Mechanical Ventilation Practices and Low Tidal Volume Ventilation in Air Medical Transport Patients: The AIR-VENT Study

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BACKGROUND: The management of mechanical ventilation critically impacts outcome for patients with acute respiratory failure. Ventilator settings in the early post-intubation period may be especially influential on outcome. Low tidal volume ventilation in the prehospital setting has been shown to impact the provision of low tidal volume after admission and influence outcome. However, there is an overall paucity of data on mechanical ventilation for air medical transport patients. The objectives of this study were to characterize air medical transport ventilation practices and assess variables associated with nonprotective ventilation. METHODS: This was a multi-center, nationwide (approximately 130 bases) retrospective cohort study conducted on consecutive, adult mechanically ventilated air medical transport patients treated in the prehospital environment. Descriptive statistics were used to assess the cohort; the chi-square test compared categorical variables, and continuous variables were compared using independent samples *t* test or Mann-Whitney U test. To assess for predictors of nonprotective ventilation, a multivariable logistic regression model was constructed to adjust for potentially confounding variables. Low tidal volume ventilation was defined as a tidal volume of ≤ 8 mL/kg predicted body weight (PBW). RESULTS: A total of 68,365 subjects were studied. Height was documented in only 4,186 (6.1%) subjects. Significantly higher tidal volume/PBW (8.6 [8.3–9.2] mL vs 6.5 [6.1–7.0] mL) and plateau pressure (20.0 [16.5–25.0] cm H_2O vs 18.0 [15.0–22.0] cm H_2O) were seen in the nonprotective ventilation group (*P* < .001 for both). According to sex, females received higher tidal volume/PBW compared to males (7.4 [6.6–8.0] mL vs 6.4 [6.0–6.8] mL, *P* < .001) and composed 75% of those subjects with nonprotective ventilation compared to 25% male, *P* < .001. After multivariable logistic regression, female sex was an independent predictor of nonprotective ventilation (adjusted odds ratio 6.79 [95% CI 5.47–8.43], *P* < .001). CONCLUSIONS: The overwhelming majority of air medical transport subjects had tidal volume set empirically, which may be exposing patients to nonprotective ventilator settings. Given a lack of PBW assessments, the frequency of low tidal volume use remains unknown. Performance improvement initiatives aimed at indexing tidal volume to PBW are easy targets to improve the delivery of mechanical ventilation in the prehospital arena, especially for females. *Key words: mechanical ventilation; prehospital; lung-protective ventilation; air medical transport.* [Respir Care 2022;67(6):647–656.

Introduction

The management of mechanical ventilator settings is a critical determinant of outcome for patients with acute respiratory failure. By mitigating ventilator-associated lung injury (VALI), lung-protective ventilation improves outcome for those with ARDS, and there is increased recognition of benefit in patients without ARDS as well.[1-13] The early period of mechanical ventilation may be even more critical, as demonstrated by the prognostic significance of initial lung-protective ventilator settings and survival in ARDS.[7] Similarly, efforts to assure early adherence to lung-protective ventilation in the emergency department (ED) have been associated with improved clinical outcomes.[8,14,15] Further stressing the importance of early ventilator settings, it has been consistently shown that ventilator settings in the ED hold influence on downstream ventilator settings in ICU and the likelihood of ever receiving lung-protective ventilation.[8,14,16-19] Therefore, an emphasis on best practices during the entire period of mechanical ventilation could improve care delivery and increase overall adherence to lung-protective ventilation.[20,21]

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Analogous to the time spent in the ED and early ICU, the approach to prehospital mechanical ventilation could be an important contributor to both overall adherence to lung-protective ventilation and outcome. In a retrospective study of 235 mechanically ventilated adults, low tidal volume ventilation was provided to only 13% of subjects in the prehospital domain, yet prehospital low tidal volume was predictive of ever receiving low tidal volume in both the ED and ICU.[22] Similarly, in another cohort study ($n = 383$), transport tidal volume was a strong predictor of ICU tidal volume such that those subjects exposed to high prehospital tidal volume were > 3 times as likely to also received high tidal volume in the ICU.[23] Finally, in a small cohort study of subjects with septic shock, prehospital tidal volume was an independent predictor of mortality.[24] However, there is a relative paucity of data regarding mechanical ventilation in the air medical transport domain, as it is overall limited to primarily small and single-center studies.[22-26] Therefore, prehospital air medical transport mechanical ventilation practices remain incompletely characterized, which may have important implications for the more than 640,000 patients who require air medical transport annually in the United States alone.[27] The objectives of this study were to (1) characterize air medical transport mechanical ventilation practices across a multi-center air medical transport provider and (2) assess variables associated with nonprotective ventilation.

QUICK LOOK

Current knowledge

Lung-protective ventilator settings during the early period of respiratory failure have been demonstrated to increase the likelihood of ever receiving lung protection in the ICU and are associated with improved outcomes. Similarly, ventilator settings during air medical transport have been shown to be associated with downstream ventilator settings in the emergency department and ICU. However, there is an overall paucity of data on prehospital mechanical ventilation for air medical transport patients.

What this paper contributes to our knowledge

The overwhelming majority of air medical transport patients has tidal volume set empirically, which may be exposing patients to nonprotective ventilator settings. Given a lack of height assessments, the frequency of lung-protective settings in air medical transport patients remains unknown. Performance improvement initiatives aimed at indexing tidal volume to predicted body weight are easy targets to improve the delivery of mechanical ventilation in the prehospital arena, especially for females.

Methods

Study Design

Consecutive, adult mechanically ventilated air medical transport patients treated in the prehospital environment between January 2015–December 2020 were studied in this retrospective cohort study. Air Methods, an air medical

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The authors have disclosed no conflicts of interest.

A version of this paper was presented by Dr Fuller at SCCM 2022, held virtually April 18–21, 2022. Some of the demographic data were also used in a manuscript that was focused on prehospital sedation practices, which has been accepted for publication in *Critical Care Explorations*.

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This study was performed at Washington University School of Medicine, Washington University in St. Louis, St. Louis, Missouri.

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transport provider with > 300 bases dispersed across 48 states in the United States, transported and treated all patients. The bases in this study were restricted to the community-based services (approximately 160 bases) as they used the same electronic patient charting system during the study period. The study is reported in accordance with the Strengthening Reporting of Observational Studies in Epidemiology statement.

No consent was required for the study, which was approved prior to study initiation by the Human Research Protection Office (HRPO) at the primary study site (HRPO number 202006068).

Participants

Query of the electronic medical record system used by Air Methods (ie, emsCharts) was used to identify all consecutive mechanically ventilated adult air medical transport patients. The study period began in 2015, owing to the fact that the electronic record system was consistent over the entire study duration, and quality documentation was consistent during this time period. Further, with an estimated sample size of approximately 70,000 subjects, we were confident we would be able to adequately address the prespecified research questions. The inclusion criteria were age ≥ 18 y and receipt of mechanical ventilation via an endotracheal tube by the air medical transport team. Facility-to-facility transfers (eg, ED to ICU) as well as scene flights (eg, patients intubated in the field) were included. Patients without a documented tidal volume were excluded.

Assessments and Outcome Measures

Baseline characteristics included age, weight, sex, race, vital signs, and select laboratory values. In subjects with multiple vital sign variables documented, the median [interquartile range (IQR)] and mean SD values were calculated. The laboratory variables were those that were documented in emsCharts by the air medical crew, and obtained prior to crew arrival, such as in the ED where the crew was dispatched to. These laboratory variables included lactate, creatinine, hemoglobin, platelets, bilirubin, and arterial blood gases. To index tidal volume to predicted body weight (PBW), in subjects with a documented height, PBW was calculated according to the following formula: men, 50 + (2.3 * [height in inches − 60]); females, 45.5 + (2.3 * [height in inches − 60]). Process of care variables included endotracheal intubation (ie, by air medical crew vs prior to arrival), vasopressor use, and duration of care. Duration of care (in hours) was calculated as the elapsed time from crew arrival and their assumption of patient care to handoff of care to clinicians at the receiving facility.

The indication for mechanical ventilation was extrapolated from the documented chief complaint and included sepsis, respiratory failure, cardiac (eg, acute myocardial infarction, congestive heart failure), airway obstruction, sudden cardiac arrest, drug overdose, cerebrovascular accident, intracranial hemorrhage, seizure, traumatic brain injury, altered mental status, trauma, and other. A structured process for adjudication of the indication for mechanical ventilation was developed and followed. In the master data file, each potential indication for mechanical ventilation was given its own column, and binary determinations were made regarding whether the documented chief complaint field contained key words suggesting a given categorization. Chief complaint categories contained either primary causal conditions (eg, airway obstruction, sepsis) or conditions that were not necessarily explanatory (eg, altered mental status). Causal conditions were prioritized for categorization. As an example, a documented chief complaint of "traumatic head injury with altered mental status" would have been adjudicated as "traumatic brain injury" as the indication for mechanical ventilation.

Ventilator-related data included mode of mechanical ventilation, tidal volume, PEEP, F_{IO_2}, breathing frequency, peak and plateau pressures, and end-tidal carbon dioxide. Lung-protective ventilation was defined as the use of tidal volume of ≤ 8 mL/kg PBW, as this has been the upper limit of tidal volume in prior work of low tidal volume ventilation in ARDS.[3]

Statistical Analysis

Patient characteristics were assessed with descriptive statistics and frequency distributions. Categorical characteristics were compared using the chi-square test. Continuous characteristics were compared using independent samples *t* test or Mann-Whitney U test. Given that height was documented in only 4,186 (6.1%) patients, we felt that statistical approaches to replace 94% of this missing variable in order to calculate PBW would be unreliable. Therefore, comparisons between the lung-protective and nonprotective ventilation groups were restricted to those with PBW measurements available. To give better insight into the provision of lung-protective ventilation, we also assessed the most frequently delivered tidal volumes (ie, the mode) according to sex. This was done given the infrequent availability of PBW values and because it has been proposed that empirically choosing a fixed tidal volume of 350 mL in females and 450 mL in males could improve adherence to low tidal volume ventilation.[28]

To assess for predictors of nonprotective ventilation, a multivariable logistic regression model was constructed to adjust for potentially confounding variables. Following recommendations that covariates be chosen a priori, we selected variables that could influence the incidence of

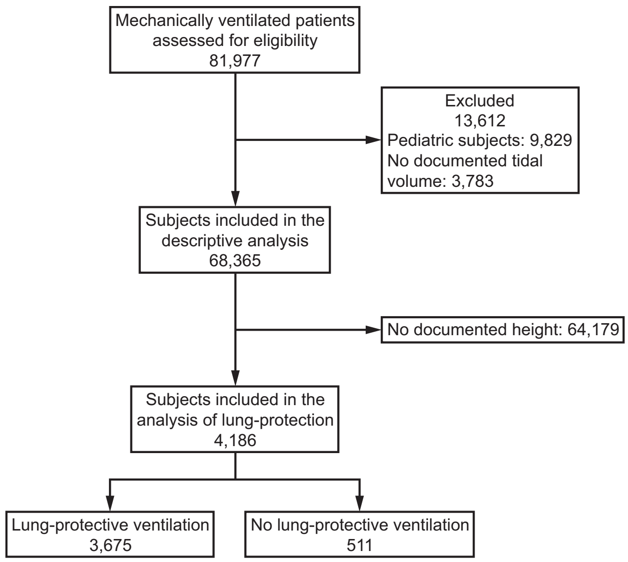

Fig. 1. Flow chart.

lung-protective ventilation, including age, weight, sex, and intubation location.[29-34] Collinearity was assessed, and the model used variables that were independent of other variables. All tests were 2-tailed, and a P value $< .05$ was considered statistically significant.

Regarding sample size, it was fixed as it was restricted to the time periods of investigation. We estimated a priori that over 10,000 patients per year would be included in this analysis. We were, therefore, confident that the sample size would be adequate to provide both a descriptive analysis that had high external validity regarding mechanical ventilation practices in the prehospital domain and allow the conduct of analyses with adequate power and precision and an adequate event per covariable ratio.[35,36]

Results

Study Population

A total of 81,977 mechanically ventilated patients were included in the data set and assessed for eligibility. After exclusion of 13,612 patients who were < 18 y of age or had no documented tidal volume, the final study population for the descriptive objective of the study consisted of 68,365 subjects (Fig. 1). Baseline characteristics of the entire cohort are in Table 1. The most common indication for mechanical ventilation was altered mental status (23.3%), followed by respiratory failure (17.4%). Median (IQR) duration of care was 1.1 h (0.9–1.5).

Four thousand one hundred eighty-six (6.1%) subjects had a documented height and, therefore, a calculated PBW. Nonprotective ventilation was provided to 511 (12.2%) of the subjects with a documented height. Baseline characteristics according to prehospital lung-protective ventilation status are in Table 2. There were significant differences in age, weight, and PBW between the 2 groups. In addition, females composed 75% of those subjects with

Table 1. Available Characteristics of Mechanically Ventilated Air Medical Transport Subjects

Baseline Characteristics	All Subjects
Age (y), $n = 68{,}365$	56.2 (18.5)
Weight (kg), $n = 67{,}798$	82.0 (70.0–100.0)
Height (inches)	69.0 (66.0–72.0)
Predicted body weight (kg), $n = 4{,}186$	68.4 (59.3–77.6)
Sex, $n = 67{,}714$	
Male	41,017 (60.6)
Female	26,697 (39.4)
Race, $n = 3{,}813$	
White	2,744 (72.0)
Black	545 (14.3)
Hispanic	387 (10.1)
Asian or Pacific Islander	34 (0.9)
Native American, Alaska Native	67 (1.8)
Other	36 (0.9)
Temperature (°C), $n = 26{,}999$	36.6 (36.1–36.9)
Heart rate (beats/min), $n = 68{,}270$	92.0 (77.5–109.0)
Mean arterial pressure, $n = 68{,}050$	89.0 (77.5–101.0)
S_{pO_2}, $n = 67{,}168$	96.6 (6.1)
Lactate (mmol/L), $n = 9{,}241$	3.8 (2.0–7.5)
Creatinine (mg/dl), $n = 38{,}994$	1.2 (0.9–1.8)
Hemoglobin (g/dl), $n = 40{,}606$	12.6 (3.0)
Platelet (10^9/L), $n = 37{,}546$	242.3 (113.8)
Bilirubin (mg/dl), $n = 1{,}159$	0.3 (0.1–0.8)
pH, $n = 25{,}246$	7.30 (7.18–7.38)
P_{aO_2}, $n = 24{,}248$	108.5 (74.0–214.0)
P_{aCO_2}, $n = 24{,}058$	42.8 (35.0–54.0)
Indication for mechanical ventilation	
Altered mental status	15,918 (23.3)
Respiratory failure	11,929 (17.4)
Trauma	8,767 (12.8)
Cardiac arrest	5,966 (8.7)
Cardiac	3,308 (4.8)
Intracranial hemorrhage	3,094 (4.5)
Seizure	2,280 (3.3)
Drug overdose	2,264 (3.3)
Sepsis	1,859 (2.7)
Traumatic brain injury	1,645 (2.4)
Airway obstruction	378 (0.6)
Other	10,957 (16.0)
Process of care variables	
Duration of care (h), $n = 65{,}517$	1.1 (0.9–1.5)
Intubation status, $n = 68{,}279$	
By air medical providers	42,054 (61.6)
Before arrival	26,225 (38.4)
Vasopressors	16,282 (23.8)

Continuous data are presented as mean (SD) or median (interquartile range), and categorical data are expressed as n (%).
The final cohort was comprised of 68,365 subjects.

Table 2. Characteristics of Mechanically Ventilated Air Medical Transport Patients According to Receipt of Lung-Protective Ventilation

	Prehospital Lung-Protective Ventilation Status		
Baseline Characteristics	Lung-Protective Ventilation (n = 3,675)	Non–Lung-Protective Ventilation (n = 511)	P
Age, y	56.7 (18.5)	59.1 (17.6)	< .001
Weight, kg	86.0 (72.0–100.0)	80.5 (68.0–100.3)	< .001
Height, inches	70.0 (66.0–72.0)	64.0 (61.0–66.0)	< .001
Predicted body weight, kg	70.7 (61.6–77.6)	54.7 (50.0–59.3)	< .001
Sex			< .001
Male	2,515 (68.4)	128 (25.0)	
Female	1,160 (31.6)	383 (75.0)	
Race			.81
White	1,919 (71.8)	266 (72.3)	
Black	357 (13.4)	41 (11.1)	
Hispanic	296 (11.1)	44 (12.0)	
Asian or Pacific Islander	21 (0.8)	4 (1.1)	
Native American, Alaska Native	57 (2.1)	9 (2.4)	
Other	21 (0.8)	4 (1.1)	
Temperature, °C	36.6 (36.2–36.9)	36.7 (36.3–37.0)	.06
Heart rate, beats/min	93.0 (78.0–109.0)	93.5 (78.0–110.0)	.73
Mean arterial pressure	89.0 (78.0–101.0)	86.0 (76.4–97.0)	< .001
S_{pO_2}, %	95.9 (9.5)	94.9 (6.4)	.03
Lactate, mmol/L	3.5 (1.9–7.3)	3.5 (1.7–7.6)	.85
Creatinine, mg/dl	1.2 (0.9–1.8)	1.2 (0.8–1.9)	.56
Hemoglobin, g/dl	12.6 (2.9)	12.0 (2.9)	< .001
Platelet, 10ˆ9/L	244.1 (110.4)	230.5 (97.6)	.09
Bilirubin, mg/dl	0.3 (0.1–0.5)	0.2 (0.1–1.9)	.84
pH	7.24 (7.11–7.35)	7.20 (7.09–7.21)	.20
P_{aO_2}, mm Hg	98.0 (69.8–175.7)	90.2 (65.3–164.8)	.13
P_{aCO_2}, mm Hg	43.0 (35.0–54.0)	41.0 (33.2–50.3)	.03
Indication for mechanical ventilation			< .001
Altered mental status	926 (25.0)	103 (20.0)	
Respiratory failure	869 (23.4)	173 (33.6)	
Trauma	507 (13.7)	45 (8.7)	
Cardiac arrest	260 (7.0)	39 (7.6)	
Cardiac	154 (4.2)	19 (3.7)	
Intracranial hemorrhage	96 (2.6)	16 (3.1)	
Seizure	116 (3.1)	15 (2.9)	
Drug overdose	122 (3.3)	9 (1.7)	
Sepsis	76 (2.0)	19 (3.7)	
Traumatic brain injury	93 (2.5)	5 (1.0)	
Airway obstruction	23 (0.6)	3 (0.6)	
Other	468 (12.6)	69 (13.4)	
Process of care variables			
Duration of care, h	1.2 (0.9–1.7)	1.3 (1.1–1.9)	< .001
Intubation status			.30
By air medical providers	2,399 (64.8)	321 (62.5)	
Before arrival	1,305 (35.2)	193 (37.5)	
Vasopressors	718 (19.4)	110 (21.4)	.28

Continuous data are presented as mean (SD) or median (interquartile range), and categorical data are expressed as *n* (%).

Table 3. Ventilator Variables and Care During Air Medical Transport

Ventilator-Related Variables	All Subjects (N = 68,365)
Ventilator mode	
VC-CMV	36,448 (53.3)
VC-IMV	21,494 (31.4)
PRVC	4,676 (6.8)
PC-CMV	3,620 (5.3)
PC-IMV	1,331 (1.9)
ASV	425 (0.6)
APRV	282 (0.4)
Tidal volume, mL	475 (425–500)
Tidal volume (mL/kg PBW), n = 4,186	6.6 (6.1–7.3)
PEEP, n = 67,796	5.7 (2.3)
F_{IO_2}, n = 67,612	76.9 (24.3)
Breathing frequency, breaths/min, n = 24,559	18.9 (17.7)
Peak pressure (cm H_2O), n = 52,553	22.0 (18.0–27.0)
Plateau pressure (cm H_2O), n = 43,308	18.0 (15.0–22.0)
End-tidal CO_2 (mm Hg), n = 67,724	36.0 (31.0–40.0)

Continuous data are presented as mean (SD) or median (interquartile range), and categorical data are expressed as n (%).
VC = volume control
CMV = continuous mandatory ventilation
IMV = intermittent mandatory ventilation
PRVC = pressure-regulated volume control
PC = pressure control
ASV = adaptive support ventilation
APRV = airway pressure-release ventilation
PBW = predicted body weight

nonprotective ventilation compared to 25% males, $P < .001$.

Ventilator-Related Variables

Ventilator variables for the entire cohort are in Table 3. Volume control (VC)–continuous mandatory ventilation (53.3%) and VC–intermittent mandatory ventilation (31.4%) were the most common ventilator modes used. Mean PEEP was 5.7 (2.3) and F_{IO_2} was 76.9% (24.3). Plateau pressure was documented in 43,308 (63.3%) subjects.

Ventilator variables according to prehospital lung-protective ventilation status are in Table 4. Subjects with nonprotective ventilation received higher tidal volume when compared to those with lung-protective ventilation (475 [425–520] mL vs 450 [405–500] mL, $P < .001$). Significantly higher tidal volume/PBW (8.6 [8.3–9.2) mL vs 6.5 (6.1–7.0] mL) and plateau pressure (20.0 [16.5–25.0] cm H_2O vs 18.0 [15.0– 22.0] cm H_2O) were also seen in the nonprotective ventilation group ($P < .001$ for both). According to sex, males received higher tidal volume when compared to females (500 [450–525] mL vs 440 [400–475] mL, $P < .001$). However, females received higher tidal volume/PBW compared to males (7.4 [6.6–8.0] mL vs 6.4 [6.0–6.8] mL, $P < .001$). The most frequent tidal volumes delivered according to sex are in Table 5. The mode value for males was 500 mL (24.4%) and
450 mL (16.4%) for females. Figure 2 demonstrates the impact of mechanical ventilation with an empiric choice of tidal volume, using the mode tidal volume settings. For shorter patients, it is more difficult to attain low tidal volume ventilation, especially in females.

Predictors of Nonprotective Ventilation

Table 6 shows the multivariable logistic regression model with nonprotective ventilation as the dependent variable. After adjusting for covariates in the model, female sex was an independent predictor of nonprotective ventilation (adjusted odds ratio 6.79 [95% CI 5.47–8.43], $P < .001$), whereas lower weight was associated with a higher odds of receiving nonprotective ventilation (adjusted odds ratio 0.996 [95% CI 0.992–0.999], $P = .03$).

Discussion

Early work on VALI demonstrated that the mechanical ventilator can cause harm over the course of a few hours.[37-39] Clinical studies from the operating room have shown that the use of lung-protective ventilation for relatively short durations can reduce systemic and pulmonary inflammation and is associated with better clinical outcomes.[9,40,41] In addition, data from the ED demonstrate that early adherence to lung protection is associated with increased overall adherence in the ICU and improved clinical outcomes.[8,14] For these reasons, one can view VALI as a time-sensitive emergency, and clinicians should strive to optimize ventilator settings from the onset of mechanical ventilation. Unfortunately, the provision of lung-protective ventilation remains suboptimal as demonstrated by a number of studies.[5,7,42] Given the overall lack of data on mechanical ventilation in the prehospital domain, and the potential importance that this clinical arena could play across the entire chain of survival with respect to lung protection, we conducted this large cohort study to characterize mechanical ventilation practices and assess predictors of nonprotective ventilation.

The first significant finding revolves around the provision of low tidal volume ventilation across the entire cohort. Lung volume is largely determined by sex and height, so tidal volume should be indexed to PBW. In those with height documented and, therefore, an available PBW, tidal volume was 6.6 (6.1–7.3) mL/kg PBW, and low tidal volume was observed in 3,675 (87.8%) subjects. If these findings could be extrapolated to the entire cohort or confirmed with future studies in which PBW was available, this suggests that air medical transport crews are providing lung protection to a much higher percentage of patients

Table 4. Ventilator Variables and Care During Air Medical Transport According to Receipt of Lung-Protective Ventilation

	Prehospital Lung-Protective Ventilation Status		
Ventilator-Related Variables	Lung-Protective Ventilation ($n = 3,675$)	Non–Lung-Protective Ventilation ($n = 511$)	*P*
Ventilator mode			< .001
VC-CMV	1,984 (53.5)	293 (56.9)	
VC-IMV	1,118 (30.1)	103 (20.0)	
PRVC	197 (5.3)	40 (7.8)	
PC-CMV	266 (7.2)	63 (12.2)	
PC-IMV	85 (2.3)	13 (2.5)	
ASV	32 (0.9)	1 (0.2)	
APRV	13 (0.4)	2 (0.4)	
Tidal volume, mL	450 (405–500)	475 (425–520)	< .001
Tidal volume, mL/kg PBW	6.5 (6.1–7.0)	8.6 (8.3–9.2)	< .001
PEEP	6.5 (3.0)	6.8 (3.0)	.05
F_{IO_2},%	79.7 (24.1)	78.2 (25.1)	< .001
Breathing frequency, breaths/min	19.7 (4.9)	19.5 (4.7)	< .001
Peak pressure, cm H_2O	22.0 (18.0–27.0)	24.0 (20.0–30.0)	< .001
Plateau pressure, cm H_2O	18.0 (15.0–22.0)	20.0 (16.5–25.0)	< .001
End-tidal CO_2, mm Hg	37.0 (32.0–41.0)	34.5 (29.0–39.5)	< .001

Continuous data are presented as mean (standard deviation) or median (interquartile range), and categorical data are expressed as *n* (%).
VC = volume control
CMV = continuous mandatory ventilation
IMV = intermittent mandatory ventilation
PRVC = pressure-regulated volume control
PC = pressure control
ASV = adaptive support ventilation
APRV = airway pressure-release ventilation
PBW = predicted body weight

Table 5. Modus Tidal Volumes Delivered During Air Medical Transport According to Sex

Tidal Volume, mL	Male	Female
300	81 (0.2)	381 (1.3)
350	222 (0.5)	1,364 (4.8)
400	1,945 (4.5)	4,292 (15.2)
450	5,785 (13.4)	4,649 (16.4)
500	10,550 (24.4)	3,396 (12.0)
550	3,622 (8.4)	778 (2.8)
600	2,050 (4.7)	379 (1.3)
650	534 (1.2)	82 (0.3)

Data are expressed as *n* (%).

than that seen in prior work from the ED or ICU.[5,7,8,14,16,17] Unfortunately, as height was available for only 6% of the cohort, it currently remains impossible to say with confidence how frequently low tidal volume ventilation is delivered in the prehospital domain. Further, there were observed differences in ventilator modes according to lung-protective ventilation status. Going forward, understanding factors associated with all chosen ventilator settings will be informative with respect to future quality improvement work. Due to a lack of PBW availability, we assessed the mode values for tidal volume according to sex, as it has been proposed that empirically choosing a fixed tidal volume of 350 mL in females and 450 mL in males could improve adherence to low tidal volume ventilation.[28] Table 5 demonstrates that tidal volume adjustments based on sex do seem to be occurring in air medical transport patients. However, as demonstrated in Figure 2, the current amount of sex-based tidal volume adjustment may be insufficient, especially in shorter females. This is especially true, even for both sexes, if a stricter definition of low tidal volume ventilation was applied, as is the standard of care for patients with established ARDS. The current study has identified an easily fixed variable for performance improvement: height assessment and documentation in order to index tidal volume to PBW and assure adherence to low tidal volume ventilation. Recognizing potential logistical challenges in measuring height during flight, surrogate values for height, such as ulna/forearm length, have been shown to be easily obtainable in emergency settings and an accurate way to index tidal volume to PBW.[43,44]

A second important finding relates to the provision of low tidal volume ventilation in relation to sex. In subjects with an available PBW, females composed 75% of those receiving nonprotective ventilation. In addition, female sex was an independent predictor of nonprotective ventilation in

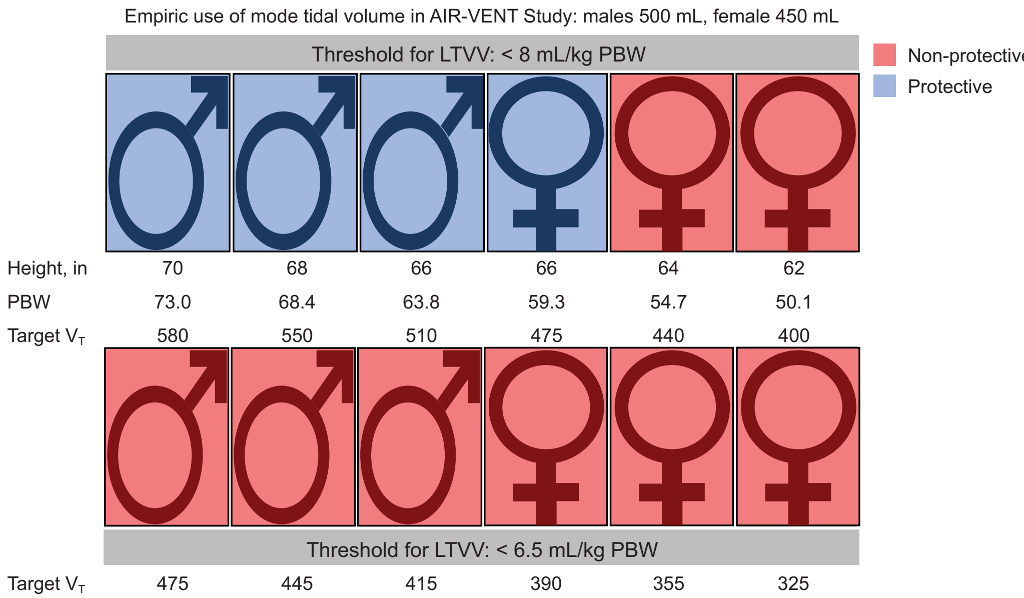

Fig. 2. The impact of mechanical ventilation with an empiric choice of tidal volume using the most common (ie, mode) tidal volume settings observed in the AIR-VENT Study. For shorter patients, it is more difficult to attain low tidal volume ventilation, especially in females. The bottom panel demonstrates that in a setting of a lower threshold (ie, 6.5 mL/kg predicted body weight [PBW]) for defining low tidal volume, indicated for patients with ARDS, empiric tidal volumes that are not indexed to PBW will result in injurious settings to all patients with these heights.

Table 6. Multivariable Logistic Regression Analysis With Nonprotective Ventilation as the Dependent Variable

Variables	Adjusted Odds Ratio	95% CI	Standard Error	*P*
Age	0.99	0.99–1.00	0.003	.48
Intubation by air medical crew	1.12	0.92–1.37	0.103	.26
Weight, kg	0.99	0.99–0.99	0.002	.03
Sex (female)	6.79	5.47–8.43	0.111	< .001

multivariable analysis. It was shown over a decade ago that female sex is a risk for nonprotective ventilation.[30] Recent work demonstrates similar findings in the ICU population.[45] Our current finding is important as it reinforces the sex inequity in lung-protective ventilation and is the first to demonstrate this in the prehospital environment. It also shows that empiric tidal volume, without accurate assessment of height, is likely to leave a significant proportion of females without low tidal volume ventilation (Fig. 2).

Finally, almost 40% of air medical transport subjects did not have plateau pressure assessed. As a surrogate for end-inspiratory stretch and marker for overdistention, plateau pressure has been demonstrated to carry important prognostic significance.[46,47] Whereas it is encouraging the plateau pressures were not high in this study, and below the recommended threshold of 30 cm H_2O, routine monitoring of this important parameter should be a part of ensuring safe mechanical ventilation.

Overall, the data from the AIR-VENT study demonstrate performance improvement possibilities in air medical transport patients. This includes indexing tidal volume to PBW by obtaining accurate height (or ulna length), paying special attention to ventilator settings in females, and assessing and limiting inspiratory plateau pressure.

Limitations

Prior work on mechanical ventilation in air medical transport patients has been limited to primarily small sample sizes. Whereas this large, nationwide study addresses that limitation, pertinent limitations exist. First, we have no clinical data beyond that obtained from the flight, so we cannot comment on the impact of prehospital ventilator settings on downstream care or on subject outcomes. Since multiple studies have shown the influence of immediate post-intubation ventilator settings on ED and ICU settings, we hypothesize that low tidal volume ventilation in the prehospital setting is associated with better downstream adherence and improved outcomes. However, future studies are needed to test this hypothesis. The AIR-VENT Study is a retrospective cohort study and carries all of the inherent limitations with this study design, such as lack of causation and data accuracy. Whereas all ventilator data are easily abstracted from the electronic record, they are subject to inaccuracy during routine documentation. Further, a lack of documentation of key variables (eg, height, plateau pressure) and missing data for other key variables (ie, laboratory variables and illness severity) limit our ability to comment on the quality of prehospital mechanical ventilation and compare differences between the 2 groups. However, it has allowed us to identify key areas for quality improvement. Going forward, future studies will also need to assess the impact of air medical transport ventilator settings as they relate to other key variables, such as respiratory effort, asynchrony, sedation depth, and neuromuscular blocker use.

Conclusions

The overwhelming majority of air medical transport subjects had tidal volume set empirically, which may be exposing patients to nonprotective ventilator settings. Given a lack of PBW assessments, the frequency of low tidal volume use remains unknown. Performance improvement initiatives aimed at indexing tidal volume to PBW and documenting plateau pressure are easy targets to improve the delivery of mechanical ventilation in the prehospital arena, especially for females.

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