into an isolated COVID-19 ECMO unit in which patients were cared for by a dedicated nurse, perfusionist, fellow, and attending physician specific to that unit. The capacity for ECMO support varied but averaged between 15 and 20 patients and was dependent on ECMO equipment, hospital capacity, and health care personnel staffing, with overall maximum availability of support being around 36. Capacity was never limited during the study period by equipment shortages but by overall hospital bed capacity and ICU staffing shortages. Venovenous (VV) ECMO cannulation teams were composed of cardiothoracic surgeons, critical care physicians, and perfusionists with the capacity to cannulate remotely if needed. All patient referrals for ECMO within this system were directed to this special team of critical care physicians and surgeons for candidacy consideration. Referrals were initiated by critical care and emergency medicine physicians locally and regionally, with the most remote consult received more than 300 miles from our center. Candidacy was initially evaluated by the on-call physician using predetermined institutional COVID-19 ECMO criteria and subsequently affirmed by a 3-physician ECMO committee that included 2 critical care attending physicians and 1 cardiothoracic surgeon. To ensure uniformity, the selection criteria and tiered approach were agreed upon by a regional consortium of ECMO center directors and were distributed to regional chief medical officers before the surge of COVID-19 cases in the area.

ECMO Initiation Criteria

Selection criteria were established at the beginning of the pandemic during March 2020. These were developed based on predetermined standard institutional criteria to objectively identify those with a higher probability of survival (Figure 1). Indications for ECMO support included 1 of the 3 criteria used in the ECMO to Rescue Lung Injury in Severe ARDS (EO-LIA) trial: a PaO2/inspired oxygen fraction ratio (P/F ratio) of <50 mm Hg for >3 hours; a P/F ratio <80 mm Hg for >6 hours; or an arterial blood pH <7.25 with Paco2 of at least 60 mm Hg for >6 hours. Exclusion criteria and initial survival predictions were dictated by the Respiratory Extracorporeal Membrane Oxygenation Survival Prediction score and excluded patients older than age 65 years, on mechanical ventilation for 10 days or longer, in acute multiorgan failure, and those with significant medical comorbidities (ie, active cancer, immunocompromised, or home oxygen requirement/irreversible lung disease). ECMO support was also declined if the patient met inclusion criteria but had not yet demonstrated failure of medical therapy, which included intermittent prone positioning, chemical paralysis, and optimized ventilator settings. In these cases, referring physicians were contacted after 24 hours for re-evaluation until a final determination for ECMO candidacy was made. Halfway through the study period the predetermined criteria for yellow phase were enacted due to capacity restraints on the hospital system as it was overwhelmed by cases. The yellow phase was triggered by a reduction in capacity for ECMO cases by >50% by the factors previously mentioned. In this phase, age cutoff was lowered to 59 years and mechanical ventilation days were reduced to 7 days or fewer, which included consideration of both invasive and noninvasive ventilation (ie, Continuous positive airway pressure or bilevel positive airway pressure and heated high flow nasal cannula) when measuring duration. These criteria were redistributed and adopted regionally across hospital systems to streamline and standardize access to ECMO for the duration of the pandemic.

Study Inclusion Criteria and Statistical Analysis

All patients between March 1, 2020, and July 31, 2021, who were referred for consideration of VV ECMO due to COVID-19–induced ARDS were included in this study. SARS-CoV-2–positive status was confirmed in all patients via reverse transcription polymerase chain reaction. Patients referred for consideration of venoarterial ECMO support were excluded. Study approval was obtained from the hospital quality review committee as quality improvement with institutional review board exemption. All referral calls, which were made both within and outside the hospital system, were facilitated and recorded by a central call system (MedCall; University of Pittsburgh Medical Center) and subsequently added to a consult database. Patient condition was evaluated over the telephone using all provided data available at the time, including duration of illness, ventilator settings, arterial blood gas values, basic laboratory values, use of prone positioning, neuromuscular blockade, and medical history. Additional patient data were obtained via retrospective chart review, if available. The 30-day outcomes were obtained by retrospective review of the electronic health record and verified by a public record search within the catchment area. Date of death, length of hospital stay, and discharge data were included if available. Pearson χ² tests were used for categorical variables. Wilcoxon and Kruskal–Wallis tests were used for continuous variables. Multivariable logistic regression was used to determine predictors of mortality following declining ECMO therapy adjusted for the different phases (green or yellow). Kaplan–Meier estimates with log-rank test were used for time to event analysis.

RESULTS

The period from March 2020 to July 2021 represented the first wave of the COVID-19 pandemic, during which hospitals peaked in December 2020 across Allegheny
Within these 17 months, 260 patients were evaluated and considered for ECMO therapy and ultimately 74.0% (n = 193) were declined (Figure 3). Basic demographic characteristics and clinical condition at the time of the consult are indicated in Table 1. The cohort was 59% (n = 114) men, with a median body mass index of 36 (interquartile range [IQR], 30-43) and age 56 years (IQR, 47-62 years). Most patients were supported on mechanical ventilation (72%; n = 138) with a median Paco$_2$ of 54 mm Hg (IQR, 44-65 mm Hg) and P/F ratio of 92 (IQR, 71-121). Prone positioning and chemical paralysis were used in 38% (n = 74) of patients at the time of consult. Criteria for ECMO consideration became more restrictive approximately 9 months into the pandemic as the volume and severity of patients increased. There were significant differences in the cohort of declined patients between the green

![FIGURE 1. Extracorporeal membrane oxygenation (ECMO) selection criteria adjusted for systemwide capacity. Distributed as part of detailed ECMO criteria and critical care guidelines to hospital system and regional stakeholders. UPMC, University of Pittsburgh Medical Center; y/o, years old; RESP, respiratory extracorporeal membrane oxygenation survival prediction; PIP, peak inspiratory pressure.](image)

County and Pennsylvania (Figure 2). Within these 17 months, 260 patients were evaluated and considered for ECMO therapy and ultimately 74.0% (n = 193) were declined (Figure 3). Basic demographic characteristics and clinical condition at the time of the consult are indicated in Table 1. The cohort was 59% (n = 114) men, with a median body mass index of 36 (interquartile range [IQR], 30-43) and age 56 years (IQR, 47-62 years). Most patients were supported on mechanical ventilation (72%; n = 138) with a median Paco$_2$ of 54 mm Hg (IQR, 44-65 mm Hg) and P/F ratio of 92 (IQR, 71-121). Prone positioning and chemical paralysis were used in 38% (n = 74) of patients at the time of consult. Criteria for ECMO consideration became more restrictive approximately 9 months into the pandemic as the volume and severity of patients increased. There were significant differences in the cohort of declined patients between the green

![FIGURE 2. Study period spanning the first 17 months of the pandemic, beginning with green phase criteria and transitioning to more restrictive yellow phase criteria just before the first peak of cases in Allegheny County, Pa, and across the state. Hospitalized data obtained from Allegheny County Health Department (alleghenycounty.us).](image)
Evolution of ECMO Trigger Criteria in COVID-19 ARDS

Outbreak of COVID-19 SARS
Dec 2019

Creation of tiered ECMO criteria based on hospital capacity:
GREEN, YELLOW, RED

Adoption of ECMO framework across the region

Restrictive criteria enacted during YELLOW surge in cases:
Age < 60
Vent time < 7 D

March 2020
Nov 2020
July 2021

260 Patients Evaluated for ECMO during 1st wave
March 2020 - July 2021

193 patients declined for ECMO

Primary Reason for Decline
Too Healthy (36%)  
Advanced Age (28%)  
Pre-existing Comorbidity (13%)  
Prolonged Vent Time (9.8%)

Increased Odds of Mortality with Multiorgan failure (OR 10.6)
Advanced age (OR 4.4)
Prolonged vent time (OR 3.54)
Pre-existing comorbidity (OR 3.1)

Rise in Mortality During Later Era of Consults
53% to 73%

FIGURE 3. One hundred ninety-three patients were evaluated and declined for extracorporeal membrane oxygenation (ECMO) out of 260 COVID-19 ECMO consults using a tiered allocation strategy. ARDS, Acute respiratory distress syndrome; SARS, severe acute respiratory syndrome; OR, odds ratio.

and yellow phases. In the latter half of the study, declined patients were notably younger (median age, 55 years; IQR, 48-60 years; \( P = .048 \)) and more critically ill, with median PaCO2 of 55 mm Hg (\( P = .03 \)) and P/F ratio of 86 compared with 108 (\( P < .01 \)) in the first phase of consults. The overall mortality of declined patients was 66% (\( n = 117 \)) with an increase in 30-day mortality from 53% (\( n = 31 \)) to 73% (\( n = 86 \); \( P = .010 \)) across phases. During this study period, 64 patients were cannulated for VV ECMO; 24 in the green phase and 40 during the yellow phase. Overall mortality for patients supported on ECMO was 55%, with 46% mortality in the green phase (\( n = 11 \)), and 60% mortality in the yellow phase (\( n = 24 \); \( P = .27 \)). Median age in cannulated patients was 53.5 years in the green phase compared with 49 years in the yellow phase (\( P = .013 \)).

The primary reason for declining the patient for ECMO support was conveyed to the referring physician and documented at the time of the consult. Lack of demonstrated

| TABLE 1. Patient characteristics |
|---------------------------------|
| Characteristic                  | N  | Overall (N = 193) | COVID-19 green phase (n = 62) | COVID-19 yellow phase (n = 131) | \( P \) value* |
| Age (y)                         |    | 193               | 56 (47-62)                      | 58 (46-68)                       | .048          |
| Sex                             |    | 193               | 79 (41)                         | 51 (50)                          | .078          |
| Female                          |    | 79 (41)           | 31 (50)                         | 48 (37)                          |               |
| Male                            |    | 114 (59)          | 31 (50)                         | 83 (63)                          |               |
| Body mass index                 |    | 133               | 36 (30-43)                      | 36 (30-43)                       | .85           |
| PaO2                            |    | 144               | 77 (65-100)                     | 79 (70-108)                      | .087          |
| PCO2                            |    | 135               | 54 (44-65)                      | 52 (41-57)                       | .030          |
| Inspired oxygen fraction        |    | 159               | 1.00 (0.80-1.00)                | 0.90 (0.70-1.00)                 | .015          |
| Positive end-expiratory pressure|    | 147               | 14.0 (12.0-16.0)                | 13.2 (10.0-15.0)                 | .084          |
| P/F ratio                       |    | 138               | 92 (71-121)                     | 108 (86-156)                     | <.001         |
| Proned and paralyzed at consult |  193 | 74 (38)           | 27 (44)                         | 47 (36)                          | .31           |
| 30-Day mortality               |    | 176               | 117 (66)                        | 31 (53)                          | .010          |

*Values are presented as median (interquartile range) or n (%). P/F ratio, PaO2 to inspired oxygen fraction ratio. *Wilcoxon rank sum test; Pearson \( \chi^2 \) test.
failure of medical therapy; that is, not yet proned and paralyzed, was the single greatest reason for decline, followed by advanced age, pre-existing comorbid conditions, and prolonged ventilator time (Table 2). When stratified by COVID-19 phase, significantly fewer patients overall were declined due to nonfailure of medical therapy as the pandemic progressed \((P = .007)\). A \(\chi^2\) analysis found that decline reason was associated with survival outcome \((P < .001)\). Lack of failure of medical therapy (ie, too healthy) was associated with better survival \((P < .001)\), but age and multiorgan failure were associated with poorer survival \((P < .05)\). There was not an association with survival for other decline reasons (Table 3). Of the reasons for not offering ECMO, acute multiorgan failure was the strongest predictor of 30-day mortality representing a nearly 11-fold increase in risk (Table 4) (odds ratio \([OR]\), 10.6; 95% CI, 1.71-65.2; \(P = .011)\), followed by age \((OR, 4.43; 95\% \text{ CI}, 1.93-10.2; \ P < .001)\), ventilator time \((OR, 3.54; 95\% \text{ CI}, 1.05-12.0; \ P = .04)\), and preexisting comorbidities \((OR, 3.14; 95\% \text{ CI}, 1.09-9.09; \ P = .03)\).

Significant differences in patients declined for ECMO were noted between those who survived and those who died within 30-days post-consult (Table 5). Patients who died were frequently older (median age 58 years vs 54 years; \(P = .002)\) and more critically ill at the time of consult, with greater median \(\text{PaCO}_2\) of 56 mm Hg (IQR, 48-67 mm Hg) compared with 50 mm Hg (IQR, 41-58; \(P = .028)\), higher inspired oxygen fraction of 100% compared with 95% in survivors \((P = .029)\) and had a significantly lower \(P/F\) ratio of 86 (IQR, 65-112) compared with 106 (IQR, 79-146; \(P = .005)\). Survival analysis found a trend towards difference in survival time. Patients in the latter yellow phase had shorter survival durations (Table 6 and Figure 4) (median, 12 days; 95% CI, 9-18 days) relative to patients in the green phase (median, 15 days; 95% CI, 10-∞ days, \(\chi^2(1) = 3.8; P = .053)\).

Discharge data were available for 53 (27.4%) of the referrals who represented 89.8% of all survivors (Table 7). In this group of patients declined for ECMO, the median inpatient length of stay was 31.0 days (IQR, 19-42 days). Discharge was either to home (43%; \(n = 23)\), inpatient rehabilitation (28%; \(n = 15)\), or long-term acute-care facility (28%; \(n = 15)\). Median duration on mechanical ventilation was 14 days (IQR, 10-20 days) until either extubation (54%; \(n = 26)\) occurred or tracheostomy (46%; \(n = 22)\) was performed. Patients discharged to home had shorter overall length of stay (median, 19 days), shorter ventilator duration (median, 10 days) and had higher rates of extubation \((84\%)\) relative to patients discharged to inpatient rehabilitation or long-term acute-care facility \((P < .05)\).

### Table 2. Reason for declining extracorporeal membrane oxygenation (ECMO) \((N = 193)\)

| Characteristic                     | Overall \((N = 193)\) | COVID green phase \((n = 62)\) | COVID yellow phase \((n = 131)\) | \(P\) value* |
|-----------------------------------|------------------------|--------------------------------|----------------------------------|--------------|
| Lack of failure of medical therapy| 70 (36)                | 31 (50)                       | 39 (30)                          | .0069        |
| Preexisting comorbidity           | 25 (13)                | 6 (9.7)                       | 19 (15)                          | .37          |
| Multiorgan failure                | 14 (7.3)               | 3 (4.8)                       | 11 (8.4)                         | .37          |
| Age                               | 54 (28)                | 18 (29)                       | 36 (27)                          | .84          |
| Body mass index                   | 6 (3.1)                | 0 (0)                         | 6 (4.6)                          | .09          |
| Ventilator time                   | 19 (9.8)               | 4 (6.5)                       | 15 (11)                          | .27          |
| Duration of illness               | 3 (1.6)                | 0 (0)                         | 3 (2.3)                          | .23          |
| Other                             | 2 (1.0)                | 0 (0)                         | 2 (1.5)                          | .32          |

Values are presented as \(n\) (%). *Fisher exact test. \(P < .001)\) post hoc; \(P < .05\) post hoc.

### Table 3. Differences in survival across decline codes \((N = 176)\)

| Characteristic                     | Overall \((N = 176)\) | Alive \((n = 59)\) | Deceased \((n = 117)\) | \(P\) value* |
|-----------------------------------|------------------------|---------------------|------------------------|--------------|
| Lack of failure of medical therapy| 63 (36)                | 36 (61)             | 27 (23)                | <.001        |
| Preexisting comorbidity           | 23 (13)                | 6 (10)              | 17 (15)                |              |
| Multiorgan failure                | 14 (8.0)               | 1 (1.7)             | 13 (11)                |              |
| Age                               | 52 (30)                | 11 (19)             | 41 (35)                |              |
| Body mass index                   | 4 (2.3)                | 1 (1.7)             | 3 (2.6)                |              |
| Ventilator time                   | 17 (9.7)               | 4 (6.8)             | 13 (11)                |              |
| Duration of illness               | 3 (1.7)                | 0 (0)               | 3 (2.6)                |              |
| Other                             | 0 (0)                  | 0 (0)               | 0 (0)                  |              |

Values are presented as \(n\) (%). *Fisher exact test. \(P < .001)\) post hoc; \(P < .05\) post hoc.
In this study, we describe the use of a tiered system of selection criteria for ECMO that was universally adopted across health systems within our region. This approach was designed to flex with changes in capacity and available resources in order to provide consistent access for those most likely to benefit from support. Patients declined for ECMO candidacy using these criteria were retrospectively evaluated, providing insight into both the influences of this framework and the natural course of the COVID-19 pandemic.

The initial wave of COVID cases abroad and in the eastern United States prompted discussions within our team to create a comprehensive strategy for ECMO utilization. It was critical to preemptively develop a framework for ECMO initiation criteria using the best available evidence at the time, which pointed to the relative success of this intervention in patients with COVID-19. Concurrently, the finite resources of the hospital system and the community at large were considered. Prior institutional experience in dealing with the influenza A pandemic in 2009 informed the knowledge that maximum hospital capacity would be accompanied by a surge in ECMO consultations. Our first step was to adjust our standard ECMO criteria in the context of the resources of our hospital and ECMO program to identify trigger points at which ECMO candidacy should be restricted. There are notable ethical challenges to consider when allocating high-cost resources in limited availability situations, such as whether or not to prioritize the sickest versus those who come in first, or those with the highest chance of survival.13 Our institutional priorities were to maximize our ability to offer ECMO to patients with a reasonable likelihood of survival while minimizing the chance of having to decline a candidate due to lack of capacity. Given the substantial physical resources, personnel, and coordination required to maintain an ECMO program14 this required careful institutional inventory and preparedness assessment. With these goals and information, we created our framework of green, yellow, and red criteria, which was discussed with regional stakeholders across health care systems and proactively distributed to all hospitals in our catchment area. By establishing a single framework adopted among multiple medical centers, we were able to maximize our collective ability to provide equitable patient care, eliminating disparities in geographic area or insurance coverage.

A comparison of declined patients from the green and yellow phases reveals 2 types of consults. On one hand were healthier patients with better oxygenation and ventilation (ie, lower median PaCO2 and higher median P/F ratio), including some who were not yet intubated. Others met

### Table 4. Predictors of 30-day mortality (N = 176)

| Characteristic                  | Odds ratio (95% CI) | P value |
|--------------------------------|---------------------|---------|
| Decline reason                 |                     |         |
| Lack of failure of medical     | Reference category  |         |
| therapy                        |                     |         |
| Duration of illness            | 7.22 (0.22-233)     | .26     |
| Preexisting comorbidity        | 3.14 (1.09-9.09)    | .034    |
| Multiorgan failure             | 10.6 (1.71-65.2)    | .011    |
| Age                            | 4.43 (1.93-10.2)    | <.001   |
| Body mass index                | 2.41 (0.26-22.2)    | .44     |
| Ventilator duration            | 3.54 (1.05-12.0)    | .042    |
| Era                            |                     |         |
| Early COVID-19 era             | –                   |         |
| Refined COVID-19 era           | 1.71 (0.84-3.48)    | .14     |

CI, Confidence interval.

### Table 5. Patient characteristics across survival status

| Characteristic                  | n   | Overall (N = 176) | Alive (n = 59) | Deceased (n = 117) | P value* |
|--------------------------------|-----|------------------|----------------|-------------------|---------|
| Age (y)                         | 176 | 56 (48-62)       | 54 (42-59)     | 58 (49-64)        | .002    |
| Sex                             | 176 |                  |                |                   | .17     |
| Female                          | 71  | 40               | 28 (47)        | 43 (37)           |         |
| Male                            | 105 | 60               | 31 (53)        | 74 (63)           |         |
| Body mass index                 | 125 | 36 (30-43)       | 38 (31-43)     | 34 (28-41)        | .11     |
| PaO2                            | 137 | 79 (65-102)      | 80 (68-108)    | 76 (65-95)        | .14     |
| Pco2                            | 128 | 54 (45-65)       | 50 (41-58)     | 56 (48-67)        | .028    |
| Inspired oxygen fraction        | 149 | 1.00 (0.80-1.00) | 0.95 (0.70-1.00)| 1.00 (0.80-1.00)  | .029    |
| Positive end-expiratory pressure| 139 | 14.0 (10.0-15.0)| 12.0 (10.0-15.0)| 14.0 (10.5-15.8)  | .29     |
| P/F Ratio                       | 131 | 91 (69-122)      | 106 (79-146)   | 86 (65-112)       | .005    |
| Prone and paralyzed at consult  | 176 | 68 (39)          | 24 (41)        | 44 (38)           | .69     |

*Values are presented as median (interquartile range) or n (%). P/F ratio; PaO2 to inspired oxygen fraction ratio. *Wilcoxon rank sum test; Pearson χ² test.
inclusion criteria but were initially declined because proven interventions such as proning and chemical paralysis had not yet been performed. These patients had a significant chance of improving with further medical management. The other group of patients were older, had been intubated for several days, or were developing multiorgan failure, and represented a cohort so critically ill that ECMO support was unlikely to alter their trajectory. Initial survival comparisons between patients declined for ECMO and those who were cannulated for ECMO during this 17-month period reveal that mortality increased in both groups over time. Overall patients were getting sicker despite our increased understanding of how to manage the disease. A nonsignificant increase in mortality in the cannulated patients during the yellow phase supports the transition to stricter selection criteria as laid out in our framework. Our overall survival with ECMO is consistent with national mortality rates published by the Extracorporeal Life Support Organization during the same period.

Additional differences in the phases of declined patients support the success in our data dissemination strategy. The lower median age of patients declined in the yellow phase is an expected change. As the age requirement for ECMO consideration lowered, so did the group of patients who were no longer eligible. The data also reveal that fewer elderly patients were being referred for ECMO in this stage, which supports the notion that the referring centers had become increasingly familiar with our criteria. Fewer patients were declined for ECMO because of being too healthy in the latter half of the study period, as physicians in outside hospitals likely became increasingly familiar with our ECMO candidacy criteria, employed evidence-based strategies as they became available, and developed more experience caring for these critically ill patients. Furthermore, consulted physicians at the ECMO center had repeated opportunities to provide education and counseling to the physicians on the referral call or follow-up call with regard to best practices for this cohort. Rather than confine the consult to 1 or 2 conversations, consulting physicians were encouraged to call back if the patient condition did not improve with strategies discussed, and our team was able to provide additional support at all times. Out of the 131 patients declined in the yellow phase, we found 30 potential candidates for ECMO under the green phase criteria had the more liberalized ranges for patient age and ventilator time been used. This does not account

### TABLE 6. Kaplan–Meier survival estimates: Postconsult

| Characteristic                     | 7 Days       | 14 Days      | 21 Days      | 28 Days      | P value |
|-----------------------------------|--------------|--------------|--------------|--------------|---------|
| COVID-19 era                      | 70 (59-83)   | 52 (40-67)   | 47 (35-63)   | 44 (32-60)   | .053    |
| Green/early COVID-19 era          | 65 (56-75)   | 41 (32-52)   | 33 (25-44)   | 27 (19-38)   |         |

Values are presented as median % (interquartile range).

![FIGURE 4. Kaplan–Meier survival stratified by consult phase.](#)
for the possibility of uncovering multiple exclusion criteria had the evaluation progressed. Mortality in this group of patients was 80% (n = 24).

Varying selection and management strategies were employed at ECMO centers around the country at the beginning of the pandemic. In establishing their criteria, each center was at risk of missing an opportunity to offer ECMO to patients who could benefit. Overly strict criteria that restrict access to ECMO to only the young and otherwise healthy may miss patients who would survive with the support of ECMO, whereas overly liberal criteria may result in the system becoming overwhelmed with patients who won’t survive. Institutions that utilized more liberalized criteria offering ECMO to those with advanced age and single organ dysfunction had unsurprisingly higher mortality rates\(^\text{a}\) than those with stricter criteria; in contrast, initial reporting out of New York University demonstrated markedly higher survival rates in patients who were younger (median age, 40 years) and with a higher median P/F ratio (ie, 84) at time of cannulation.\(^\text{b}\)

Gannon and colleagues\(^\text{c}\) utilized similar criteria to our institution during the pandemic, although were limited by capacity and ultimately able to cannulate and support only 40% of patients who met their criteria. Although in some respects this can be interpreted favorably because every available ECMO bed was utilized, it also highlights the challenge that all ECMO centers faced during the pandemic: The needs of our hospital systems far outpaced our capacity. At our center, the criteria became progressively stricter, even reaching red phase with an age cutoff of 50 years at a later surge in COVID-19 cases not covered in this analysis. Despite the large number of patients who were ultimately declined for ECMO during this study period, the application of this selection criteria had positive influences beyond creating a uniform regional response. Referring physicians received unequivocal answers that could be put into practice immediately, whether that was critical care guidance or a declined ECMO case that could facilitate end-of-life conversations. With clear guidelines that were adhered to throughout the region, physicians on the ECMO team were similarly unburdened of feeling solely responsible for a decision during this time of great emotional strain.

There were many potential areas for improvement in the implementation of our ECMO referral criteria. First, there was some lack of standardization in what was considered positive pressure ventilation. Although it is known that patients with ARDS with shorter duration between intubation and cannulation have improved survival,\(^\text{d}\) the effects on survival of noninvasive positive pressure ventilation (eg, bilevel positive airway pressure and heated high flow nasal cannula) are not well defined.\(^\text{e}\) Our decision to include noninvasive ventilation when counting days on respiratory support was driven by our observations that intubation was being delayed until later in the disease process when the fibrotic stage of ARDS was setting in. Secondly, we did not have a system in place to check on the consults in real time. Although the ECMO team made follow-up telephone calls for all patients who were being considered with management suggestions, most of the medical management was guided by the physicians at referring hospitals. In addition, while lung transplant is a potential option for patients with irreversible lung injury due to COVID-19,\(^\text{f}\) our criteria were not constructed for the consideration of ECMO as a bridge to transplantation. Because we were unable to directly review the outside hospital medical records for all patients, our knowledge of the extent of medical management was frequently limited to verbal confirmation of prone positioning, positive pressure ventilation, and chemical paralysis. We do not have information on COVID-19 specific medical management with steroids or antibody therapy that may have benefitted certain groups of patients seeking ECMO support. We were also limited in our ability

### Table 7. Discharge data

| Characteristic                  | n   | Overall (n = 53) | Home (n = 23) | IPR (n = 15) | LTAC/select (n = 15) | P value* |
|--------------------------------|-----|-----------------|--------------|-------------|---------------------|----------|
| Length of stay (d)             | 50  | 31 (19-42)      | 19 (15-32)\(^a\) | 38 (28-45)\(^a\) | 39 (31-42)\(^a\) | .003     |
| Prone and paralyzed at consult | 53  | 24 (45)         | 9 (39)       | 8 (53)      | 7 (47)              | .69      |
| Age (y)                        | 53  | 54 (41-58)      | 45 (34-56)   | 55 (49-57)  | 55 (48-60)          | .21      |
| Sex                            | 53  |                 |              |             |                     | .054     |
| Female                         | 25  | (47)            | 15 (65)      | 6 (40)      | 4 (27)              |          |
| Male                           | 28  | (53)            | 8 (35)       | 9 (60)      | 11 (73)             |          |
| P/F Ratio                      | 43  | 103 (75-153)    | 90 (73-123)  | 113 (79-162)| 119 (88-134)        | .42      |
| Duration to extubation/tracheostomy (d) | 47  | 14 (10-20)      | 10 (8-13)\(^a\) | 16 (14-20)\(^a\) | 19 (13-24)\(^a\) | .003     |
| Ventilation                    | 48  |                 |              |             |                     | <.001    |
| Extubation                     | 26  | (54)            | 16 (84)\(^|\) | 8 (53)      | 2 (14)\(^|\)       |          |
| Tracheostomy                   | 22  | (46)            | 3 (16)\(^|\) | 7 (47)      | 12 (86)\(^|\)      |          |

*Values are presented as median (interquartile range) or n (%). IPR, Inpatient rehab; LTAC, long-term acute care; P/F ratio; Pao2, to inspired oxygen fraction ratio. *Kruskal-Wallis rank sum test; Pearson \(\chi^2\) test. |P < .05 post-hoc. Columns with different superscripts (y, z) are statistically different post hoc.
to identify and track the COVID-19 variants in this cohort, which may have additionally influenced survival. As local physicians became more familiar with our ECMO candidacy criteria, it is possible that we received fewer referrals for patients who would be turned down, which may have biased our results. Finally, this is a retrospective study with all of the inherent limitations in its design.

CONCLUSIONS

ECMO has been shown to be a valuable tool in supporting patients with ARDS caused by COVID-19. We present a proactive allocation and triage strategy that was used successfully to balance the needs of acutely ill patients with COVID-19 ARDS against the finite resources of our hospital system during the beginning of the pandemic. Using this framework, we identified patients who were not appropriate for ECMO support either due high risk of mortality or high likelihood of improvement without extracorporeal life support. Further research is needed to determine optimal criteria to provide maximal survival benefit for this disease. Particularly in times of strain on the health care system, high-resource interventions need to be allocated thoughtfully with mechanisms in place to track outcomes and provide feedback for improvement.

Webcast
You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/1359.

Conflict of Interest Statement
The authors reported no conflicts of interest.

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Key Words: COVID-19, ARDS, extracorporeal membrane oxygenation, ECMO criteria, survival.
Discussion

Presenter: Dr Rachel Deitz

Dr Nathalie Roy (Boston, Mass). I would like to thank the American Association for Thoracic Surgery for the opportunity to discuss this manuscript and also thank the authors for providing me a copy of the manuscript in advance of the meeting. You report outcomes of patients who were referred for, but not supported on extracorporeal membrane oxygenation (ECMO), based on your tiered triage system established early in the COVID-19 pandemic. The system was established proactively to ensure equitable resource utilization and optimal outcomes, and that’s what I will focus on with my questions.

First, I want to congratulate you on this effort. Early in the pandemic, the editorial board of the New England Journal of Medicine published a “fair allocation of scarce medical resource” article, and although the benefit of ECMO was unclear at that time, it became obvious from this Paris group and other authors, in propensity-matched cohort studies, that there was a significant survival advantage with this ECMO technology. Your presentation reflects the natural history of severe COVID-19 acute respiratory distress syndrome (ARDS).

In that context, I first want to reflect on the severe toll COVID-19 acute respiratory distress syndrome (ARDS). Survival advantage with this ECMO technology. Your from this Paris group and other authors, in propensity-matched cohort studies, that there was a significant survival advantage with this ECMO technology. Your presentation reflects the natural history of severe COVID-19 acute respiratory distress syndrome (ARDS). In that context, I first want to reflect on the severe toll of the pandemic, which has taken the lives of 6.3 million documented humans.

My questions are the following: You described in your manuscript patients that were “too healthy” or did not have optimal medical therapy—what was the survival of this specific cohort? Did you look at it? And how many patients were later clinically reassessed by your group for a second consultation?

Dr Rachel Deitz (Pittsburgh, Pa). I’ll answer the last question first. The consultation was an active process in which we were constantly discussing with the critical care physicians at the outside hospitals. We would give them suggestions such as ventilatory management, use of proning and paralysis, and we made sure that we returned telephone calls or called them back within a 12-hour time period to ensure that those strategies were being employed. And we also encouraged continued communication with us. Although, it’s possible that a few of those patients may have gotten lost to follow-up, just because the consults were coming in so frequently. To answer your first question, I don’t have the exact value for patients who were “too healthy,” but in a different calculation, we did find it to be a protective benefit against mortality.

Dr Roy. Thank you. Did you consider propensity matching the patients who are refused as your phase evolved from green to yellow, and now to red—further on in the pandemic, in your cohort of nonsupported patients?

Dr Deitz. I think our statistical analysis was a little limited because we gathered all the information that we had available to us from these referring hospitals, in a series of small snapshots of how the patients were doing over time. And because a lot of these patients were out of network, we weren’t able to compare a lot of their variables.

Dr Roy. Thank you. You mentioned that these data have helped to counsel families for patients who are not eligible. In the future and with the knowledge of these data, what have you done—I guess my question is, what have you learned and what would you do if there was a dramatic change in the course of this pandemic or if there was a new pandemic?

Dr Deitz. Well, it’s a good question. Our preliminary data, when we talked about the overall mortality rates in the green phase and the yellow phase—while we were initiating those conversations with the critical care physicians at outside hospitals, we were able to sort of clearly tell them, “Well, this is our criteria and from what we’ve seen, you may expect X mortality rate for this patient.” And I think that helped those physicians in initiating those conversations with families in making important end-of-life decisions. And I think it’s important, going forward, to continue to reevaluate this data. Of course, we didn’t look at our delta wave red phase criteria yet, so that would be an area for further study.

Dr Scott Silvestry (Orlando, Fla). I enjoyed your paper. I think it’s a very thoughtful, contemplative look at what we did and what we might be able to do in the future. It’s very difficult because if you look at your data that suggest that young patients have the best chance of survival if they’re declined, but they also have the best chance on ECMO—in the previous talk with Dr Jeffrey Jacobs’ group, they noted that younger age is the primary driver of survival. So when you talk about equity, it would be interesting to see if you can model what survival looks like for the declined patient and, paradoxically, the patient with the best survival and the best use of resources.

One model for scarcity allocation requires that they get the venovenous ECMO, yet they have the best chance of surviving outside the lifeboat, so to speak. And so to follow-up on the other question, what criteria should we use to select patients in a scarce resource (whether we’re red or black)—and what criteria shouldn’t we use? Because 57% survival for the young patients declined is actually better than the ECMO survival in many series depending on it. And so I have to rethink—I mean, we took care of almost 200 COVID-19 ECMO patients at our institution, and I have to think about what we did and what we should do. And tell me what we should do.
Dr Deitz. Thank you for your question. That of course necessitates a more in-depth conversation, but I agree—it’s challenging to figure out where the ideal spot is between whether patients are going to have a good chance of survival outside of ECMO or whether we’re doing them justice by putting those patients on.

Dr Silvestry. I was involved in our health system’s model for allocation, and among the nonphysician stakeholders was a businessman who makes the glue that holds together all the boxes in the United States. So he’s a very successful businessman, and he said it should be first come, first served. And this perspective is just as valid when applied to the allocation of medical resources.

Dr Deitz. Indeed.

Dr Pablo Sanchez (Pittsburgh, Pa). I’m among the senior authors, and I just want to help clarify a few things. The University of Pittsburgh Medical Center system is composed of 34 hospitals. Before all this, most patients would get transferred to University of Pittsburgh Medical Center Presbyterian, where our ECMO center is—either to the medicine intensive care unit if you had severe ARDS, or to a cardiothoracic surgery intensive care unit for ECMO. So among the things that changed is that we had to stop that. We could not transfer every single ARDS patient to University of Pittsburgh Medical Center Presbyterian anymore, it was impossible. So among the gains of all this was that the severity of illness that our branching hospitals were able to handle increased, not only through the education of what were the criteria, but also what were the best practices of ARDS. So in a way, it served to raise the bar in our associated hospitals. That’s among the things that improved.

What proportion of healthy patients were put on ECMO eventually? I’ll say it was around 25%. That’s a very good estimate. Our ECMO survival was around 50%. It was not really off of what we’ve seen before. The 1 thing that I think is worth discussing is that, at any point, we’ll have anywhere between 14 and 18 patients on ECMO, but we never reached that level. And I think we never reached it because of all the way we tried to stratify our selection process.

Dr Rakesh C. Arora (Cleveland, Ohio). I think it was just answered by Dr Sanchez. But just so I understand what the capacity criteria was, was it based on the number of ECMO circuits, capacity in the intensive care unit, hospital capacity of overall COVID-19 burden? Or do all the above factor into that?

Dr Deitz. Thank you for the question. Our availability was never limited by ECMO circuits. It was limited by overall hospital capacity and specifically nursing staff in the intensive care unit, which, as we all know, was a really big challenge during this time.

Dr Arora. Thank you. Of your 3 criteria, the 1 I found curious was for the red phase. Although in addition to the age criteria, the predicted survival was 92%. I’m not sure I put many of those patients on ECMO. Do you have a rough idea of how you came to that criteria and how many people you would have anticipated that would have met that?

Dr Deitz. Sorry, can you repeat that?

Dr Arora. So if I understand your slide correctly with the 3 different colored categories, the estimated survival for someone in the red category level of crisis, you’d have to have a predicted survival of 92% to benefit from ECMO. That’s a really restrictive group and maybe not if you needed ECMO. Could you comment on that particular selection criteria choice?

Dr Deitz. Sure. That estimate of survival is certainly not based specifically on COVID-19 patients that would have been put on ECMO.

Dr Sanchez. To help clarify: When we established these criteria, we were borrowing data that were published from early COVID-19 experiences and ECMO outcomes that were ARDS-related. We believed that based on those criteria, the expected survival of that population should be 92%, but maybe it’s not. So that was when we were trying to justify why we were only allocating ECMO for that really tight group of red. So that wasn’t the real survival. That was our expectation of what the survival should look like in that group.

Moderator. Great. Thank you very much.

Dr Deitz. Thank you.