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Prehospital tidal volume influences hospital tidal volume: A cohort study

Andrew J. Stoltze, MD, JD^a, Terrence S. Wong, BA^a, Karisa K. Harland, PhD, MPH^a, Azeemuddin Ahmed, MD, MBA^a, Brian M. Fuller, MD, MSCI^b, and Nicholas M. Mohr, MD, MS^{a,c}

^aDepartment of Emergency Medicine, University of Iowa Carver College of Medicine, 200 Hawkins Drive, 1008 RCP, Iowa City, IA 52242

^bDivision of Emergency Medicine, Division of Critical Care, Department of Anesthesiology, Washington University School of Medicine, 660 South Euclid Avenue

^cDivision of Critical Care, Department of Anesthesia, University of Iowa Carver College of Medicine, 200 Hawkins Drive, 1008 RCP, Iowa City, IA 52242

Abstract

Purpose—To describe current practice of ventilation in a modern air medical system, and to measure the association of ventilation strategy with subsequent ventilator care and acute respiratory distress syndrome (ARDS).

Materials and Methods—Retrospective observational cohort study of intubated adult patients (n=235) transported by a university-affiliated air medical transport service to a 711-bed tertiary academic center between July 2011 and May 2013. Low tidal volume ventilation was defined as tidal volumes ≤ 8 mL/kg predicted body weight (PBW). Multivariable regression was used to measure the association between prehospital tidal volume, hospital ventilation strategy, and ARDS.

Results—Most patients (57%) were ventilated solely with bag-valve ventilation during transport. Mean tidal volume of mechanically ventilated patients was 8.6 mL/kg PBW (SD 0.2 mL/kg). Low tidal volume ventilation was used in 13% of patients. Patients receiving low tidal volume ventilation during air medical transport were more likely to receive low tidal volume ventilation in the emergency department ($p < 0.001$) and intensive care unit ($p = 0.015$). ARDS was not associated with pre-hospital tidal volume ($p = 0.840$).

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Corresponding Author: Nicholas M. Mohr, MD, MS, Department of Emergency Medicine, University of Iowa Carver College of Medicine, 200 Hawkins Drive, 1008 RCP, Iowa City, IA 52242, Tel: 319-353-6360, Fax: 319-353-7006, nicholas-mohr@uiowa.edu.

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Conclusions—Low tidal volume ventilation was rare during air medical transport. Air transport ventilation strategy influenced subsequent ventilation, but was not associated with ARDS.

Keywords

emergency care; prehospital; respiration; artificial; respiratory distress syndrome; adult; intubation; prevention and control

Introduction

Prehospital and early hospital care has been recognized as an influential period in the evolution of critical illness.[1, 2] Critically ill and injured patients being treated by air medical providers are often intubated and undergo mechanical ventilation. Mechanical ventilation is common in the prehospital and inter-hospital environment, but little has been reported on the details of its actual implementation in the prehospital setting.

Mechanical ventilation has been known to cause harm [i.e. ventilator-induced lung injury (VILI)] for decades [3], and the use of lung protective ventilation to mitigate VILI is associated with improved mortality in patients with acute respiratory distress syndrome (ARDS).[4] Only recently, however, have investigators begun to appreciate the role of routine lower tidal volumes (6 – 8 mL/kg predicted body weight [PBW]) to prevent the complications of ARDS.[5, 6] Randomized trials suggest that lung injury can be prevented by low tidal volume ventilation [7–9], and two recent systematic reviews suggest that routine use of low tidal volume ventilation may prevent ARDS development and improve patient outcomes.[10, 11]

Prior reports suggest that ARDS can develop within hours to days [6, 12] so targeting strategies aimed at lung protection during the earliest period of mechanical ventilation has been postulated to prevent ARDS and downstream complications occurring after intensive care unit (ICU) admission.[13] Prior studies have reported poor adherence with low tidal volume ventilation in the ICU and in the emergency department (ED).[14, 15]

Early medical decisions have been shown to influence subsequent care.[14, 16] This association, or “therapeutic momentum”, has not previously been examined in the context of pre-hospital transport. Many important and time-sensitive intervention are begun during the transport of a critically ill patient, and the importance of these decisions could be magnified if they influence hospital-based care. Ventilator strategy is a critical component of a critically ill patient’s care, and whether prehospital ventilation influences outcome is debated.

The primary objective of this study was to describe the ventilation strategy used for intubated patients transported in a modern aeromedical transport system, with a focus on use of low tidal volume ventilation. Secondary objectives included to (1) measure the impact of prehospital ventilator tidal volume on subsequent inpatient ventilator tidal volume, and (2) estimate the prevalence of ARDS in transported patients, the subsequent incidence after admission, and the association between prehospital ventilator strategy and the subsequent development of ARDS.

Our hypotheses were that low tidal volume ventilation would be uncommon in the prehospital environment, therapeutic momentum from prehospital ventilation would influence ED and inpatient tidal volume selection, and ARDS would be present in a minority of transported patients, but would be influenced by patient- and treatment-related factors present in the prehospital environment.

Materials and Methods

Study Design, Population, and Setting

This study was a retrospective observational cohort study of intubated adult (age ≥ 18 years) patients transported by a university-affiliated air medical transport service to a 711-bed tertiary academic medical center between July 2011 and May 2013. The study hospital is located in a rural Midwestern state, and has a 60,000-visit ED with a two-helicopter air ambulance service with 800 annual flights. The first helicopter is based at the university, and the second is based at a community hospital approximately 85 miles from the university. Both helicopters are staffed with a nurse-paramedic flight crew, and no crew members staff both helicopters. Both helicopters carry a Crossvent 3 transport ventilator (Bio-Med Devices, Inc., Guilford, CT) and bag-valve for manual ventilation. The medical flight crew ventilation protocols are detailed in Supplementary Appendix 1.

Upon hospital arrival, patients were admitted to the ED, operating room, or directly to an intensive care unit. Patients were ventilated in the emergency department and during intra-hospital transport using a Respironics Trilogy 202 (Philips Healthcare, Andover, MA) and in the ICU with the Maquet Servo-i (Maquet Holding B.V. & Co. K.G., Germany). In all patient care areas, ventilation settings are determined by the treating physician.

Patients who (1) died within 72 hours of hospital arrival, (2) were under the age of 18 at time of transfer, or (3) were admitted to a transferring hospital prior to definitive transfer were excluded from the study. The reason for excluding patients who died within 72 hours is that (i) it is impossible to assess clinical outcomes (such as ARDS) with a short period of observation and (2) patients who die early are a heterogeneous group that includes patients who are both very ill and patients who are being transported for palliative care and expectant management. Because of the variability in this group, it is challenging to interpret appropriateness of ventilator settings in this cohort. This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) Statement [17], and was approved by the Institutional Review Board (IRB#201305726) of the principal investigator's institution under waiver of informed consent.

Study Protocol

Data Collection—Two data abstractors were trained in data abstraction techniques and extracted data from the electronic medical record (AJS, TSW). Variables for collection were defined *a priori*, and a standardized form was used to ensure uniform data collection. Intubated patients were identified using flights logs from the air ambulance service. Ventilation parameters were abstracted from the flight medical record, and were routinely recorded as the ventilator settings selected for the flight (changes are documented in the

record by standard procedure, but changes were rare). Baseline patient characteristics, hospital ventilation settings, other treatment variables, and outcomes were abstracted from the hospital electronic medical record. ED and ICU ventilator settings were selected to be the first ventilator settings written by physician order (e.g., the first settings that were sustained in each of these areas). Data were transferred to an electronic database for validation, verification, and analysis. Inconsistencies in the data were resolved by a third data abstracter (NMM).

Definitions—Height and weight were defined as recorded in the electronic medical record, and were used for calculation of body mass index (BMI) and PBW. PBW (in kg) was calculated for males as, $50 + 2.3 (\text{height (in)} - 60)$; and for females as, $45.5 + 2.3 (\text{height (in)} - 60)$. [18]

Low tidal volume ventilation was defined as tidal volumes ≤ 8 mL/kg PBW. A modified APACHE-II score was calculated as previously reported omitting the neurologic portion because of difficulty in assessing the detailed neurologic exam retrospectively. [14, 19]

ARDS was defined using the Berlin Definition, using physiologic, radiographic, and clinical criteria, as previously described. [20] For patients in whom no arterial blood gas analysis was available, oxygenation criteria were evaluated using the SpO_2 : FiO_2 ratio, as previously described. [21] Two independent investigators trained in chest x-ray interpretation for ARDS adjudication [20, 22] reviewed all radiographic images to assess for the presence of bilateral infiltrates consistent with ARDS. Radiographs were classified as “consistent”, “inconsistent”, or “equivocal” for ARDS, and the diagnosis of ARDS was made by consensus. Patients with dialysis-dependent end-stage renal disease or a history of congestive heart failure were excluded from ARDS assessment because of the difficulty in adjudicating volume status retrospectively among critically ill ventilated patients with these comorbidities. To assess ARDS at the time of transport, initial oxygenation parameters from hospital arrival and from the first available radiographs were used, assuming that since these parameters were collected within 1 hour of arrival that they approximated in-flight physiology.

Data Analysis

Descriptive analysis was conducted to report means, medians, and proportions according to standard definitions for parametric and non-parametric data, and univariate analysis was conducted using the Student’s t-test, the Mann-Whitney U test, and the chi-squared test, as appropriate. An explanatory multivariate logistic regression model was constructed to measure the association between prehospital tidal volume and initial hospital ventilation strategy.

An additional explanatory multivariable logistic regression model was developed to predict ARDS development based on prehospital tidal volume among those without ARDS at the time of transport. Statistical interactions and collinearity were evaluated for both models. Clinically relevant variables and univariate associations ($p < 0.20$) were considered for inclusion in the multivariable model, but final variable inclusion was determined by purposeful selection.

Patients were excluded for missing data if the ventilator strategy could not be elucidated from the medical record, but this number was small ($n = 18$, 7.6%). Univariate analysis was performed evaluating primary clinical outcomes of ARDS, 28-day ventilator-free days, hospital length-of-stay and mortality. Statistical significance was defined as $p < 0.05$ for two-tailed tests, and adjusted odds ratios with 95% confidence intervals are reported. SAS version 9.2 (SAS Institute, Cary, NC) was used for all analyses.

Results

Two-hundred thirty-five patients were included in the final analysis (Figure 1). Patient characteristics are described in Table 1.

Bag-Valve Ventilation

Most intubated patients (57%) were ventilated with bag-valve ventilation only and were not placed on a mechanical ventilator. Patients with brain injury ($p = 0.011$), spinal cord injury ($p = 0.016$), and those with shorter flight times ($p < 0.001$) were less likely to be transported on a ventilator. Although no other clinical factors were identified that predicted manual ventilation, helicopter transport service (between the two in our system) was associated significantly with the decision to use the ventilator during transport (16% vs. 93% for each helicopter, respectively, $p < 0.001$). Adjusting for clinical factors, helicopter transport service remained significantly associated with the decision to use the ventilator during transport (adjusted odds ratio 2.76, 95% CI 1.01 – 7.51).

Mechanical Ventilator Parameters

The most common ventilator mode was assist control/volume control (VC) (94%). Of those transported using a mechanical ventilator, the mean tidal volume was 8.6 mL/kg PBW (SD 0.2 mL/kg) with a minority (34%) being prescribed low tidal volume ventilation (Figure 2). Patients who were shorter ($p < 0.001$) and with higher BMI ($p < 0.001$) were less likely to receive low tidal volume ventilation. Despite the majority of patients requiring high concentrations of oxygen for the transport duration, only 9 patients (10%) were transported with PEEP > 5 cm H₂O. Additionally, 100% FiO₂ was utilized in the majority of patients (60%).

Table 2 shows univariate analysis. Patients receiving high tidal volumes (tidal volume > 8 mL/kg PBW) during transport were significantly more likely to be exposed to high tidal volumes in the ED ($p < 0.001$) and the ICU ($p = 0.015$) (Figures 3, 4). Using multivariable logistic regression to adjust for BMI, transport tidal volume was the strongest predictor of subsequent ventilation strategy ($p = 0.003$) (Figure 5). There was no association between tidal volume and the incidence of ARDS, length of stay, or mortality.

Acute Respiratory Distress Syndrome

Twenty-three patients (9%) had ARDS at the time of hospital arrival and 24 (10%) subsequently developed ARDS. Median time to development of ARDS was 2 days (IQR 1–4 days). Only 1 patient with ARDS upon hospital arrival (14%) was transported using low tidal volume ventilation (4.3%).

Patients who developed ARDS had higher APACHE-II scores (29 vs. 22, $p < 0.001$) and higher BMI (30 vs. 27, $p = 0.013$) than those without ARDS. Air medical transport tidal volume (8.4 vs. 8.4 mL/kg PBW, $p = 0.840$), ED tidal volume (9.1 vs. 8.5 mL/kg PBW, $p = 0.124$), and ICU tidal volume (8.0 vs. 8.0 mL/kg PBW, $p = 0.808$) were not associated independently with development of ARDS among patients who did not have ARDS at the time of transfer. Patients with ARDS had longer time on the ventilator as measured by 28-day ventilator-free days ($p < 0.001$), but no difference in mortality ($p = 0.186$). Average hospital stay among the entire cohort was 10 days (SD 9 days), and patients who developed ARDS had longer length of stay than those who did not (15 vs. 9 days, $p < 0.001$).

Discussion

Emergency medical services (EMS) are an important link in treating critically ill patients. This study represents the second report of the ventilation strategies being employed during air medical transport, but it is the first to examine the downstream effects of the ventilation decisions made by air crews on clinical outcomes and hospital-based decision-making.

This study highlights the importance of transitions of care from the prehospital environment. Low tidal volume ventilation in the aeromedical environment was associated with an increased probability of low tidal volume ventilation after hospital arrival, both in the ED and in the ICU. Therefore, any risk of exposure to potentially injurious tidal volumes and resultant ventilator-induced lung injury may not be limited to the time during which a patient is transported – decisions made in the prehospital environment carry over into inpatient management. We have described this therapeutic momentum previously in other care settings [14, 16], and it may magnify the effect prehospital providers have on patient-oriented clinical outcomes. Even if the effect size of suboptimal ventilation in the prehospital environment is low with short transport times, this effect may remain relevant in influencing a patient's clinical outcome if those settings are preserved for hours or days after hospital admission.[6, 23] Further research into this important issue is warranted as through understanding this impact we will be better able to account for it in our systems-based practice.

In a prior prehospital study, lung protective ventilation was practiced in 68% of patients when defined as: 1) PEEP ≥ 5 cmH₂O, 2) peak inspiratory pressure ≤ 35 cmH₂O and 3) Vt ≤ 12 mL/kg PBW, but only 35% when held to a more stringent (8 mL/kg) tidal volume criterion. This study differs from our report in that it did not evaluate the effects of the mechanical ventilation prescription on post-transport hospital care.[24]

Several interesting practices about mechanical ventilation in our region differ from the prior report. One of the most surprising findings is the frequency with which intubated patients are transported without the use of the mechanical ventilator, despite institutional protocols recommending its use. Clearly, use of the ventilator requires additional effort, cost, cleanup, and for short flights, flight crews may see this investment as unnecessary. Prior studies suggest that manual ventilation can provide variable tidal volumes, which could have broad implications since ventilator use seems to influence later care.[25]

This finding may also inform our understanding about other studies of EMS interventions in the critically ill. For example, studies disagree on the utility of prehospital intubation, but most do not report prehospital ventilation strategy. Authors have commonly cited complications from intubation itself to explain worse survival in intubated patients, but prehospital ventilation strategy may be an important covariate that has not been adequately considered in its influence on clinical outcomes.[26–28] If bag-valve ventilation rarely provides protective ventilation, then it seems plausible that patients who are intubated and bagged may be harmed either by the intubation *or by prehospital ventilation practices*. Injurious ventilation could contribute to worsening in cardiac output, lung injury, and other clinical outcomes.

Our low tidal volume ventilation rate of 34% is similar to the 35% reported by Singh et al. [24], but including patients in whom the ventilator was never used dropped our compliance to 13% (assuming bag-valve ventilation is not low tidal volume). Expectedly, flight and patient-specific factors contributed to this decision, but a significant portion of the variability in ventilator use could only be ascribed to institutional culture. The two helicopters in our study use the same protocols, but they are based at different hospitals and have different crews. One crew has, on average, longer transport times and slightly different patients, but these factors did not describe the variability – the culture of the flight crews was a dominant factor in ventilator utilization.

In addition, PEEP was used rarely. This mirrors our previous report on ED ventilation [14], but is concerning given the importance of PEEP as a component of lung protection. Repetitive atelectrauma from inadequate PEEP has been shown to worsen lung inflammation [29–31], and a recent trial incorporating a high FiO₂/low PEEP strategy during surgery suggested worse outcomes when coupled with a high tidal volume strategy. [8]

ARDS was found to be common in our cohort of patients transported by helicopter (22%), and it frequently developed after transfer (51% of patients with ARDS). Further, ARDS developed rapidly, in accordance with prior reports.[6, 14] Unfortunately, few of the patients with ARDS at the time of transfer were ventilated with low tidal volume ventilation strategies, which have been shown, as part of a lung protective strategy, to reduce mortality in ICU patients being treated with ARDS.[18] While no association between potentially injurious ventilation and ARDS was detected in our data, we did not power our study to detect this difference, and the absence of association may simply be lack of power. Further research should continue to explore the effect of mechanical ventilation and ARDS in at-risk patients.

Several limitations must be considered for this study. As a retrospective study, only data recorded in the medical record is available for analysis, and accuracy of the record is critical for our conclusions. We have sought to select measures likely to be recorded accurately, and we have taken steps to corroborate and validate data when possible.

The diagnosis of ARDS can be difficult, and prior authors have observed variability in interpretation of chest radiography as a diagnostic criterion.[32] We used two independent

reviewers and both underwent training in the Berlin definition with training radiographs, which should limit variability in our diagnosis.[20] Our observed ARDS rate and progression are consistent with previous reports.[14] Further, we eliminated dialysis patients and patients with congestive heart failure to improve the retrospective ability to assess accurately fluid status.

We defined low tidal volume ventilation as ≤ 8 mL/kg PBW. Lung protective ventilation usually includes measurement of plateau pressures and adequate levels of PEEP, but these variables cannot be defined so clearly in retrospective data without controversy. There is evidence that even at 8 mL/kg PBW patients can still have identifiable levels of lung injury. [33] For purposes of this study, we therefore defined low tidal volume ventilation consistent with the upper limit of a prior randomized trial [18], although we acknowledge that true lung protective ventilation involves PEEP, limitation of stretch, and limitation of FiO_2 .

Conclusions

Utilization of low tidal volume mechanical ventilation settings is uncommon in intubated patients transported by air ambulance to a tertiary care center. Prehospital ventilator strategy is associated with in-hospital tidal volume selection. Further study to better define clinical outcomes based on prehospital care should be pursued, and prospective interventions to improve lung protective ventilation in the prehospital environment may be beneficial to limit iatrogenic injury to critically ill patients at high risk of complications.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviation List

APACHE-II	Acute Physiology and Chronic Health Evaluation, 2 nd edition
ARDS	acute respiratory distress syndrome
BMI	body mass index
ED	emergency department
FiO_2	fraction of inspired oxygen
ICU	intensive care unit
PBW	predicted body weight
PEEP	positive end-expiratory pressure

SpO₂	oxygen saturation by pulse oximetry
VILI	ventilator-induced lung injury

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Figure 1.
Study patient flow diagram

Figure 2. Tidal volume during (A) prehospital transport, (B) emergency department (ED), and (C) intensive care unit (ICU) phases of care. Grey bars denote tidal volume in the lung protective range [8 mL/kg predicted body weight (PBW)].

Figure 3.

Hospital ventilation strategy stratified on prehospital ventilation cohort. (A) Prehospital air transport ventilation for intubated patients; (B) hospital ventilation strategy for those ventilated with prehospital low tidal volume ventilation; (C) hospital ventilation strategy for those ventilated with prehospital bag-valve ventilation; (D) hospital ventilation strategy for those ventilated with prehospital high tidal volume ventilation.

LTV, lung protective ventilation; NLTV, non-lung protective ventilation.

Figure 4.

Association between prehospital tidal volume and first hospital tidal volume (measured in the emergency department or intensive care unit).

PBW, predicted body weight

Figure 5.

Multivariable logistic regression, predicting low tidal volume ventilation after aeromedical transport, controlling for BMI and stratified by ventilation strategy. Referent group is high tidal volume ventilation.

Table 1

Characteristics of intubated air medical transport patients (n = 235).

Factors	N = 235
Age, y ^a	53 (36–66)
Male, n (%)	133 (56.6%)
Height, cm	170 (160–180)
Weight, kg	79 (65–92)
PBW, kg	64 (55–73)
BMI, kg	27 (23–31)
Comorbidities, n (%)	
COPD	40 (17.0%)
Diabetes mellitus	37 (15.7%)
CHF	19 (8.1%)
Malignancy	17 (7.2%)
Dialysis	13 (5.5%)
Cirrhosis	5 (2.1%)
Reason for Transfer	
Intracranial Hemorrhage	58 (25)
Traumatic Brain Injury	43 (18)
Cardiac Arrest	25 (11)
Burns/Smoke Inhalation	10 (4)
Overdose	3 (1)
Other Trauma	38 (16)
Heart rate, bpm	98 (77–115)
SBP, mmHg	136 (113–154)
DBP, mmHg	84 (69–95)
APACHE-II	16 (10–20)
First Hospital Blood Gas	
pH	7.35 (7.27 – 1.41)
pCO ₂	40 (35 – 48)
pO ₂	166 (83 – 324)
HCO ₃	22 (19 – 24)
Flight Time, min	29 (23–36)

^aContinuous variables reported as median (IQR).

PBW, predicted body weight; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; SBP, systolic blood pressure; bpm, beats per minute; DBP, diastolic blood pressure; mmHg, mm of mercury; APACHE-II, Acute Physiology and Chronic Health Evaluation-II (excluded Glasgow Coma Scale as discussed in text); IQR, interquartile range

Table 2

Clinical and ventilator factors during air medical transport.

		Prehospital Mechanical Ventilation		
	Bag Valve Ventilation	Low Tidal Volume	Non-low Tidal Volume	
Air Transport Flight Variables	(n = 126)	(n = 31)	(n = 60)	<i>p</i>
Length of flight, min (mean, SD)	25 (10)	34 (8)	33 (9)	0.911
Air Transport Ventilation Variables				
Tidal volume, mL (mean, SD)	N/A	486 (72)	577 (99)	<0.001
Tidal volume, mL/kg PBW (mean, SD)	N/A	6.8 (0.7)	9.5 (1.2)	<0.001
PEEP, cm H ₂ O (mean, SD)	N/A	3 (3)	3 (3)	0.739
ED Ventilation Variables				
ED tidal volume, mL (mean, SD)	539.5 (79.8)	562.0 (104)	532.2 (92.3)	0.261
ED tidal volume, mL/kg PBW (mean, SD)	8.5 (1.6)	7.7 (1.1)	9.0 (1.6)	0.002
ED low tidal volume ventilation, <i>n</i> (%)	40 (40)	14 (70)	10 (24)	<0.001
ED PEEP, cm H ₂ O (mean, SD)	5.5 (1.6)	5.2 (0.5)	5.5 (1.9)	0.296
ICU Ventilation Variables				
ICU tidal volume, mL (mean, SD)	503.1 (118.9)	507.1 (114.1)	504.6 (122.1)	0.928
ICU tidal volume, mL/kg PBW (mean, SD)	7.9 (1.8)	7.1 (1.4)	8.3 (1.9)	0.003
ICU low tidal volume, <i>n</i> (%)	66 (52.80)	22 (70.97)	25 (43.86)	0.015
ICU PEEP, cm H ₂ O (mean, SD)	5.8 (2.0)	5.5 (1.4)	5.7 (1.9)	0.559
Patient Variables				
Height, m (mean, SD)	1.7 (0.1)	1.78 (0.1)	1.67 (0.1)	<0.001
Weight, kg (mean, SD)	81 (20)	80 (20)	84 (22)	0.364
BMI (mean, SD)	28 (6)	25 (6)	30 (6)	0.001
APACHE-II (mean, SD)	15 (7)	16 (7)	16 (7)	0.945
Hospital days (LOS)	11 (10)	9 (6)	11 (9)	0.242
Total intubation time (h)	95 (124)	51 (53)	88 (101)	0.027
ARDS, <i>n</i> (%)	32 (27.4)	3 (9.7)	12 (20.0)	0.249
Death, <i>n</i> (%)	21 (16)	3(10)	7(12)	0.999

PEEP, positive end-expiratory pressure; ED, emergency department; PBW, predicted body weight; ICU, intensive care unit; BMI, body mass index; APACHE-II, Acute Physiology and Chronic Health Evaluation-II (excluded Glasgow Coma Scale as discussed in text); LOS, length of stay; ARDS, acute respiratory distress syndrome