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Ventilation Strategies During Extracorporeal Membrane Oxygenation for Neonatal Respiratory Failure: Current Approaches Among Level IV Neonatal ICUs

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Ventilation Strategies During Extracorporeal Membrane Oxygenation for Neonatal Respiratory Failure: Current Approaches Among Level IV Neonatal ICUs

OBJECTIVES: To describe ventilation strategies used during extracorporeal membrane oxygenation (ECMO) for neonatal respiratory failure among level IV neonatal ICUs (NICUs).

DESIGN: Cross-sectional electronic survey.

SETTING: Email-based Research Electronic Data Capture survey.

PATIENTS: Neonates undergoing ECMO for respiratory failure at level IV NICUs.

INTERVENTIONS: A 40-question survey was sent to site sponsors of regional referral neonatal ECMO centers participating in the Children's Hospitals Neonatal Consortium. Reminder emails were sent at 2- and 4-week intervals.

MEASUREMENTS AND MAIN RESULTS: Twenty ECMO centers responded to the survey. Most primarily use venoarterial ECMO (65%); this percentage is higher (90%) for congenital diaphragmatic hernia. Sixty-five percent reported following protocol-based guidelines, with neonatologists primarily responsible for ventilator management (80%). The primary mode of ventilation was pressure control (90%), with synchronized intermittent mechanical ventilation (SIMV) comprising 80%. Common settings included peak inspiratory pressure (PIP) of 16–20 cm H₂O (55%), positive end-expiratory pressure (PEEP) of 9–10 cm H₂O (40%), I-time 0.5 seconds (55%), rate of 10–15 (60%), and FiO₂ 22–30% (65%). A minority of sites use high-frequency ventilation (HFV) as the primary mode (5%). During ECMO, 55% of sites target some degree of lung aeration to avoid complete atelectasis. Fifty-five percent discontinue inhaled nitric oxide (iNO) during ECMO, while 60% use iNO when trialing off ECMO. Nonventilator practices to facilitate decannulation include bronchoscopy (50%), exogenous surfactant (25%), and noninhaled pulmonary vasodilators (50%). Common ventilator thresholds for decannulation include PEEP of 6–7 (45%), PIP of 21–25 (55%), and tidal volume 5–5.9 mL/kg (50%).

CONCLUSIONS: The majority of level IV NICUs follow internal protocols for ventilator management during neonatal respiratory ECMO, and neonatologists primarily direct management in the NICU. While most centers use pressure-controlled SIMV, there is considerable variability in the range of settings used, with few centers using HFV primarily. Future studies should focus on identifying respiratory management practices that improve outcomes for neonatal ECMO patients.

KEY WORDS: extracorporeal membrane oxygenation; neonate; respiratory failure; ventilation; ventilator

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Extracorporeal membrane oxygenation (ECMO) continues to be a lifesaving therapy for neonates with severe refractory cardiorespiratory failure since its first successful reported application in 1975 (1). Respiratory



KEY POINTS

- **Question:** The goal of this study was to understand and describe the scope of ventilator management strategies during neonatal respiratory extracorporeal membrane oxygenation (ECMO) among high-volume neonatal ECMO centers participating in the Children's Hospitals Neonatal Consortium (CHNC).
- **Findings:** This is a report of an electronic survey of U.S. neonatal ECMO centers participating in the CHNC. Despite several aspects of neonatal ventilator management during ECMO that appear to be common among a majority of centers, a universal understanding of ideal "lung rest" remains elusive, and there remains a diversity of ventilator management strategies with apparently conflicting priorities.
- **Meaning:** Additional research is needed to correlate individual clinical practice strategies with pulmonary outcomes toward the goal of identifying and recommending best practices for ventilator management during neonatal ECMO for respiratory failure.

failure remains the most common indication for neonatal ECMO, with an overall survival rate to discharge or transfer of 69% (Extracorporeal Life Support Organization [ELSO] report, April 2021) (2). Common indications include congenital diaphragmatic hernia (CDH), meconium aspiration syndrome, and persistent pulmonary hypertension, together accounting for almost 75% of all neonatal ECMO runs.

Worldwide, there has been a proliferation of ECMO centers over the past decade, primarily due to the increasing use of this therapy for adult respiratory failure, whereas the number of neonatal and pediatric cases has remained relatively stagnant (2). From 2016 to the present, the average patient volume per center for neonatal and pediatric patients has been 10 cases per year for combined cardiorespiratory failure (2). Because of increased regionalization, many neonatologists routinely refer ECMO candidates to regional children's hospitals and have lost currency in neonatal ECMO management.

The ELSO recently published guidelines for neonatal respiratory failure that include recommendations for ventilator management on ECMO (3). ELSO recommends initiating lung rest ventilator settings once a patient has transitioned to venoarterial or venovenous support to mitigate ongoing lung injury, utilizing limited peak pressure and low rate. ELSO guidelines, however, are nonspecific regarding the amount of positive end-expiratory pressure (PEEP) that should be provided, as there is limited evidence in neonates regarding optimal PEEP during ECMO. Historically, the use of a high versus low PEEP strategy has been debated, along with the optimal degree of lung inflation that should be targeted to minimize ventilator-induced lung injury (VILI). Additionally, some centers have preferred to use high-frequency ventilation (HFV) over conventional ventilation to theoretically provide more efficacious lung rest. Keszler et al (4) published a multicenter randomized trial in the early 1990s comparing a high to low PEEP strategy in neonates on venoarterial ECMO and showed that a higher PEEP approach was associated with reduced ECMO duration, fewer complications, and better short-term lung compliance but with similar survival.

Adherence of individual centers and providers to the published ELSO guidelines regarding ventilator management for neonates with respiratory failure remains unclear. Alapati et al (5) published data collected from the ELSO registry from 2008 to 2013, reporting rest ventilator settings recorded at 24 hours after neonatal ECMO initiation. The authors found wide variation in the ventilatory support used for lung rest as well as mixed outcomes depending on the PEEP strategy used. The data from this article are now more than a decade old, and it is unclear how more recent trends in regionalized neonatal ECMO care and advances in ventilator and ECMO technology may impact these practices.

The primary objective of this study was to understand the spectrum of ventilation management strategies used for neonates with respiratory failure on ECMO among busy referral ECMO centers, as well as to better clarify the role of neonatologists in this care. Aligning with the above-mentioned objective, we conducted a multicenter survey among a subset of large regional level IV neonatal ICUs (NICUs) in children's hospitals that provide neonatal ECMO.

METHODS

Data Source

The Children's Hospitals Neonatal Consortium (CHNC) is a multicenter collaborative of level IV NICUs in children's hospitals in the United States and Canada dedicated to developing quality and research initiatives across participating institutions. Participating NICUs have more than 400 annual admissions or more than 25 NICU beds and more than 50% of infants outborn. Data are collected prospectively in the Children's Hospitals Neonatal Database (CHND) and used to study clinical outcomes and resource utilization of a unique population of medically complex infants. For this study, the survey was sent to 33 members of the CHNC who perform neonatal ECMO and are actively involved with the CHNC ECMO Focus Group. The Institutional Review Board (IRB) at each participating institution approved participation in CHND and associated research studies, including ethical clearance in the use of de-identified database data (6). Specifically, the primary survey author's center participation was approved on January 8, 2010, by the Nemours Delaware IRB, Nemours Office of Human Subjects Protection (No. 149542-1). The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as most recently amended. Survey participants provided informed consent for the use of their responses in the reporting of this study.

Study Design

We conducted a cross-sectional survey of site sponsors at CHNC-participating ECMO centers. The survey was created, and study data were collected using Research Electronic Data Capture (REDCap) hosted at Children's Hospital of Philadelphia (7, 8). REDCap is a secure, web-based software platform designed to capture data for research studies.

Survey Development

The survey was developed by the study investigators, who are members of the CHNC ECMO Focus Group, a collaborative of neonatologists and pediatric surgeons from CHNC-participating NICUs with interest

and expertise in neonatal ECMO aiming to benchmark and improve neonatal ECMO outcomes. Survey questions underwent several iterations for content, clarity, and understandability based on feedback from members of the focus group. The final survey contained 40 targeted questions with subcategories (**Supplemental Table 1**, <http://links.lww.com/CCX/B75>).

Survey Distribution

The survey was distributed to CHNC site sponsors by email via the organizational listserv initially in June 2019 and again in July 2019 with all responses finalized by August 2019. The email contained a link to the online survey, which collected data in REDCap.

Statistical Analysis

We conducted data analysis using descriptive statistics and percentages of respondents.

RESULTS

We received responses from 20 of the 33 CHNC level IV NICUs involved with the focus group (61% response rate). Eight of the respondents (40%) were high-volume centers with more than 10 neonatal respiratory ECMO runs per year. Venoarterial ECMO (13 centers, 65%) was more commonly identified as the primary mode for neonatal ECMO compared with venovenous ECMO (seven centers, 35%). In contrast, for patients with CDH, most reported using venoarterial ECMO (18 centers, 90%). Fifty percent of hospitals reported that they had dedicated ECMO teams in addition to the primary ICU team. In 70% of these centers, ventilator management was directed by the ECMO team. Neonatologists either on the ECMO team or as part of the ICU team managed ventilator settings at 16 centers (80%), while at other sites, pediatric intensivists, cardiac intensivists, or pediatric surgeons were primarily responsible (**Table 1**). At 15 centers (75%), neonatal ECMO for respiratory failure is performed in the NICU, while two centers (10%) reported managing neonatal ECMO in the PICU. Of interest, one center shares NICU and PICU space, and two centers reported using multiple different units, including the NICU, PICU, and/or cardiac ICU.

TABLE 1.
Background of the Physicians Managing the Ventilator During Neonatal Extracorporeal Membrane Oxygenation

Physician Specialty	No. of Centers (%)
Neonatologist	16 (80)
Pediatric intensivist	5 (25)
Cardiac intensivist	2 (10)
Pediatric surgeon	4 (20)
Cardiac surgeon	None
Other	None

Ventilator Strategies During Neonatal ECMO

The majority of respondents (13 centers, 65%) use a standardized protocol to target initial ventilator settings and then adjust management based on chest radiograph findings and the underlying disease process throughout the ECMO run. Five centers (25%) use an initial individualized case approach based on the underlying disease, chest radiograph findings, or both, while only two centers leave ventilator management to the on-service attending's discretion. While some variability exists regarding the primary mode of ventilation, several modes of ventilation were employed by different centers during the ECMO run with the majority (17 centers, 85%) using synchronized intermittent mechanical ventilation (SIMV) pressure control, seven centers (35%) using volume-targeted SIMV, six centers (30%) using pressure-regulated volume control, three centers (15%) using assist-control pressure control, and three centers (15%) using airway pressure release ventilation (APRV) (Table 2). Neurally adjusted ventilatory assist (NAVA) use was reported by only one center. Of interest, three centers (15%) reported extubation as a ventilation strategy while on ECMO for select patients.

In regard to the specific conventional ventilation settings used (Table 3), the majority (14 centers, 70%) targeted a PEEP of 7 cm H₂O or greater, although only one center reported using a PEEP of more than 10. The most commonly reported peak inspiratory pressure (PIP) range was 16–20 (11 centers, 55%). Among the 50% of centers reporting a specific tidal volume target, the most common range (35%) was 5–6 mL/kg. Eleven centers (55%) used an inspiratory time of 0.5 seconds.

TABLE 2.
Modes of Ventilation Used During Neonatal Respiratory Extracorporeal Membrane Oxygenation

Modes of Ventilation	No. of Centers (%)
High-frequency oscillatory ventilation	14 (70)
High-frequency jet ventilation	3 (15)
High-frequency percussive ventilation (e.g., VDR, bronchotron, TXP)	1 (5)
SIMV, pressure control	17 (85)
SIMV, volume targeted	7 (35)
AC, pressure control	3 (15)
AC, volume targeted	None
Pressure-regulated volume control	6 (30)
Airway pressure release ventilation	3 (15)
Neurally adjusted ventilatory assist	1 (5)
Extubation	3 (15)

AC = assist control, SIMV = synchronized intermittent mandatory ventilation, VDR = Volume Diffusive Respirator.

The majority (16 centers, 80%) used ventilator rates of less than 20 beats/min, with none using rates of more than 25 beats/min. Most centers (15, 75%) maintain ventilator FIO₂ between 0.21 and 0.30 and five centers (25%) between 0.31 and 0.40.

Only one center (5%) identified HFV (high-frequency oscillatory ventilation [HFOV], high-frequency jet ventilation, or flow interrupter) as the preferred mode of ventilation for neonates on ECMO. Overall, the majority of centers (14, 70%) reported utilizing HFV for selected indications but not as the primary modality (Table 2). Air leak was stated as the most common indication for HFV (10 centers, 50%). For HFOV specifically, three sites reported an individualized approach to setting mean airway pressure (MAP) based on the underlying lung disease. Three centers reported using MAPs of 10–11 cm H₂O, while four centers reported a higher MAP of 12–13. For amplitude, three centers reported a range of 21–26, with only one center each reporting ranges of 10–15, 16–20, and 26–30. Seven centers use an initial high-frequency rate between 7 and 10 Hz, while three centers prefer a higher frequency between 11 and 14 Hz.

The majority of centers discontinued inhaled nitric oxide (iNO) administration during ECMO (11 centers, 55%), while nine centers (45%) selectively continue

TABLE 3.
Conventional Mechanical Ventilation Rest Settings at Extracorporeal Membrane Oxygenation Initiation

Ventilator Setting	No. of Centers (%)
Positive end-expiratory pressure (cm H ₂ O)	
5–6	6 (30)
7–8	5 (25)
9–10	8 (40)
11–12	1 (5)
Peak inspiratory pressure (cm H ₂ O)	
12–15	2 (10)
16–20	11 (55)
21–25	6 (30)
Inspiratory time (s)	
< 0.5	6 (30)
0.5	11 (55)
1	3 (15)
Rate (beats/min)	
10–15	12 (60)
16–20	4 (20)
21–25	4 (20)
Tidal volume (mL/kg)	
3–4	3 (15)
5–6	7 (35)
No criteria	10 (50)

iNO. Among those discontinuing iNO routinely, six centers wean off over 24 hours, while five discontinue it immediately.

Lung Recruitment and Decannulation Thresholds

All respondents agreed that some extent of lung de-recruitment is typically expected following cannulation and weaning of ventilatory support. However, most respondents (11 centers, 55%) consider white-out (or complete lung opacification) on chest radiograph unacceptable. Four centers (20%) reported that they would accept complete lung de-recruitment, and two others (10%) specified that the degree of lung inflation on chest radiograph would not alter their protocol-defined ventilator settings.

Many centers use a variety of active lung recruitment maneuvers during ECMO. These include hand

ventilation (10 centers, 50%), chest physiotherapy (10 centers, 50%), bronchoscopy (11 centers, 55%), change of ventilator mode (10 centers; 50%), alteration in ventilator settings (16 centers, 80%), and administration of exogenous surfactant (five centers, 25%). Six centers reported “other” maneuvers without further specification. Five centers (20%) reported that they did not use active recruitment measures, allowing spontaneous lung recruitment while maintaining ventilator rest settings. For bronchoscopy specifically, 50% of sites reported it is not a routine practice, while the other 50% noted they would consider bronchoscopy prior to decannulation on an individual basis.

The most commonly accepted PEEP for decannulation (nine centers; 45%) was 6–7 cm H₂O, while four centers (20%) did not have specific criteria. Four centers (20%) use a higher PEEP threshold of 8–10, while three centers (15%) require a lower PEEP of 5–6. The majority of responding centers (11 centers, 55%) were comfortable coming off ECMO with a PIP of 21–25 cm H₂O, while only three centers (15%) typically tolerate 26–30. The remainder did not report a specific limit. For centers that use tidal volume targets, 5–5.9 mL/kg was most commonly identified as an acceptable threshold for decannulation (nine centers, 45%) (**Table 4**). For HFOV, 50% of centers reported no specific MAP as a threshold for decannulation. Of those reporting MAP targets, six centers (30%) accept 14–15 cm H₂O and three (15%) a MAP of 10–13.

Ten centers (50%) reported they often use iNO to help transition off ECMO, while eight respondents (40%) rarely use iNO for this purpose. Other non-inhaled pulmonary vasodilators (e.g., epoprostenol, treprostinil, sildenafil, and milrinone) are occasionally and selectively used by up to 50% of centers.

DISCUSSION

We conducted a survey of CHNC neonatal ECMO centers to assess variations in ventilation strategies across different level IV NICUs during neonatal ECMO for respiratory failure. The majority of responding centers implemented a standardized protocol to target initial ventilator lung rest settings, although this was further adjusted based on chest radiograph findings and the underlying disease, reflecting a flexible approach that adapts as lung disease evolves. While neonatologists may be less involved in extracorporeal life support (ECLS) outside of regional referral NICUs, our survey

TABLE 4.
Acceptable Conventional Ventilator Decannulation Thresholds

Ventilator Threshold Settings	No. of Centers (%)
Positive end-expiratory pressure (cm H ₂ O)	
3–5	3 (15)
6–7	9 (45)
8–10	4 (20)
No criteria	4 (20)
Peak inspiratory pressure (cm H ₂ O)	
< 20	2 (10)
21–25	11 (55)
26–30	3 (15)
Tidal volume (mL/kg)	
4–5	2(10)
5–6	9 (45)
6–7	2 (10)
No criteria	7 (35)

indicates that, within level IV neonatal ECMO centers, respiratory care during ECMO remains primarily managed by neonatologists. SIMV pressure control remains the most common initial ventilation mode used. However, wide variability remains regarding specific ventilator settings used. HFV, while not the preferred primary ventilatory mode, is used by the majority of centers during ECMO for specific indications. The results of our survey further fortify the necessity for more rigorous research in the field of lung ventilation strategies and recruitment during neonatal ECMO.

Since its first neonatal use more than 40 years ago (1), ECMO has been shown to improve survival in late preterm and term infants with severe cardiorespiratory failure, pulmonary hypertension, and hypoxemia refractory to conventional therapies. By temporarily supporting cardiorespiratory function, ECMO serves as a bridge to allow organs, particularly the lungs, time to recover (9). The optimal ventilation strategy to provide “lung rest” on neonatal respiratory ECMO remains unclear and an area of speculation, while there remains a paucity of evidence-based literature to guide therapy.

Before ECMO is initiated, exposure to high ventilator settings and free radicals from 100% oxygen can worsen lung injury in neonates with respiratory failure.

Mechanisms of injury include volutrauma from alveolar overdistension, barotrauma from high ventilator pressures, atelectotrauma from alveolar collapse, and biotrauma from inflammation (10–12). There may also be an inherent genetic susceptibility to increased inflammation in some patients, contributing to further damage (10). The pathophysiology of VILI includes increased alveolar permeability with pulmonary edema, cellular destruction with disordered repair, diffuse alveolar damage, accumulation of proteinaceous alveolar fluid with neutrophil influx, surfactant dysfunction with patchy areas of alveolar collapse, deposition of hyaline membranes, and formation of microthrombi (13, 14). Furthermore, following ECMO initiation, diffuse atelectasis induced by lower mechanical ventilation, together with pulmonary inflammation and complement activation following blood contact with foreign surfaces of the ECMO circuit, can contribute to pulmonary opacification (15, 16).

An approach that decreases peak pressures, avoids excessive tidal volumes, and optimizes PEEP to prevent alveolar collapse could minimize additional lung injury and promote healing, shorten time on bypass, potentially reduce ventilator days post-ECMO, and possibly improve pulmonary outcomes.

An international survey of ventilation management strategies for venovenous ECMO conducted across 141 ELSO-registered centers reported almost a third utilizing an established mechanical ventilation protocol (17). Of the neonatal/pediatric centers evaluated, most used pressure-control mode for lung rest. The majority of centers surveyed targeted a tidal volume of 6 mL/kg or less and PEEP of 6–10 cm H₂O while on venovenous support. Similarly, a large retrospective analysis of ELSO registry data (2008–2013) also reported common utilization of conventional mechanical ventilation for lung rest during neonatal respiratory ECMO (5). Alapati et al (5) compared outcomes based on PEEP levels at 24 hours after ECMO initiation (low PEEP 4–6, mid-level PEEP 7–9, or high PEEP 10–12). There was no difference in survival among the three groups. Infants in the high-PEEP group required the shortest mean duration of ECMO but had an increased duration of mechanical ventilation after decannulation compared with the low-PEEP group.

Our study showed that when on pressure-control SIMV support, higher PEEP settings are employed for lung rest by most centers, likely in an attempt

to maintain some degree of alveolar aeration. This strategy may reduce atelectasis while improving lung compliance. However, there may be a subset of patients whose lungs may remain opacified radiographically despite higher PEEP settings because of the severity of the underlying lung disease. With higher PEEP, pulmonary function may also improve earlier, promoting a shorter time on ECMO support (18). A decrease in pulmonary vascular leak and alveolar macrophage activation has been reported with the use of higher PEEP on ventilatory support (19). One must also be mindful of the damaging effect of very high PEEP on the lungs, including worsening pulmonary vascular resistance and the potential for hemodynamic compromise from impaired venous return, especially in the presence of underlying inflammation.

The concept of higher PEEP utilization to accelerate lung recovery was first introduced by Pesenti et al (20), while the only prospective multicenter randomized controlled trial comparing low PEEP (3–5 cm H₂O) with high PEEP (12–14 cm H₂O) in neonatal ECMO support was performed more than 30 years ago (4). This study reported shorter ECMO duration, fewer complications, improved lung compliance, and less pulmonary opacification on radiograph in the higher PEEP group. Interestingly, the evolving practice of extubating patients and allowing awake spontaneous breathing during ECLS introduces a contradictory yet equally successful approach. With extubation comes the removal of PEEP and the concern for complete atelectasis. However, limited clinical experience has shown that, with spontaneous breathing and coughing to provide airway clearance, patients can self-recruit as the pulmonary disease process and inflammation resolve. In some cases, intubation and positive airway pressure are required to initiate lung recruitment. Our survey revealed that extubation on ECMO remains an uncommon practice among regional neonatal ECMO centers (three centers, 15%). But even this represents an evolving practice compared with the findings of Marhong et al (17), who reported no neonatal or pediatric centers practiced extubation as recently as 2015. In addition, Jenks et al (21) reported this practice among 27% of pediatric centers, 42% of mixed, and 52% of adult centers. The practice of extubating patients on ECMO for maximal lung protection and encouraging spontaneous lung recruitment is much more commonplace in the adult ECLS population, with limited

reported experience in neonates. Although our survey did not inquire about the reasons for this practice, there may be a subset of patients (e.g., severe or refractory air leak) who could benefit from this approach (22, 23). A recent case series of eight neonates electively extubated during neonatal respiratory ECMO reported effective resolution of lung disease and successful decannulation of all patients (22). The authors concluded that, besides facilitating the resolution of air leaks without the risks of chest tube placement, spontaneous breathing alone can often be sufficient to recruit lungs for successful decannulation.

We found that HFV is used on a case-by-case basis, particularly for patients with air leaks (e.g., pneumothorax). In a previous study (5), only 12% of the surveyed centers used HFV as the primary mode of ventilation. That study reported that infants in the HFV group required a longer duration of ECMO and mechanical ventilation after decannulation. Interestingly, those patients who were placed on HFV had lower pH, higher respiratory severity score, higher oxygenation index, and lower blood pressure before cannulation, likely reflecting more severe lung disease rather than any causative effect of the use of HFV.

The type and timing of lung recruitment maneuvers reported by responding centers were mostly individualized based on such factors as underlying disease process, fluid balance, and signs of lung expansion. Common recruitment strategies included hand ventilation, chest physiotherapy, change of ventilator mode and settings, and administration of exogenous surfactant. There was variability in the use of bronchoscopy, although this procedure was not routinely employed. Few centers preferred waiting for the lungs to open spontaneously without any active recruitment measures. This observation was also reported in a previous study, in which bronchoscopy was used more routinely by centers managing adult patients or both adult (76%) and pediatric patients (81%) compared with pediatric centers (25%) (21). Although the indication for bronchoscopy in the adult population was different, only 25% of the centers used it for atelectasis.

A unique feature of our survey was addressing the use of iNO and noninhaled pulmonary vasodilators as adjuvant therapies to facilitate weaning from ECMO. Nearly half of respondents sometimes continue iNO through the entire ECMO run, although most (55%) discontinue iNO following ECMO initiation.

Our cross-sectional study has several limitations as a survey of CHNC level IV NICUs providing neonatal respiratory ECMO. Our survey response rate of 61% enables nonresponder bias, as our assessment does not entirely represent management practices among all the active CHNC neonatal ECMO centers. Being an observational retrospective study, the possibility exists for observer and recall bias, as the results may have been influenced by the experiences and opinions of the responding individuals. The study was unable to detail the evolution of ventilator management over time during the ECMO run, nor does it characterize practices based on underlying disease processes or clinical patient specifics.

We did not assess ventilator strategy variation for ECMO patients with specific or complex lung diseases, such as bronchopulmonary dysplasia and CDH, who may require a different approach for lung rest or alternative management protocols.

In conclusion, our survey shows that, although there are many commonalities across centers in respiratory management during neonatal ECMO (**Table 5**), there remains a wide variation in practice as well, with no clear consensus on optimal ventilator strategies. This significant inter-center variability likely reflects the paucity of compelling high-quality evidence to drive standardization of practices. With evolving technology, newer modes of ventilation like NAVA and APRV are now available; however, there are currently no studies or recommendations regarding their use in neonatal respiratory ECMO. Prospective studies with multi-center collaboration are needed to compare ventilator management strategies during neonatal respiratory ECMO, particularly with respect to clinical outcomes.

TABLE 5.
Summary of Common Ventilation Practices

Common Ventilation Practices
Primary mode of ventilation: synchronized intermittent mechanical ventilation, pressure control
Develop and follow protocolized guidelines of care
Neonatologists most commonly direct ventilator management
Maintain lung aeration with moderate to high positive end-expiratory pressure, avoid complete atelectasis
Consider adjunct therapies to recruit lungs when needed to facilitate decannulation

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