



Extracorporeal Membrane Oxygenation for Pediatric Patients With Coronavirus Disease 2019–Related Illness*

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Objective: To describe current hospital guidelines and the opinions of extracorporeal membrane oxygenation leaders at U.S. children's hospitals concerning the use of extracorporeal membrane oxygenation for coronavirus disease 2019–positive pediatric patients.

Design: Confidential, self-administered questionnaire.

Setting: One hundred twenty-seven U.S. pediatric extracorporeal membrane oxygenation centers.

Subjects: Extracorporeal membrane oxygenation center program directors and coordinators.

Interventions: None.

Measurements and Main Results: In March 2020, a survey was sent to 127 pediatric extracorporeal membrane oxygenation centers asking them to report their current hospital extracorporeal membrane oxygenation guidelines for coronavirus disease 2019–positive patients. Respondents were also asked their opinion on three ethical dilemmas including: prioritization of children over adults for extracorporeal membrane oxygenation use, institution of do-not-resuscitate orders, and the use of extracorporeal cardiopulmonary resuscitation for coronavirus disease 2019–positive patients. Forty-seven extracorporeal membrane oxygenation centers had enacted guidelines including 46 (100%) that offer venovenous-extracorporeal membrane oxygenation and 42 (89%) that offer venoarterial-extracorporeal membrane oxygenation for coronavirus disease 2019–positive pediatric patients. Forty-four centers (94%) stated that the indications for extracorporeal membrane

oxygenation candidacy in coronavirus disease 2019 disease were similar to those used in other viral illnesses, such as respiratory syncytial virus or influenza. Most program directors (98%) did not endorse that children hospitalized with coronavirus disease 2019 should be made do-not-resuscitate and had variable opinions on whether children should be given higher priority over adults when rationing extracorporeal membrane oxygenation. Over half of program directors (60%) did not support the use of extracorporeal cardiopulmonary resuscitation for coronavirus disease 2019.

Conclusions: The majority of pediatric extracorporeal membrane oxygenation centers have proactively established guidelines for the use of extracorporeal membrane oxygenation for coronavirus disease 2019–related illnesses. Further work is needed to help guide the fair allocation of extracorporeal membrane oxygenation resources and to determine the appropriateness of extracorporeal cardiopulmonary resuscitation. (*Pediatr Crit Care Med* 2020; 21:893–897)

Key Words: coronavirus; coronavirus disease 2019; do-not-resuscitate; extracorporeal cardiopulmonary resuscitation; extracorporeal membrane oxygenation

*See also p. 902.

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The coronavirus disease 2019 (COVID-19) pandemic, caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has significantly burdened the healthcare system and forced the medical community to examine the fair allocation of medical resources to the highest priority patients, including infants and children (1). Although the coronavirus causes mild symptoms in the majority of patients, it can also cause severe cardiorespiratory failure necessitating life-sustaining therapies, including mechanical ventilation and extracorporeal membrane oxygenation (ECMO). Reports from China demonstrate that infants and children are not immune to the SARS-CoV-2 virus with almost 6% of infected children requiring critical care interventions (2). In the United States, children comprise 1.7% of all COVID-19 cases, of which 0.5–2% require admission to the ICU (3). To date, three pediatric patients diagnosed with COVID-19 have required ECMO support in the United States,

a number anticipated to grow as the coronavirus outbreak peaks across all 50 states (4).

The pandemic has sparked national debate regarding the ethics of rationing life-saving technologies such as ventilators and ECMO (5). Although national organizations have proposed basic guidelines for the use of ECMO in COVID-19–positive patients in both adults and children, much latitude has been left to individual hospitals (6). As a result, there remains no national consensus regarding the use of ECMO in critically ill children with COVID-19. Advocates for the use of ECMO in COVID-19 patients state that careful planning, resource allocation, and personnel training are required for successful implementation (5). Others suggest that ECMO should not be “rushed to the front lines” in inexperienced centers with already limited resources available during the current pandemic (7).

In this study, we seek to describe the guidelines implemented across U.S. children’s hospitals regarding the use of ECMO for pediatric patients with COVID-19–related illnesses. Given the ethically contentious nature of the use of this technology during a pandemic, we elucidated expert opinions of ECMO program directors and coordinators on whether children should be prioritized over adults to receive ECMO support, the institution of do-not-resuscitate (DNR) orders, and the use of extracorporeal cardiopulmonary resuscitation (ECPR).

METHODS AND METHODS

In March 2020, we sent a confidential, self-administered, 34-item electronic questionnaire titled “ECMO for Pediatric Patients with COVID-19 Related Illnesses” to program directors and coordinators from 127 neonatal and pediatric ECMO centers. The centers were selected from the publically available Extracorporeal Life Support Organization (ELSO) neonatal and pediatric membership directory. Using the Tailored Design Method, up to three separate invitations were sent. Only one link was sent to each individual program. This study was reviewed and approved by the Washington University School of Medicine Institutional Review Board (IRB # 202003179). Study data were collected and managed using REDCap (Research Electronic Data Capture, a secure, web-based research application).

Program directors and coordinators were asked about the prevalence of COVID-19–positive pediatric patients and whether any of those patients have required ECMO support. Respondents were then asked if their respective hospital had enacted guidelines for the use of ECMO in pediatric patients with COVID-19–related illness. The primary outcome variables included a series of questions regarding the use of venovenous and venoarterial-ECMO, indications for and restrictions against ECMO use, limits of duration of ECMO support, and precautions for healthcare providers when performing ECMO. If a center did not have guidelines currently in place for the use of ECMO in COVID-19–positive pediatric patients, respondents were asked to indicate their level of agreement with the same items using a Likert scale with categories of “Strongly Agree,” “Agree,” “Disagree,” and “Strongly Disagree.” Finally, respondents were asked their opinion on three current ethical dilemmas regarding the treatment of

COVID-19–positive pediatric patients. Respondents were asked to indicate their degree of agreement or disagreement with the following statements: “Pediatric patients should be given higher priority over adult patients when rationing ECMO for COVID-19 related illness,” “Pediatric patients hospitalized with confirmed COVID-19 should be made do-not-resuscitate (DNR), regardless of the wishes of the patient or their family members,” and “Extracorporeal cardiopulmonary resuscitation (ECPR) should be offered to COVID-19 positive pediatric patients who experience a cardiac arrest.” We also examined ECMO center region, ELSO Center of Excellence status (details of qualification found at www.ELSO.org) (8), and hospital setting, as well as responder demographic characteristics (age and sex).

RESULTS

Of the 127 potential respondents, one (1%) could not be contacted. Of the remaining 126 participants, 81 returned completed surveys, for a response rate of 64%. The characteristics of the respondents are shown in **Table 1**. Response rates varied somewhat according to region (South, 40%; Midwest, 25%; Northeast, 15%; West, 21%; $p = 0.082$) and according to age category (< 50 yr, 60%; ≥ 50 yr, 40%; $p = 0.013$) but not according to sex. In addition, 81% of respondents (67/83) self-identified their program as being an ELSO Center of Excellence. Table 1 displays unweighted results.

As **Table 2** shows, 47 ECMO centers (58%) have enacted guidelines for the use of ECMO support in pediatric patients with COVID-19–related illnesses. Of the respondents with

TABLE 1. Demographics of the Extracorporeal Membrane Oxygenation Program Directors Who Responded to the Survey^a

Demographics	Survey Response No./Total n (%)
Female sex	39/78 (50)
Age	
< 50 y	47/78 (60)
Region	
Midwest	20/81 (25)
Northeast	12/81 (15)
South	32/81 (40)
Practice setting type	
University based	47/81 (58)
Community based	10/81 (12)
Community hospital, university affiliated	21/81 (26)
Other	3/81 (4)
Extracorporeal Life Support Organization center of excellence	67/83 (81)

^aPercentages may not total 100 because of rounding.

TABLE 2. Extracorporeal Membrane Oxygenation Guidelines for Pediatric Patients With Coronavirus Disease 2019–Related Illness^a

Guidelines	Survey Response No./Total n (%)
ECMO offered for coronavirus disease 2019–positive pediatric patients	
Venovenous	46/46 (100)
Venoarterial	42/47 (89)
Guideline restrictions for the use of ECMO	
Terminal disease	45/47 (96)
Severe CNS damage	43/47 (92)
Renal failure	9/47 (19)
Multisystem organ failure	38/47 (81)
Mechanical ventilation for > 7 d	15/47 (32)
Do-not-resuscitate status	41/47 (87)
Guideline precautions for the use of ECMO	
Limitation to only essential personnel	44/47 (94)
Use of proper personal protective equipment (i.e., N95 masks)	47/47 (100)
Separation of operating room team from ECMO circuit	8/47 (17)
Supplies prepared outside the room	31/47 (66)
Cannulation only in the ICU to minimize patient transport	33/47 (70)

ECMO = extracorporeal membrane oxygenation.

^aPercentages may not total 100 because of rounding.

established guidelines, 46 (100%) offer venovenous-ECMO and 42 (89%) offer venoarterial-ECMO for COVID-19–positive pediatric patients. Forty-four centers (94%) stated that the indications for ECMO candidacy in COVID-19 disease were similar to those used in other viral illnesses, such as respiratory syncytial virus or influenza. Guidelines restrict the use of ECMO in patients with terminal disease (45, 96%), severe CNS damage (43, 92%), DNR status (41, 87%), multisystem organ failure (38, 81%), prolonged mechanical ventilation defined as more than 7 days (15, 32%), and renal failure (9, 19%). Other reported restrictions included cardiopulmonary arrest and underlying immunodeficiency. Precautions in place for healthcare providers when performing ECMO included the use of proper N95 masks and other personal-protective equipment (47, 100%), limiting cannulation to only essential personnel (44, 94%), cannulation only performed in the ICU to minimize patient transport (33, 70%), preparation of supplies outside the room (31, 66%), and separation of the operating room team from the ECMO circuit (8, 17%).

In the ECMO centers that did not have established guidelines, 34 (100%) and 30 (88%) of program directors “Agree” or

“Strongly Agree” with offering venovenous- and venoarterial-ECMO, respectively (**Supplemental Table 1**, Supplemental Digital Content 1, <http://links.lww.com/PCC/B384>). All directors without established center guidelines also agreed (34, 100%) the indications for ECMO candidacy in COVID-19 disease should be similar to those used in other viral illnesses.

There was, however, variability in agreement as to whether pediatric patients should be given higher priority over adult patients when rationing ECMO for COVID-19–related illnesses, with 54 program directors (68%) Agree or Strongly Agree, and 26 (33%) Disagree or Strongly Disagree (**Table 3**). Most program directors and coordinators (79, 98%) did not believe that pediatric patients hospitalized with confirmed COVID-19 should be made DNR unilaterally (regardless of the wishes of the patient or their family). Finally, program directors were divided on offering ECPR to COVID-19–positive pediatric patients who experience a cardiac arrest, as 48 (60%) reported they would not support this intervention during the current pandemic. In multivariable logistic regression models, controlling for hospital setting and ELSO center of excellence, age, sex, and region were not significantly associated with responses to any of the three relevant items.

DISCUSSION

These data provide crucial insight into the guidelines and opinions of ECMO program directors and coordinators across the country regarding the use of ECMO in COVID-19–positive pediatric patients. First, although the majority of responding pediatric ECMO centers have enacted guidelines for the use of ECMO in pediatric patients with COVID-19–related illnesses, over one-third have not. The vast majority of hospital guidelines use the same indications for ECMO in COVID-19 patients as for other viral illnesses. In addition, all programs offer venovenous-ECMO and the majority offer venoarterial-ECMO. The centers with enacted guidelines did so on average 4 days prior to their first COVID-19–positive admission, showing a proactive response to the growing pandemic. The opinions of directors and coordinators from centers without guidelines in place were largely congruent with those of the centers with established policies. Barriers to implementation of ECMO guidelines at these centers remain unclear.

Among centers with established ECMO guidelines for COVID-19–related illnesses, only three (6%) limit the number of days a child can be placed on ECMO support (range, 14–21 d). Previously published guidelines have suggested that for COVID-19–related illness, ECMO can be discontinued after 21 days of therapy if no lung or cardiac recovery is seen (6). Limiting ECMO duration is widely contested. In other clinical settings, such as ECMO for congenital diaphragmatic hernia, duration may be limited based on outcomes data and cost (9, 10). In contrast, there are reports of extended venovenous-ECMO runs for pediatric respiratory failure (11). The limited experience with ECMO for COVID-19–related illness likely contributes to the hesitancy to limit the duration of ECMO support offered to these patients (12).

TABLE 3. Agreement or Disagreement on Aspects of Extracorporeal Membrane Oxygenation for Coronavirus Disease 2019–Related Illnesses^a

Survey Item	Strongly Agree	Agree	Disagree	Strongly Disagree
To What Extent Do You Agree or Disagree With the Following Statements:				
	<i>n (%)</i>			
Pediatric patients should be given higher priority over adult patients when rationing extracorporeal membrane oxygenation for COVID-19–related illnesses.	10/80 (13)	44/80 (55)	24/80 (30)	2/80 (3)
Pediatric patients hospitalized with confirmed COVID-19 should be made do-not-resuscitate, regardless of the wishes of the patient or their family members.	0/81 (0)	2/81 (3)	28/81 (35)	51/81 (63)
Extracorporeal cardiopulmonary resuscitation should be offered to COVID-19–positive pediatric patients who experience a cardiac arrest.	4/80 (5)	28/80 (35)	35/80 (44)	13/80 (16)

COVID-19 = coronavirus disease 2019.

^aPercentages may not total 100 because of rounding.

Respondents were divided regarding whether pediatric patients should be given priority over adult patients when rationing ECMO (68% agree vs 32% disagree). Although many would agree that the allocation of scarce medical resources should be directed to the patients who will receive the greatest benefit, there remains significant disagreement over whether we should aim to “save the most individual lives” or “save the most life-years.” (1) Some fear that focusing on “life-years” and thereby prioritizing pediatric patients will reinforce cultural ageism. In contrast, emphasis on the most individual lives saved would prioritize those who are most likely to survive the treatment regardless of age. Previous community engagement research demonstrates a wide range in acceptability of using various guiding principles, such as “prioritize those who have lived fewer life stages,” when determining the allocation of scarce resources during a disaster (13).

Furthermore, directors were also split about the use of ECPR for COVID-19–positive patients (40% agree vs 60% disagree). Some physicians believe that ECPR should be used with great caution due to both poor outcomes and high risk of infection to staff. They argue that ECPR should be considered only in carefully selected patients who develop cardiac arrest (5). Other guidelines state that ECPR should only be considered for in-hospital cardiac arrest at experienced centers after a risk-to-benefit ratio is performed for its use in patients with COVID-19 (6). Interestingly, almost all respondents disagreed that a COVID-19–positive patient should be made DNR regardless of the wishes of the patient or their family (98%). Although this ethical dilemma is still being debated throughout the medical community, in part due to efforts to limit infection risk of healthcare workers, there was near consensus on this issue among survey respondents.

Our study has some important limitations. Associations identified in a cross-sectional study cannot establish causal relationships. Moreover, it is possible that the attitudes of

program directors and coordinators who did not respond to the survey differ from those who did respond. Furthermore, the views of the respondents may not reflect the opinions of all surgical and critical care providers at a given center especially at centers without established clinical practice guidelines.

CONCLUSIONS

Our data suggest that the majority of pediatric ECMO centers have proactively established guidelines for the use of ECMO for pediatric patients with COVID-19–related illness. Further deliberation is needed to guide physicians regarding the allocation of ECMO if there becomes a shortage of circuits as well as the appropriateness of ECPR for COVID-19–positive patients.

Drs. MacGregor and Antiel are co-first authors.

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The authors have disclosed that they do not have any potential conflicts of interest.

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