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# Initiation of a Lung Protective Ventilation Strategy in the Emergency Department: Does an Emergency Department-Based ICU Make a Difference?

**BACKGROUND:** Lung protective ventilation (LPV) is a key component in the management of acute respiratory distress syndrome and other acute respiratory pathology. Initiation of LPV in the emergency department (ED) is associated with improved patient-centered and system outcomes, but adherence to LPV among ED patients is low. The impact of an ED-based ICU (ED-ICU) on LPV adherence is not known.

**METHODS:** This single-center, retrospective, cohort study analyzed rates of adherence to a multifaceted LPV strategy pre- and post-implementation of an ED-ICU. LPV strategy components included low tidal volume ventilation, avoidance of severe hyperoxia and high plateau pressures, and positive end-expiratory pressure settings in alignment with best-evidence recommendations. The primary outcome was adherence to the LPV strategy at time of ED departure.

**RESULTS AND CONCLUSIONS:** A total of 561 ED visits were included in the analysis, of which 60.0% received some portion of their emergency care in the ED-ICU. Adherence to the LPV strategy was statistically significantly higher in the ED-ICU cohort compared with the pre-ED-ICU cohort (65.8% vs 41.4%;  $p < 0.001$ ) and non-ED-ICU cohort (65.8% vs 43.1%;  $p < 0.001$ ). Among the ED-ICU cohort, 92.8% of patients received low tidal volume ventilation. Care in the ED-ICU was also associated with shorter ICU and hospital length of stay. These findings suggest improved patient and resource utilization outcomes for mechanically ventilated ED patients receiving care in an ED-ICU.

**KEY WORDS:** emergency medicine; hyperoxia; intensive care unit; mechanical ventilation; quality improvement; tidal volume

Approximately 240,000 patients receive mechanical ventilation in U.S. emergency departments (EDs) annually. Lung protective ventilation (LPV), the standard of care in acute respiratory distress syndrome (ARDS), is also associated with improved mortality and resource utilization in non-ARDS populations (1–4). LPV minimizes ventilator-induced lung injury by use of lower tidal volume ( $V_T$ ) and plateau pressure ( $P_{plat}$ ) to minimize alveolar overdistention and barotrauma, titration of oxygen to avoid severe hyperoxia, and application of positive end-expiratory pressure (PEEP) to prevent alveolar collapse at end-expiration. As failure to adhere to LPV from the onset of mechanical ventilation is associated with worse outcomes, initiation of LPV in the ED is recommended (3–9). Despite this, prospective adherence to LPV in ED populations remains low due to implementation barriers (3, 4, 10–12).

Consequently, protocols have been developed to standardize processes of care in mechanically ventilated patients, with improved LPV adherence through the use of ventilator care bundles in the ED (3, 7, 13–17). Implementation of these

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bundles is feasible, improves downstream LPV adherence in the ICU, and is associated with decreased mortality, development of ARDS, and cost (3, 4, 7, 13, 17).

Prolonged ED length of stay (LOS) in patients receiving mechanical ventilation is common in U.S. EDs, and ED boarding of critically ill patients has been associated with worse outcomes (9, 18–24). To combat this and to optimize early delivery of high-quality critical care, ED-based ICUs (also known as Resuscitative Care Units) have been implemented at a small number of institutions across the United States (25). In other disease processes, an ED-ICU has been associated with improved outcomes, including decreased mortality, inpatient ICU admission, and resource utilization (15, 26–31). There are no prior investigations on the impact of an ED-ICU on adherence to LPV for ED patients receiving mechanical ventilation.

The objective of this study was to determine rates of adherence to a multicomponent LPV strategy for adult ED patients undergoing mechanical ventilation before and after implementation of an ED-ICU. We hypothesized that patients who received care in the ED-ICU would have higher adherence to LPV compared with those who did not.

## MATERIALS AND METHODS

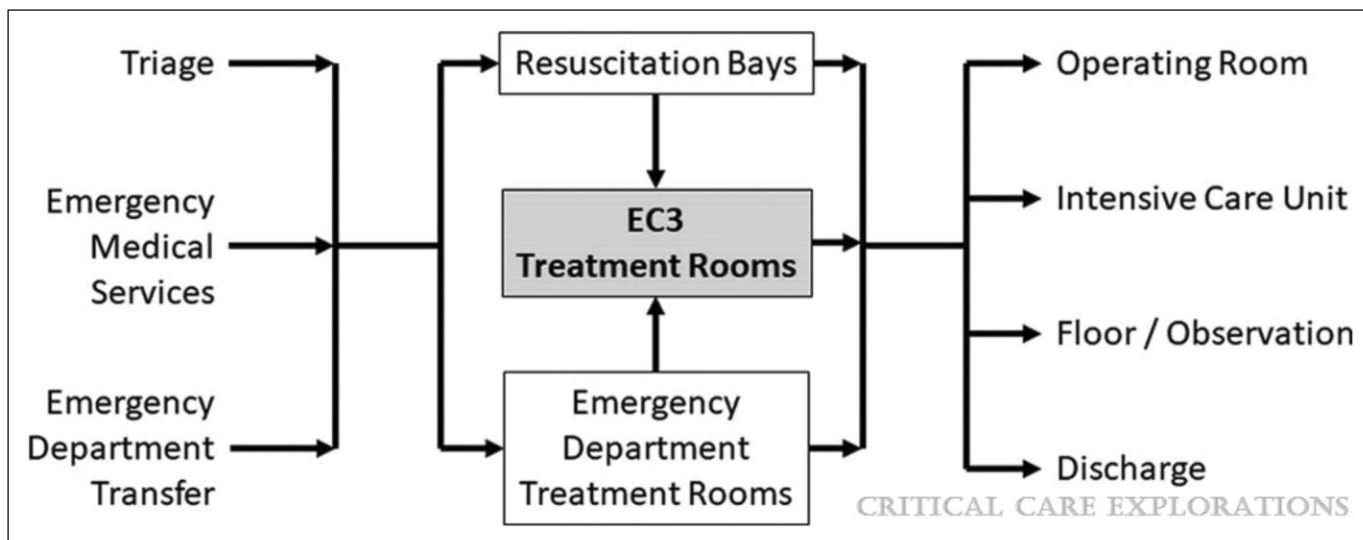
### Study Design, Setting, and Selection of Patients

This was a retrospective, single-center, cohort analysis to assess adherence to a LPV strategy in adult ED patients receiving mechanical ventilation. It was

conducted at a single academic medical center in the United States with approximately 75,000 adult ED visits per year. The institutional review board at the University of Michigan reviewed and approved this study (HUM00156783). This study is reported in compliance with the Strengthening of the Reporting of Observational Studies in Epidemiology statement (32).

The Joyce and Don Massey Family Foundation Emergency Critical Care Center (EC3) is an ED-ICU that opened in February 2015 with the intention of delivering early, high-quality critical care to adult ED patients. Patients presenting to the ED are first seen and managed by ED clinicians. When the need for further critical care interventions is identified, care is transferred from the ED clinicians to a separate group of EC3 clinicians, regardless of whether an inpatient ICU bed is available (Fig. 1). EC3 is staffed by attending physicians, board certified in Emergency Medicine with or without Critical Care fellowship training, fellows, residents, physicians assistants, pharmacists, respiratory therapists, and ED nurses with critical care training experience (26).

An electronic health record (EHR) search identified all visits of patients older than 18 years old between September 2012 and December 2018 who received mechanical ventilation while in the ED. Patients who underwent endotracheal intubation by EMS, at an outside facility prior to transfer, or in the ED were included. Patients transferred to another facility from the ED, extubated within 24 hours, deceased within 24 hours, or missing primary outcome data were excluded (Fig. 2).



**Figure 1.** Emergency Critical Care Center (EC3) patient flow diagram. Reproduced with permission from Wolters Kluwer Health from Joseph et al (29).

Visits were then further divided into three cohorts: pre-EC3, defined as those prior to EC3 opening (September 1, 2012 to February 16, 2015); non-EC3, defined as those after EC3 opening (February 17, 2015 to December 31, 2018) who did not receive a portion of their care in EC3; and EC3, defined as those after EC3 opening (February 17, 2015 to December 31, 2018) who received a portion of their care in EC3.

## Measurements

Age, sex, ED and hospital disposition, Charlson Comorbidity Index (CCI), initial and last filed ventilator settings in the ED, and initial and last filed arterial blood gas (ABG) values in the ED were collected from the EHR. ED, EC3, ICU, and hospital LOS were also determined (ED LOS is inclusive of EC3 LOS). As the majority of traditional severity scoring systems are validated in ICU cohorts and are poor predictors of mortality when used in the ED, CCI was used as a marker of patient comorbidity in concordance with a prior ED-ICU study (26). The primary outcome was the presence of a LPV strategy at the time of ED or EC3 departure. The LPV strategy was defined as  $V_T$  less than or equal to 8 mL/kg predicted body weight (PBW),  $P_{plat}$  less than 30 cm H<sub>2</sub>O, PEEP greater than or equal to 5 mm Hg, and  $P_{aO_2}$  less than 200 torr (26.7 kPa). All four criteria had to be met in order to fulfill the definition of the primary outcome.

Secondary outcomes included the presence of individual LPV strategy components at the time of ED

or EC3 departure and their association with LOS and hospital mortality.

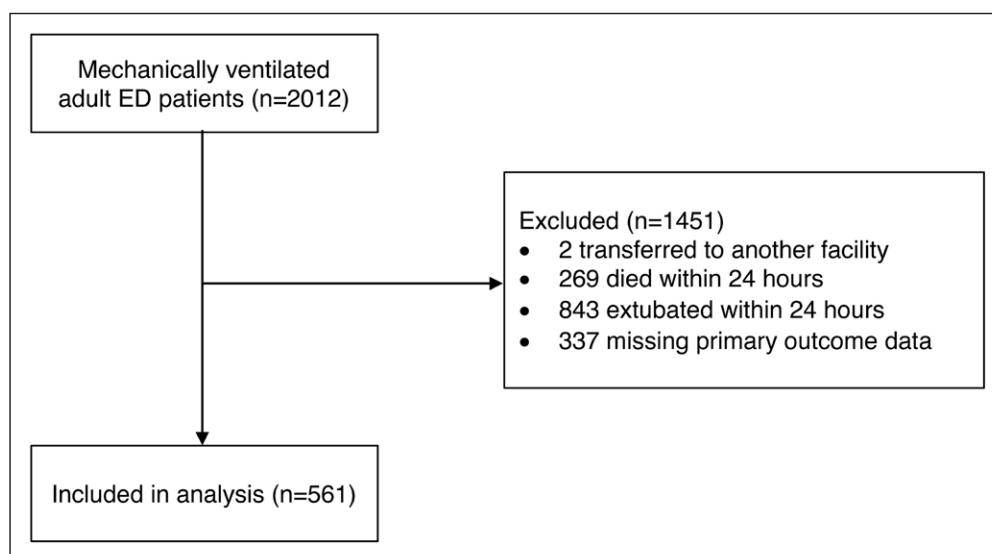
## Analysis

We analyzed data from 561 ED visits, representing 555 individual patients. Group differences in continuous variables were tested with one-way analyses of variance with Tukey Honest Significant Difference test for post hoc comparisons. Between-group comparisons of proportions were tested using a modified version of the chi-square test for small sample sizes (33). Multivariable logistic regression analysis was used to test for group differences in the odds of LPV at time of departure from ED after statistically controlling for covariates of age, sex, race, CCI, and ED LOS. An alpha level of 0.05 was used for all analyses, and all statistical significance tests were two-tailed. Analyses were conducted using IBM Statistical Package for the Social Sciences for Windows, Version 27 (IBM Corp., Armonk, NY).

## RESULTS

We identified 2,013 visits of adult patients who received mechanical ventilation in the ED during the study period, with 1,452 visits excluded from analysis. Baseline characteristics of the 561 visits are shown in **Table 1**. Of mechanically ventilated patients who received care in EC3, 39.7% were female and the mean age was 60.9 years (SD = 14.8 yr). EC3 patients had higher CCI (mean = 6.2, SD = 3.6) and lower initial  $P_{aO_2}$  (mean = 143.1 torr [19.1 kPa], SD = 108.5) than pre-EC3 or non-EC3 patients.

Nearly two-thirds of EC3 patients were ventilated with all four components of the lung protective strategy at the time of ED departure, compared with 41.4% of pre-EC3 patients and 43.1% of non-EC3 patients ( $p$ s < 0.001) (**Table 2**). Adherence to PEEP greater than or equal to 5 cm H<sub>2</sub>O and  $P_{plat}$  less than 30 cm H<sub>2</sub>O was



**Figure 2.** Flow diagram for study inclusion. ED = emergency department.

**TABLE 1.**  
**Baseline Demographics and Characteristics of Mechanically Ventilated Adult Patients in the Emergency Department**

Variable	Pre-EC3 (n = 87)	Post-EC3 (n = 474)		p = Pre-EC3 vs EC3	p = EC3 vs Non-EC3	p = Pre-EC3 vs Non-EC3
		EC3 (n = 307)	Non-EC3 (n = 167)			
Mean age, yr (sd)	58.0 (17.4)	60.9 (14.8)	56.1 (17.8)	0.13	0.002	0.39
Sex, % female	42.5	39.7	37.7	0.64	0.67	0.55
Mean height, in (sd)	65.6 (10.8)	66.8 (4.5)	65.3 (13.7)	0.28	0.09	0.80
Mean body mass index, kg/m <sup>2</sup> (sd)	28.2 (7.4)	29.6 (10.4)	29.3 (8.4)	0.23	0.74	0.40
Race, %						
Asian	2.3	2.0	1.8	0.86	0.88	0.79
Black/African American	14.9	11.7	5.4	0.42	0.03	0.01
White/Caucasian	80.5	85.0	83.8	0.31	0.73	0.51
Other/unknown	2.3	1.3	8.4	0.50	< 0.001	0.06
Mean Charlson Comorbidity Index <sup>a</sup> (sd)	5.2 (3.9)	6.2 (3.6)	3.4 (3.3)	0.01	< 0.001	< 0.001
Mean initial arterial blood gas values (sd)						
pH	7.30 (0.1)	7.33 (0.1)	7.31 (0.1)	0.07	0.10	0.64
PaO <sub>2</sub> , torr	222 (147)	143 (109)	218 (150)	< 0.001	< 0.001	0.81
Paco <sub>2</sub> , torr	43 (16)	42 (19)	42 (17)	0.79	0.87	0.72
Lactate, mmol/L	3.5 (3.5)	2.9 (3.2)	3.7 (3.6)	0.15	0.01	0.66

EC3 = Emergency Critical Care Center.

<sup>a</sup>The modified Charlson Comorbidity Index (CCI) is a validated predictor of in-hospital mortality based on 12 weighted comorbid conditions (34). A score of zero presumes no comorbidities, with a maximum score of 24. Higher CCI scores predict higher in-hospital mortality.

**TABLE 2.**  
**Rates of Adherence to Lung Protective Ventilation**

Variable	Pre-EC3 (n = 87)	Post-EC3 (n = 474)		p = Pre-EC3 vs EC3	p = EC3 vs Non-EC3	p = Pre-EC3 vs Non-EC3
		EC3 (n = 307)	Non-EC3 (n = 167)			
Lung protective ventilation strategy at time of emergency department departure, %	41.4	65.8	43.1	< 0.001	< 0.001	0.79
Tidal volume ≤ 8 mL/kg predicted body weight, %	82.8	92.8	78.4	0.004	< 0.001	0.43
Positive end-expiratory pressure ≥ 5 cm H <sub>2</sub> O, %	100	99.7	99.4	0.61	0.62	0.47
PaO <sub>2</sub> < 200 torr, %	56.3	78.5	57.5	< 0.001	< 0.001	0.85
Plateau pressure < 30 cm H <sub>2</sub> O, %	95.4	90.6	95.2	0.15	0.07	0.94

EC3 = Emergency Critical Care Center.

observed in more than 90% of patients in each cohort, with no statistically significant between-group differences. EC3 patients had statistically significantly higher rates of V<sub>T</sub> less than or equal to 8 mL/kg PBW and Pao<sub>2</sub> less than 200 torr (26.7 kPa) compared with both the pre-EC3 and non-EC3 cohorts.

To address the potential confounder of increased awareness of benefits of LPV over time, we compared the pre-EC3 cohort and non-EC3 cohort. There were no statistically significant differences in any of the outcomes.

The mean ED LOS was longer in the EC3 cohort, whereas mean ICU and hospital LOS were shorter in the EC3 cohort (Table 3). There was no difference in hospital mortality among the three groups.

To address potential confounders due to differences in baseline characteristics, we conducted a multivariable logistic regression analysis of the intervention as a predictor of LPV strategy at time of departure from ED (Table 4). Results showed that when age, sex, race, CCI, and ED LOS were statistically controlled, the effects of the intervention on the odds of LPV strategy at time of departure from the ED or EC3 remained statistically significant (adjusted OR, 1.9; 95% CI, 1.1–3.4).

## DISCUSSION

In mechanically ventilated ED patients, receiving a portion of care in the ED-ICU was associated with better adherence to a multifaceted LPV strategy targeting

low V<sub>T</sub> ventilation, avoidance of high P<sub>plat</sub> and severe hyperoxia, and provision of at least 5 mm Hg of PEEP. This association persisted when comparing the EC3 cohort with both the pre-EC3 and non-EC3 cohorts.

This is the first study to demonstrate the impact of an ED-ICU on LPV adherence. Notably, the EC3 cohort had a lower incidence of severe hyperoxia and a 92.8% adherence rate to low V<sub>T</sub> ventilation, which is significantly higher compared with previously reported data from other ED and ICU settings (3, 4, 10–12, 35–38). Since ED ventilator settings are frequently continued on ICU admission, these early ventilator adjustments are vital for continued high-quality care. The higher rate of adherence in the EC3 cohort is likely multifactorial, including lower clinician-to-patient ratios, continuous respiratory therapist presence, increased utilization of mechanical ventilator protocols, and more frequent serial ABG monitoring, ventilator setting modifications and/or bedside reassessments.

This study builds upon existing literature that has demonstrated an association between LPV adherence and improved resource utilization. Despite the older age, higher CCI, and lower initial Pao<sub>2</sub> in the EC3 cohort, these patients had shorter ICU and hospital LOS, suggesting that adherence to an LPV strategy may help attenuate ventilator-associated lung injury.

As pre-post observational studies can inherently favor the post-cohort due to changes in practice or confounding interventions over time, we compared rates

**TABLE 3.**  
**Resource Utilization Among Mechanically Ventilated Adult Patients in the Emergency Department**

Clinical Course	Pre-EC3 (n = 87)	Post-EC3 (n = 474)		p = Pre-EC3 vs EC3	p = EC3 vs Non-EC3	p = Pre-EC3 vs Non-EC3
		EC3 (n = 307)	Non-EC3 (n = 167)			
Mean emergency department LOS <sup>a</sup> , hr (sd)	5.5 (4.2)	15.6 (7.6)	4.8 (4.1)	< 0.001	< 0.001	0.39
Mean EC3 LOS, hr (sd)	–	11.8 (6.5)	–			
Mean hospital LOS <sup>b</sup> , d (sd)	16.8 (18.7)	12.9 (13.5)	16.2 (16.4)	0.03	0.02	0.76
Mean ICU LOS, d (sd)	9.8 (10.9)	7.1 (6.6)	11.5 (15.3)	0.03	< 0.001	0.24
Hospital mortality, %	27.6	27.7	29.3	0.98	0.71	0.78

EC3 = Emergency Critical Care Center, LOS = length of stay.

<sup>a</sup>Emergency department (ED) LOS is inclusive of EC3 LOS.

<sup>b</sup>Hospital LOS is inclusive of ED LOS.

**TABLE 4.**  
**Multivariable Logistic Regression of Predictors of Lung Protective Ventilation Strategy at Time of Emergency Department Departure**

Variable	Adjusted OR (95% CI)	<i>p</i>
Age	1 (0.99–1.02)	0.25
Sex (male)	1.5 (1.0–2.1)	0.03
Race (Black or African American)	0.6 (0.3–1.1)	0.09
Charlson Comorbidity Index	1 (0.9–1.1)	0.89
Emergency department length of stay	1.03 (1.0–1.1)	0.03
Group		
Pre-EC3	Reference	–
Non-EC3	0.9 (0.6–1.8)	0.89
EC3	1.9 (1.1–3.4)	0.02

EC3 = Emergency Critical Care Center, OR = odds ratio.

of LPV in ED patients managed pre-EC3 and non-EC3 (41.4% vs 43.1%;  $p = 0.79$ ). This similarity suggests the observed findings of increased LPV in EC3 were not driven by temporal trends alone.

The observed findings have implications both locally and externally. At our institution, the observed rates of LPV at the time of departure from the ED leave room for additional improvement. A recent quality assurance effort resulted in improved rates of accurate height measurements to provide ideal body weight and resultant low  $V_T$  ventilation (conducted after this study period, thus unlikely to confound the observed results) (15). Future efforts can focus on improving rates of measuring and documenting  $P_{plat}$ , implementing standardized optimal PEEP strategies, and titrating oxygen to target normoxia. More broadly, as focus is shifting from proving the benefit of LPV to proving it can be implemented and adhered to, an ED-ICU is one strategy to increase LPV adherence (39). Additionally, these findings add to the robust patient and resource utilization outcomes in other common disease states associated with an ED-ICU (26–31). Health systems may consider these results when determining the feasibility of ED-ICU implementation and future work should examine outcomes associated with ED-ICUs at other institutions.

The retrospective, observational nature of this study limits conclusions to association and causation cannot be inferred. This project was conducted at a single U.S. academic medical center and external generalizability of results is unknown. Additionally, given the paucity

of published data of ED-ICU patient populations from other institutions, it is difficult to compare, contrast, or contextualize the presenting disease severity of our patient population. The sample sizes in each cohort were relatively small, in part related to a significant number of patients without an ABG collected while in the ED ( $n = 290$ ). The lack of an ABG likely reflects common ED practice but also may underestimate the magnitude of the observed results. It is possible that ED clinicians deferred collecting an ABG, or serial ABGs, and instead titrated mechanical ventilator settings to pulse oximeter or venous blood gas values. However, avoidance of severe hyperoxia has been included as a best practice in societal guidelines, and thus we defined our primary outcome inclusive of  $P_{aO_2}$  less than 200 torr (26.7 kPa) to reflect this (9). Similarly, patients missing any of the four components necessary to determine the primary outcome were excluded, which likely introduced selection bias. We did not report data on indication for mechanical ventilation, presence of ARDS, or duration of mechanical ventilation, which have been previously described in larger ED cohort studies, and the high rates of observed  $P_{plat}$  less than 30 cm  $H_2O$  may reflect a large proportion of patients with normal lung compliance, rather than clinician driven ventilator changes to avoid barotrauma (3, 4, 7, 10, 16). To help mitigate this potential confounder, we excluded patients extubated within 24 hours, as these patients were presumptively intubated for airway protection (i.e., for toxic ingestion or procedure such as esophagogastroduodenoscopy) rather than respiratory

failure. However, this also further reduced sample size, with over 40% of patients excluded due to this criterion.

## CONCLUSIONS

In mechanically ventilated ED patients, receiving a portion of care in an ED-ICU was associated with better adherence to a multifaceted LPV strategy. As the benefit of early LPV in mechanically ventilated ED patients is well established, an ED-ICU is one strategy to increase earlier LPV adherence and potentially improve patient and resource utilization outcomes.

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