COCONUT CREEK
BUTTERFLY CAPITAL OF THE WORLD®

September 9, 2021

Broward Regional EMS Council
Broward County
Office of Medical Examiner and Trauma Services
5301 SW 31st Avenue
Fort Lauderdale, Florida 33312

RE: Broward County EMS Grants

Please find the enclosed fully executed EMS-Broward County Grant application for prehospital mechanical ventilators for Coconut Creek Fire Rescue. Coconut Creek Fire Rescue appreciates being part of the EMS grant program and would like to be part of any future grant considerations. If you have any question or concerns, please don't hesitate to contact me at the phone number or email listed below.

Respectfully submitted,

Tony Chin
Division Chief of EMS

954-914-6756
jchin@coconutcreek.net

2022 BROWARD COUNTY EMS GRANT APPLICATION

"Funding to improve or expand prehospital EMS Systems"

Section I

1. **Project Title:** Pre-Hospital Ventilator

   Is this a pilot project? ☐ Yes ■ No

2. **Project Cost $:** $33,749.91

3. **Agency Name:** Coconut Creek Fire Rescue

   Address: 4800 Copans Road, Coconut Creek, FL 33063

   Telephone: 954-543-7101 Fax: jchin@coconutcreek.net

4. **Project Manager:** The individual with direct knowledge of project and responsible for project implementation.

   Name: Tony Chin

   Telephone: 954-914-6756 Email: Jchin@coconutcreek.net

5. **Authorized Signatory:** The individual authorized to sign the application on behalf of the agency or entity.

   Name of Signatory: _____

   Title of Signatory: Division Chief of EMS

6. **Projects Impacting Direct Services to Emergency Victims:** This may include, but is not limited to: vehicles, medical and rescue equipment, communications, dispatch, navigation, and other equipment that impacts on-site treatment. (Countywide projects must offer participation to all licensed EMS providers, based upon levels of service.) Attach Form A.

   Countywide: ☐ Yes ■ No

   Multiple Agencies: ☐ Yes ☐ No How Many? ____

   Single Agency: ■ Yes ☐ No

7. **Projects Impacting Indirect Services:** Training of all types (public, first responders, law enforcement personnel, EMS personnel and other healthcare staff), research, and documentation. (Countywide projects must offer participation to all licensed EMS providers.) Attach Form A.

   Countywide: ☐ Yes ☐ No

   Multiple Agencies: ☐ Yes ☐ No How Many? ____

   Single Agency: ■ Yes ☐ No

8. Problem/Unmet Need Description: Provide a narrative of the problem or need and the population affected by describing the present situation and management (if any) and the potential adverse consequences if not addressed.

During a twenty four hour shift Coconut Creek Fire Rescue (CCFR) units respond to a variety of different emergency medical responses. These responses range from simple public assists to complex medical scenarios. One of the most difficult medical calls that are managed is a cardiac arrest. When paramedics arrive on scene there are several benchmarks that need hit if the patient has any chance of survival care early. The ultimate goal when managing a cardiac arrest is to " restart " the heart, and to maintain adequate spontaneous circulation.

To achieve this, we must provide adequate ambulance resources and paramedics who are able to provide a high quality of professional care early. In the initial stages of cardiac arrest management, after initiating compressions and defibrillation, a basic airway adjunct can be inserted to maintain airway patency. An oropharyngeal or nasopharyngeal airway will suffice in the absence of foreign body airway obstruction until more resources become available and an laryngeal mask airway (LMA) or endotracheal tube (ETT) can be inserted. With a basic airway adjunct in position, 2 ventilations occur after 30 compressions, making a compression to ventilation ratio of 30:2. Ventilations may be provided without pause in compressions when an advanced airway is in place. The BVM is squeezed on the upstroke of CPR, as the thorax is in recoil.

At times during an arrest, the airway may become soiled, with either blood from the trauma of compressions of vomitus from the stomach. At such time, suction should be provided to maintain patency. An ETT may be inserted to adequately secure the airway if not already done so and proper ventilation need to be accomplished in accordance with AHA guidelines and the department's emergency medical protocols.

Current Scenario: This life changing scenario has become more common in Coconut Creek. Once known as a retirement community, population continues growing at a rate of 2% per year over the past 10 years (US Census Bureau). Along with this significant population increase, cardiac arrest calls are increasing as well. CCFR responded to 66 cardiac arrests 2018, 97 in 2019, and in 2020, CCFR responded to 107 cardiac arrests. This combined total not only represents 1% of the City's 61,000 population, but also indicates an increasing trend of cardiac arrest type calls in Coconut Creek, up over a third (%) in the past three years.

Each of these calls are followed by transports to a hospital or resuscitation center. During this critical time, a patient ' s oxygen levels must be maintained for optimum survivability. CCFR requires prehospital ventilators to improve its prehospital emergency medical response to meet the expanding number of transports at current staff levels, while minimizing first responder fatigue and oversights during those high call-volume times of the week.

Supporting Literature: Research shows for optimal outcomes, immediate chest compressions and if appropriate, defibrillation to restart the heart, are essential in the chain of survival. During CPR, airway interventions range from hands only, to mouth-to-mouth, to bag-mask or advanced airway. After return of spontaneous circulation (ROSC), most patients would present with post-cardiac arrest syndrome and/or are comatose with impaired airway reflexes. This condition would mandate establishing an advanced airway to take control of the normal airway to facilitate transportation to the emergency department. Once an advanced air way such as tracheal intubation is established, it is up to the paramedic to deliver an adequate amount of tidal volume to restore depleted oxygen levels and correct tissue hypoxia, while preventing hyperoxia.

Problem: While paramedics are working to restore depleted oxygen levels, they have a human nature to deliver rapid and hard ventilations with a bag valve mask (BVM). Increasing ventilation rate or tidal volume during CPR increases the mean intrathoracic pressure and reduces venous return to the heart, increases lung volume and pulmonary vascular resistance, reduces cardiac output, decreases coronary perfusion and aortic blood pressure. This proposed grant provides a device capable of solving this problem for paramedics, particularly during days with high call-volumes when fatigue becomes a factor.

9. EMS Improvement and Expansion to Resolve Problem or Address Needs: Describe proposed solutions to the problem and/or need (question #8 – problem description). State the improvements that are reasonably foreseeable and measurable. Use data, scientific, or anecdotal information to support the agency's request. Explain how the project will improve and/or expand prehospital EMS in Broward County. Be specific.

Solution: This above problem would be resolved with a device able to deliver a pre-selected rate and tidal volume of oxygen to patients in need of ventilatory assistance. It would remove the human factor from delivering an excessive amount (or not enough) of tidal volume to have adequate chest rise and tissue re-perfusion. This equipment would effectively give CCFR the ability to properly auto-ventilate the increasing number of patients requiring a pre-measured amount of tidal volume for tissue perfusion without increasing intrathoracic pressure.

The proposed device is an Pneupac VR1 Ventilator/Resuscitator. The device is illustrated in the attachment quote and listed in the budget section of this application. This purchase provides for one pre-hospital ventilator for every front-line Advanced Life Support (ALS) apparatus plus one pre-hospital ventilator to be put in service for emergency activations such as hurricanes, large-scale accidents such as on the Sawgrass Expressway/Florida Turnpike, and grand citywide special events such as the July 4th Celebration where hundreds gather during hot/humid days, and utlized at large gathering area's such as the Coconut Creek Casino.

Coconut Creek Fire Rescue has not purchased any pre-hospital positive pressure devices, requiring respiratory support. Therefore, the proposed request improves and expands prehospital EMS in Broward County. The fact that CCFR is without a device for adequate delivery of tidal volume and rate for our residents will have a negative impact on cardiac arrest events, as the number of responses to these calls will likely continue to increase as our trend data suggests.

2022 BROWARD COUNTY EMS GRANT APPLICATION

"Funding to improve or expand prehospital EMS Systems"

10. Measurable Outcomes: Outcomes should be viewed from the perspective of the project and provide for: improved conditions/service - for patients as well as EMS personnel; expanded services; new knowledge; or improved knowledge. **Outcomes must be measurable and attainable. (Attach additional pages, as needed.)**	
A. Project	The purchase and in-service training on pre-hospital ventilators for all paramedics employed with Coconut Creek (CCFR)
B. Activities	Although no match is required for this grant program, CCFR needs this equipment and will provide training funds if this grant is awarded. Training funds are anticipated to be approximately $6480.00, providing more than a 50/50 match for this award.
C. Outcomes	ROSC and pre-hospital survival statics for persons needing pre-hospital ventilators will be cultivated and monitored for improved patient outcomes by in-house Coconut Creek Fire Rescue EMS Division. ROSC is the accepted gold standard bench mark for outcome measurement.
D. Indicators	Training will consist of a ditactic and hands on session and will be documented within Target Solutions training software for one hundred percent compliance.
E. Data Source	Pre and post cardiac arrest data from mycares.org. This data was obtained by Margate Fire Rescue du to the fact the CCFR will assume fire rescue services on October 1st, 2021. After the in service date, CCFR will compile and maintain any data pertaining to the grant.
F. Data Collection Method	Manual excel spread sheet, ESO, mycares.org cardiac outcomes utilizing the Utestein method for cardiac arrest.

11. Project Schedule: Please complete the table below. Insert additional rows if needed.

Months after Grant is Executed	Activity
1	Training site for operation and capabilities
3	Deployment of pre-hospital ventilators on apparatus
3	Monitor training for one hundred percent compliance
4	Evaluate patient outcomes
12	Close out grant

12. Supporting Research or Literature? ☒ Yes (Attachment A) ☐ No
(Required if this is a Pilot Project.)

13. Letters of Support or Reference? ☐ Yes (Attachment B) ☒ No

14. Budget: Do not use brand names when listing items. Use only generic names. Round up/down to the nearest dollar. Please use the table below. Insert additional rows if needed. Do not include extended warranties.

Item	Unit Cost	Quantity	Total
Pneupac VR1 Ventilator/Resuscitator	$3749.99	9	$33,749.91
Delivery charges, if any			
Total			$$33,749.91

15. Future Expenses: Estimate the maintenance or other required recurring expenses per unit after the first grant year (if applicable). Note: No funding will be provided for these expenses under this grant program and must be absorbed by the grant recipient(s). Discuss this issue with your agency as it may affect its budget.

Items	Cost
Training hours (2 hours per paramedic, x 81 = 162 training hours)@$40.00	$6,480

Grant monies cannot be used to replace existing equipment.

TC

Initials of authorized signatory acknowledging the individual understands this statement.

16. **Medical Director Approval:** For all projects requiring approval from the agency's Medical Director in accordance with Chapter 401, Florida Statutes, or Chapter 64J-1, Florida Administrative Code.

The undersigned, as Medical Director for this agency, supports and approves this project.

Signature: _____ Date: 9/13/21

Printed Name: Craig Kushner

17. **Partial Funding:** Will the agency accept partial funding?
(Note: If the agency is awarded partial funding, an amendment to the outcomes and budget forms must be submitted).

☐ Yes, the agency will accept partial funding

☐ No, the agency will not accept partial funding

Signature: _____
(Authorized Signatory)

Printed Name: _____

AGENCY NAME: Coconut Creek Fire Rescue

AUTHORIZED SIGNATORY: _____

DATE: 09/14/2021

PRINT AUTHORIZED SIGNATORY NAME: Jeffery Gary

TITLE: Fire Chief

PROJECT MANAGER'S SIGNATURE: _____

PRINT PROJECT MANAGER'S NAME: TONY CHIN

TITLE: Division Chief EMS

TELEPHONE: 954 914 6756

EMAIL: JCHIN@CoconutCreek.net

If this is a Single Agency Project, this is the last page of the application.

If this is a Multiple Agency/Countywide Project (excluding Countywide training projects), please continue by completing the Participating Agency Summary Sheet (Form A) and Section II for *each* Participating Agency.

Grant Application Submission Deadline:

Wednesday, September 15, 2021 at 3 p.m.

******* Remainder of Page Intentionally Left Blank *******

Form A

Participating Agency Summary Sheet
(Attach a copy of negative responses)

Agency Name	Not Interested	No Response	Quantity Requested
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	

SECTION II
(Complete for ALL "Multiple Agencies" or "Countywide" Projects, EXCLUDING Countywide Training Projects)

Does your agency desire to participate in the grant project?

If No, ignore the remaining questions and return the form to the Project Manager (GRANTEE).

_____
Initials of authorized signatory for Participating Agency

If Yes, complete remaining items and return to:

Project Manager (name) _____

The undersigned Participating Agency _____
(Agency name)
agrees to enter into an ADDENDUM TO BROWARD COUNTY EMS GRANT FUNDING AGREEMENT and acknowledges that it has joined in with the
_____(GRANTEE) on a Project Application for

(Project Title and Summary) _____

_____

_____

_____

as part of the BROWARD COUNTY EMS GRANT FUNDING. The Participating Agency acknowledges that, to be included as a Participating Agency under the agreement between BROWARD COUNTY and GRANTEE for BROWARD COUNTY EMS GRANT FUNDING ("Agreement"), it will be required to agree to the terms and conditions for the funding.

1. Medical Director Approval:

For projects requiring approval from the agency's Medical Director in accordance with Chapter 401, Florida Statutes, or Chapter 64J-1, Florida Administrative Code, the agency's Medical Director must complete the following:

As Medical Director for above Participating Agency, I support and approve this project.

AUTHORIZED SIGNATURE: _____

PRINT NAME: _____ **DATE:** _____

2. Recurring Expenses after the grant year:

The estimate for maintenance or other required expenses per unit after the first grant year, if applicable, are listed below. These costs will be absorbed by the grant recipient(s) (including each Participating Agency) and not paid from grant funds.

Item _____ Cost $ _____

_____ **Initials of authorized signatory for** _____
(Participating Agency)

3. State the number of items requested or Training Participants. _____

4. PARTICIPATING AGENCY AUTHORIZED SIGNATORY:

_____ **DATE:** _____

PRINT NAME: _____

TITLE: _____

5. PARTICIPATING AGENCY PROJECT LEADER SIGNATURE:

_____ **DATE:** _____

PRINT NAME: _____

PARTICIPATING AGENCY PROJECT LEADER TITLE:

_____

EMAIL: _____

6. PROJECT MANAGER (GRANTEE'S RESPONSIBLE AGENT) SIGNATURE:

_____ **DATE:** _____

PRINT NAME: _____

PROJECT MANAGER TITLE: _____

DATE: _____ **TELEPHONE:** _____

EMAIL: _____

Bound Tree
Your Partner in EMS

Pneupac® VR1 Ventilator

Manufacturer: SMITHS MEDICAL ASD, INC.

Your Price:

$3,749.99 EA

List Price: $3,749.99 EA
View Ordering Options

Monthly Usage | View All Specs

Product description:

The Pneupac® VR1 has been designed as a ventilator/resuscitator for medical personnel in the hospital, ambulance, fire, and police services, and also for use in industrial and commercial markets. The nature of the environment in which caregivers have to operate requires the product to work in demanding conditions.

Features:

- Single knob tidal volume/frequency control
- Auto/manual control
- Air mix switch
- Patient demand system
- MRI compatible to 3 tesla
- Patient valve
- Linked manual controls
- Ergonomically designed
- Simplicity
- Safety
- Portability
- Durability

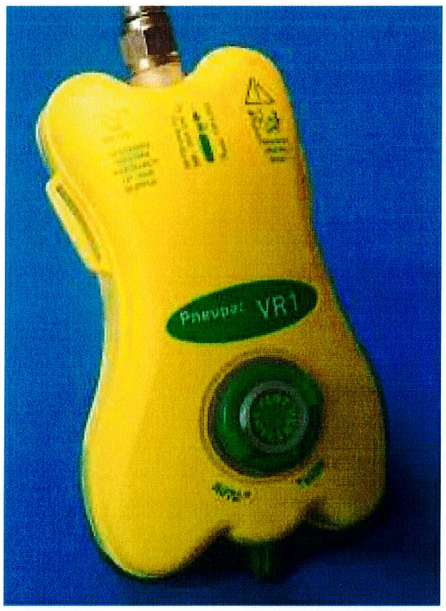
SM520A1125

Add To Supply List

0 Total Items Selected

Add To Cart

Pneupac VR1



Pneupac VR1 has been described as "the best hand-held ventilator in the world".

At Smiths Medical, we conceived, designed, patented, verified, approved, manufactured and launched this brand new range of hand-held, emergency ventilators. The VR1 is used in emergency resuscitation and transport of patients who have respiratory failure. The VR1 has automatic and manually triggered modes and is suitable for adults and children over 10kg and is designed for use in a magnetic resonance imaging (MRI) environment up to 3 Tesla. We also developed a compatible range of patient circuits and accessories such as the chemical, biological, radiation and nuclear (CBRN) circuit, as well as other masks and filters.

The CBRN circuit is used with the VR1 Airmix variant to conserve oxygen supply when operating in a contaminated area in mass toxic casualty scenarios as it allows spontaneous breathing of filtered air should the supply gas fail. A customised, rubber moulding was created to interface to the CBRN canister, as per patent WO2007088330.

Mechanical Ventilation in the Prehospital and Emergency Department Environment

Robert J Stephens, Jeffrey E Siegler, and Brian M Fuller

Patients who require mechanical ventilation in the prehospital and emergency department environments experience high mortality and are at high risk of ventilator-associated ventilator-induced lung injury and ARDS. In addition, little attention has been given in the literature, trainee education, or clinical emphasis to ventilator management in these patients. ARDS and ventilator-induced lung injury are time-sensitive disease processes that develop early in mechanical ventilation and could potentially be prevented with early lung-protective ventilation. Prehospital and emergency department ventilation, in general, is characterized by potentially injurious tidal volume, high F_{IO_2}, and low PEEP. Recent literature highlights improved subjects outcomes in the setting of early lung-protective ventilation in both subjects with and those without ARDS. This review of the literature led us to recommend that lung-protective ventilation with avoidance of hyperoxia be the default goal ventilator strategy for all patients with prehospital and emergency department mechanical ventilation. This can be achieved by delivering low tidal volumes with stepwise, concurrent titration of F_{IO2} and PEEP to facilitate adequate oxygenation. *Key words: mechanical ventilation; prehospital; emergency department; ventilator-associated lung injury; lung-protective ventilation.* [Respir Care 2019;64(5):595–603. © 2019 Daedalus Enterprises]

Introduction

Patients who require mechanical ventilation in the prehospital and emergency department environment experience high mortality and morbidity.[1] Mechanical ventilation can lead to iatrogenic injury via ventilator-induced lung injury as well as hyperoxia. Phenotypically, this usually presents as worsening pulmonary mechanics, pneumonia, and/or ARDS, with the peak incidence occurring

Mr Stephens is affiliated with Washington University School of Medicine in St. Louis, St. Louis, Missouri. Dr Siegler is affiliated with the Section of Emergency Medical Services, Division of Emergency Medicine, Washington University School of Medicine in St. Louis, St. Louis, Missouri. Dr Fuller is affiliated with the Division of Critical Care, Division of Emergency Medicine, Department of Anesthesiology, Washington University School of Medicine in St. Louis, St. Louis, Missouri.

The authors have disclosed no conflicts of interest.

early in the course of mechanical ventilation (ie, day 1 or day 2).[2,3] This suggests that appropriate management of mechanical ventilation immediately after endotracheal intubation is crucial, and emerging evidence has demonstrated a vital role for appropriate ventilator management in the prehospital and emergency department treatment of patients who are critically ill. Compared with the ICU or intraoperative environment, mechanical ventilation in the prehospital and emergency department setting has historically received very little attention in terms of research, trainee education, and clinical emphasis.[4-6] As such, potentially injurious practice patterns are common.[1,7,8]

In this article, we discuss the landscape of mechanical ventilation and advances in scientific understanding in the care of patients with acute respiratory failure in the prehospital and emergency department settings. We provide recommendations for the provision of mechanical ventilation to patients in both of these environments. Although we recognize the importance of airway management and noninvasive positive-pressure ventilation, these topics are outside the scope of this review. In addition, many factors (ie, sedation, fluid administration, transfusions) play a role in the ultimate outcome of patients on mechanical ventilation in the emergency department; this review focused on the delivery of invasive mechanical ventilation.[9,10]

The Concept of Ventilator-Induced Lung Injury as a Time-Sensitive Emergency

Excessive stretch, regional lung overdistention, and repetitive airway opening all play roles in ventilator-induced lung injury and ARDS.[11] Biologic mediators and hyperoxia can contribute to progressive pulmonary dysfunction, multiple organ failure, and death.[12-14] In volutrauma, overdistention of alveoli results in damage to the intercellular junctions and the cellular membranes due to increased strain on pneumocytes.[15] Similarly, barotrauma occurs when pneumocytes are damaged due to an increase in transalveolar pressure or stress. Cyclic recruitment–derecruitment as alveoli collapse between respirations results in atelectrauma, which increases stress at any given pressure due to reduced compliance.[16,17] These forces are especially important in ARDS, when the amount of lung tissue available for gas exchange is reduced, often referred to as a "baby lung."[17-19] Hyperoxia and the resultant reactive oxygen species formation are thought to cause injury both in the lung parenchyma and in sites distal to the pulmonary system.[12,13] Time- and dose-dependent increases in inflammatory markers have been observed in experimental animals that received mechanical ventilation.[20-22]

Before knowledge of the existence of ventilator-induced lung injury, normalization of oxygenation and ventilation was given priority. As such, mechanical ventilation strategies involved the delivery of high tidal volume (V_T) (12–15 mL/kg predicted body weight [PBW]) and low levels of PEEP.[23] Subsequently, seminal work in the field provided strong evidence that the mechanical ventilator can cause harm, as animal and ex vivo models clearly demonstrated the mitigation of lung injury by the application of lung-protective concepts (ie, lower V_T, more-appropriate PEEP).[24-26] Perhaps most important to this review, on prehospital and emergency mechanical ventilation, these effects were observed over the course of only a few hours.[24-26]

Clinical studies that involved subjects without ARDS support this premise.[4,27,28] Data that compared various strategies of lung-protective ventilation versus conventional ventilation during surgery showed that early application of lung protection for comparatively short durations can mitigate pulmonary and systemic inflammation and is associated with a reduction in pulmonary and extrapulmonary complications.[29-31] Similarly, higher driving and plateau pressures among patients in the emergency department were associated with increased progression to ARDS. There was a dose-dependent, stepwise relationship with an increasing incidence of ARDS with increasing driving pressure, plateau pressure, compliance, and mechanical power.[32]

In subjects without ARDS and in the ICU, observational studies,[2,33,34] a small randomized trial,[27] and 2 systematic reviews[4,28] showed an association between higher V_T and increased incidence of ARDS, with a typical peak incidence around ICU day 2. This suggests that initial ventilator dosing influences downstream complications. In addition, in patients with ARDS, delayed delivery of lung-protective ventilation is associated with increased mortality.[35]

Multiple studies have shown that initial ventilator settings, both in the emergency department and the prehospital setting, influence ventilator settings that subjects received in the ICU. These settings remained unchanged in up to 75% of subjects through the first 24 h.[1,2,33,36-38] Similar therapeutic momentum has been documented in other areas of critical care, such as sedation and antibiotic dosing, and may result in prolonged iatrogenic risk.[9,39] Therefore, the most immediate period of care is a potential therapeutic target to increase adherence to best practice. Because mortality in patients in the emergency department and on mechanical ventilation can exceed 30%[1] and can be as high as 50% if ARDS develops,[37] early use of these practices may have the potential to have a large impact on

Correspondence: Robert J Stephens, Division of Emergency Medicine, Washington University School of Medicine in St. Louis, 660 S Euclid Avenue, St. Louis, MO, 63110. email: stephensr@wustl.edu.

DOI: 10.4187/respcare.06888

patient outcome. In sum, ARDS and ventilator-induced lung injury occur early in patients on mechanical ventilation and are time-sensitive processes that benefit from early recognition and treatment.

Prehospital Mechanical Ventilation

The Landscape of Prehospital Ventilation

Prehospital mechanical ventilation is delivered during ~4% of emergency medical service activations annually in the United States.[40] Much of the data about prehospital care of patients who are critically ill comes from the realm of interfacility transport; however, even these data are limited to a few primarily observational studies. The majority of patients (73–83%) receive volume control continuous mandatory ventilation during transport, with a minority receiving pressure control continuous mandatory ventilation or volume control intermittent mandatory ventilation. In a cohort study of subjects with hypoxemic respiratory failure, the mean ± SD F_{IO_2} was high during transport (0.95 ± 0.12), and mean ± SD PEEP was relatively low (9.6 ± 4.7 cm H_2O).[41] The investigators note, however, that F_{IO_2} is often increased preemptively in the prehospital setting to levels higher than would be in the ICU to prevent critical desaturation.[41] The V_T values are often high, with one cohort study that showed that low V_T ventilation occurred in only 14% of subjects on prehospital ventilation.[42]

For the majority of patients who require prehospital ventilation, a transport ventilator is not available and bag-valve-mask is frequently used to provide ventilation, even among patients transported on aeromedical units.[42] Although, to our knowledge, there are no studies that compared patient-centered outcomes and the use of transport ventilators versus bag-valve-masks, one small randomized controlled trial (28 subjects) found that paramedics randomized to use transport ventilators believed that they were better able to perform patient care tasks than paramedics randomized to the use of a bag-valve-mask.[43] In addition, the standard adult bag-valve-mask delivers high-volume, low-PEEP ventilation contrary to current recommendations for lung-protective ventilation.[44] Manual ventilation with bag-valve-masks in simulated resuscitation scenarios has been shown to often deliver with high peak pressures, in certain scenarios that exceeded 100 cm H_2O, even among experienced respiratory therapists.[45] Previous reviews recommend the use of adjustable, disposable PEEP valves when providing ventilation via bag-valve-masks for preoxygenation before intubation.[46] The impact of PEEP valves on patient-centered outcomes in bag-valve-mask ventilation has not been studied, and it is unclear how often they are used in practice.

Emergency medical services providers are trained to ventilate in a way that achieves observable chest rise, yet bag-valve-masks do not provide feedback on the delivered V_T. Pneumotachograph devices are not routinely used or carried by emergency medical services providers. One simulation study demonstrated that the use of a standard pediatric bag-valve-mask resulted in a significantly greater proportion of V_T in the 6–8 mL/kg PBW range than the use of adult bag-valve-masks (17.7% versus 5.1%).[44] Median (interquartile range) V_T delivered via endotracheal tube were also significantly greater when an adult bag-valve-mask (981.5 [901–1085] mL) was used compared with a pediatric bag-valve-mask (663 [615-696] mL).[44] A separate simulation study demonstrated that gripping the bag-valve-mask with fewer fingers, in conjunction with pediatric bag size resulted in an even greater proportion of volumes being in a lung-protective range when compared with an adult bag-valve-mask alone (46.4% versus 0.4%).[47] Analysis of these data indicated that injurious ventilation could occur in patients who receive ventilation via adult bag-valve-masks, although no patient-centered outcomes exist.

Complications Associated With Prehospital Mechanical Ventilation

Critical events (ie, major resuscitative procedure, hemodynamic deterioration, or inadvertent extubation) occur in as many as 1 in 20 aeromedical transports of patients who are critically ill, and the need for mechanical ventilation is independently associated with a 2- to 3-fold increase in risk of critical events during transport.[48,49] Hypoxemic episodes during transport have been reported with relatively high frequency across studies that measured this end point (1.3–28%).[48,50] Despite these risks, transfers of patients to facilities with higher levels of care are generally considered safe and deaths during transport are relatively rare, having occurred in 0.0–0.1% of transports described in the literature.[41,48,51]

Hypocapnia secondary to hyperventilation also occurs frequently during prehospital ventilation. This has been most commonly documented among patients with traumatic brain injury and occurred in up to 79% of patients.[52,53] Prehospital hyperventilation and the resulting hypocapnia are associated with poor outcomes, including worsened mortality in multiple analyses.[54-56] The major mechanism of this injury is believed to be decreased cerebral blood flow and vasoconstriction that causes ischemia in cerebral tissue.[54-57] Use of prehospital quantitative end-tidal capnometry to avoid unintentional hypocapnia has been associated with a decreased incidence of hyperventilation.[58]

Clinical Impact of Prehospital Ventilatory Care

Changing transport practices have impacted the clinical course of prehospital patients. In particular, dedicated critical-care transportation teams can provide a similar level of care as an ICU. Patients treated by these teams experience fewer critical events than those treated by advanced life support paramedics.[48] Across multiple studies, critical-care transport teams with training in complex ventilator management are associated with improved P_{aO_2} after transfer from outside facilities in patients with hypoxic respiratory failure.[41,50,51] Wilcox et al[41] describe a cohort in which high rates of neuromuscular blockade were observed; 58 subjects (43.3%) received initial neuromuscular blockade from the critical care transport team. The transporting team changed ventilator settings during transport in 89% of the subjects, most commonly decreasing V_T (35.9% of subjects), increasing PEEP (29.1%), and increasing F_{IO_2} (30.1%).[41] These changes were associated with increases in P_{aO_2} on arrival at the receiving facility.[41] Increasing F_{IO_2} and PEEP, and administration of neuromuscular blockade were most strongly associated with increased P_{aO_2} after transport. In addition, ventilator changes were associated with reduced peak inspiratory pressure and trended toward reduced plateau pressures. Prehospital mechanical ventilation management not only influences oxygenation and critical events during transport but may also carry downstream effects as well. V_T provided by prehospital aeromedical crews have been shown to influence initial hospital V_T, both in the emergency department and ICU.[42]

Emergency Department Ventilation

Landscape of Mechanical Ventilation Provided in the Emergency Department

Conservative estimates show that, in the United States, 250,000 patients are on mechanical ventilation in the emergency department annually.[59] This rate is increasing,[60,61] along with overcrowding and emergency department boarding of patients who are critically ill.[62,63] A survey of emergency department directors revealed that >90% of emergency departments report problems with crowding and that daily crowding occurred in 39% of emergency departments, which resulted in delayed care and diagnosis in almost 40% of the patients.[64] Crowding and prolonged boarding is associated with worsened mortality and prolonged mechanical ventilation duration.[61,65-67] Increased duration of mechanical ventilation in the emergency department has been independently associated with increased mortality.[67]

Until recently, mechanical ventilation in the emergency department has received little attention in the literature outside of initial airway management.[4] Survey studies showed that emergency physicians and trainees are often uncomfortable with ventilator management,[5,6] and multiple studies showed that potentially injurious ventilation is commonly delivered in the emergency department.[1,8,38] Volume control continuous mandatory ventilation is the most common mode of mechanical ventilation used in the emergency department (65–90% of patients).[1,8,68] Analysis of the observational data from the emergency department showed that subjects received mean levels of PEEP of ~5 cm H_2O and high F_{IO_2}.[1,8] A single-center study demonstrated median (interquartile range) emergency department V_T to be 8.8 (7.8–10.0) mL/kg PBW and that lung-protective ventilation was delivered in only 27.1% of the subjects.[1]

Similar findings were observed in a multi-center study. Although a greater proportion of subjects in this cohort received lung-protective ventilation (55.7%), 11.4% still received V_T of >10 mL/kg PBW.[8] In a cohort at a different network of centers described by Wilcox et al,[68] approximately half of the subjects received ventilation with both F_{IO_2} of 1.0 and PEEP of ≤5 cm H_2O, and nearly 40% of the subjects received nonprotective ventilation. The median F_{IO_2} in this cohort was 1.0, and the median PEEP was 5 cm H_2O. Patients often receive prolonged exposure to both high V_T values (median V_T = 230 [0-320] min) and high F_{IO_2} (median V_T = 251 [148-373] min) while in the emergency department.[7] Initial ventilator settings remain static in up to 78% of subjects in the emergency department for the duration of ventilation, which suggested that the historical practice of ventilator management in the emergency department did not involve active titration of settings.[1,67,68]

Clinical Impact of Mechanical Ventilation in the Emergency Department

As demonstrated by several cohort studies, the historical approach to mechanical ventilation in the emergency department involved the following: (1) relatively high V_T; (2) PEEP of 5 cm H_2O; (3) F_{IO_2} of 1.0; and (4) the delivery of mechanical ventilation in the supine, flat position.[1,8,68] The LOV-ED (Lung-Protective Ventilation Initiated in the Emergency Department) trial was designed to target these practice patterns through a quality-improvement initiative with protocolized dosing of V_T, PEEP, F_{IO_2}, and head of bed elevation for subjects in the emergency department who are on mechanical ventilation.[36,69] This protocol was largely driven by respiratory therapists who measured accurate heights in all subjects to effectively implement lung-protective V_T based on PBW and titrated F_{IO_2} and PEEP to maintain adequate oxygenation.[36,69] The protocol that was used clinically is displayed in Figure 1. This protocol was effectively implemented, with a significant increase in lung-protective ventilation from 48.2% in the pre-intervention

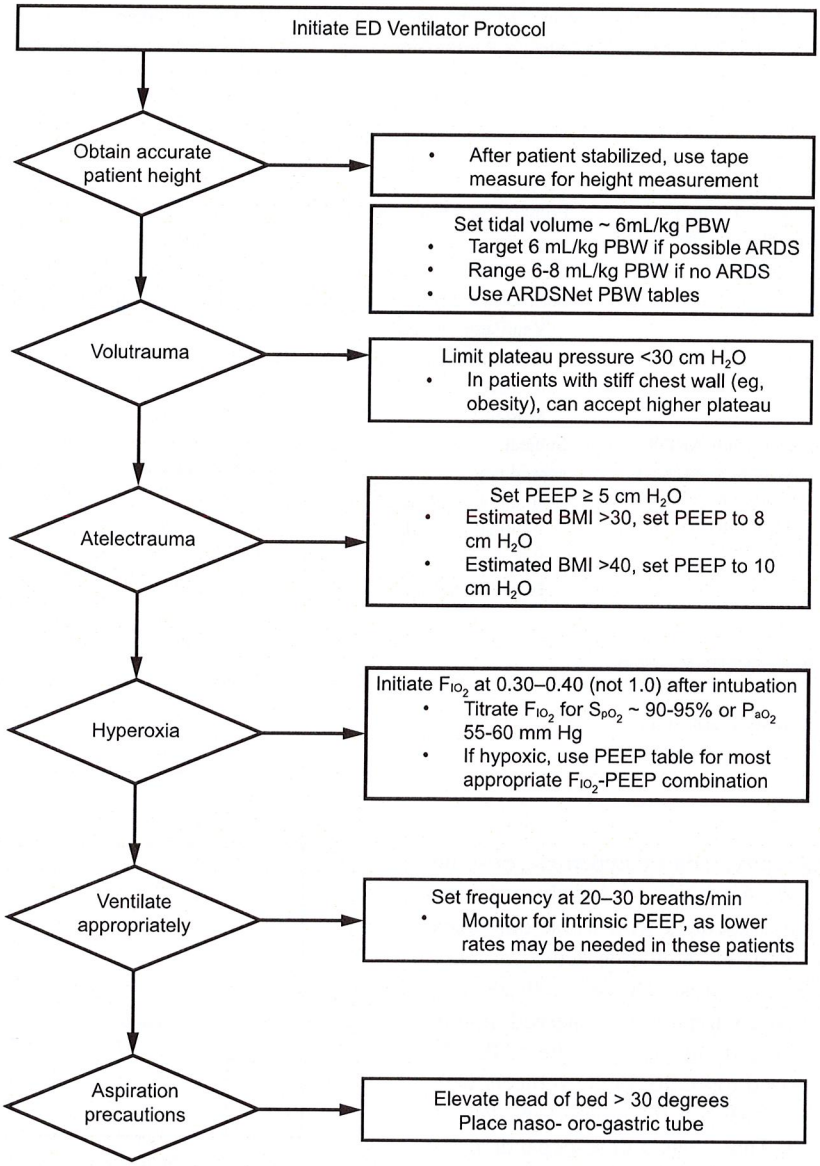


Fig. 1. Emergency department ventilator protocol. ED = emergency department; PBW = predicted body weight. From Reference 36, with permission.

cohort to 96.2% in the intervention cohort. Among subjects without ARDS, the post-intervention cohort received lower median dosing of F_{IO_2} (median (IQR), 0.4 [0.4–0.6] versus 0.80 [0.5–1.0]) and V_T (8.1 [7.3–9.1] mL/kg PBW versus 6.3 [6.0–6.7] mL/kg PBW).[36]

The LOV-ED protocol was associated with a reduction in mortality from 34.1% to 19.6% and a reduction in pulmonary complications (composite outcome of ARDS and ventilator-associated conditions) from 14.5% to 7.4%. In addition, ventilator, ICU, and hospital-free days were greater among the subjects who received protocolized lung-protective ventilation while in the emergency department, with mean differences of 3.7, 95% CI 2.3–5.1 d; 2.4, 95% CI 1.0–3.7 d; and 2.4, 1.2–3.6 d, respectively.[36] Similar results were seen in the subjects with ARDS. Receipt of the emergency department–based lung-protective intervention was the only predictor of subjects with ARDS ever receiving lung protection in the ICU and was associated with a mortality reduction from 54.8% to 39.5% and with an increase in ventilator-free days from 7.7 to 11.6.[37] Results of both studies are detailed in Table 1.

Although analysis of these data indicated that emergency department lung-protective ventilation is associated with improved patient outcome, it is unclear whether the observed clinical benefit was secondary to mitigation of

Table 1. Outcomes of Before-After Studies That Implemented Lung Protective Ventilation in the Emergency Department

Study	Patients	Outcome	Pre-Intervention Group*	Intervention Group*	Adjusted Odds Ratio or Between-Group Difference, 95% CI
Fuller et al,[36] 2017†	Subjects without ARDS and who were on mechanical ventilation	Subjects	490	490	
		Primary composite outcomes‡	71 (14.5)	36 (7.4)	0.47, 0.31–0.71
		ARDS	53 (10.8)	20 (4.1)	0.35, 0.21–0.60
		VAC	37 (7.6)	23 (4.7)	0.60, 0.35–1.03
		Secondary outcomes			
		Ventilator-free days	14.7 ± 11.7	18.4 ± 10.4	3.7, 2.3–5.1
		Hospital-free days	9.4 ± 9.5	11.7 ± 9.2	2.4, 1.2–3.6
		ICU-free days	13.6 ± 11.1	16.0 ± 9.9	2.4, 1.0–3.7
		Mortality	167 (34.1)	96 (19.6)	0.47, 0.35–0.63
Fuller et al,[37] 2017	Subjects with ARDS (onset in emergency department or ICU) and on mechanical ventilation	Subjects	186	43	
		Mortality§	102 (54.8)	17 (39.5)	0.36, 0.16–0.82
		Secondary outcomes			
		Ventilator-free days	7.7 ± 9.9	11.6 ± 10.8	4.0, 0.6–7.3
		ICU-free days	7.2 ± 9.4	9.1 ± 9.2	1.9, −1.2 to 5.0
		Hospital-free days	4.0 ± 6.3	5.7 ± 7.7	1.6, −0.9 to 4.2

* Data are mean ± SD or *n* (%).
† Outcomes are reported from a propensity score-matched analysis.[36]
‡ The primary outcome was a composite of the event rate of VAC and ARDS, which represent patient-centered pulmonary complications; primary outcome and mortality were evaluated by using a logistic regression model.
§ Mortality was evaluated by using a logistic regression model.
VAC = ventilator-associated conditions

ventilator-induced lung injury, reduced hyperoxia, or some therapeutic combination. Analysis of the clinical data showed that hyperoxia is associated with worse outcomes across a wide range of patients, including acute coronary syndrome and after cardiac arrest. However, these data had largely been limited to hyperoxia observed in the ICU.[70,71] An a priori planned substudy[7] of the LOV-ED trial demonstrated increased mortality in the subjects with hyperoxia (P_{aO_2} >120 mm Hg) in the emergency department (29.7% vs 19.4%). There was a dose-dependent relationship between increasing ranges of hyperoxia and observed mortality as well (Fig. 2). Although clinicians recognize the negative impacts of hyperoxia, this typically is not reflected in their oxygen administration patterns.[72,73] As such, hyperoxia is common in patients on mechanical ventilation in the ICU and the emergency department, and a possible target for improved outcomes.[7,72]

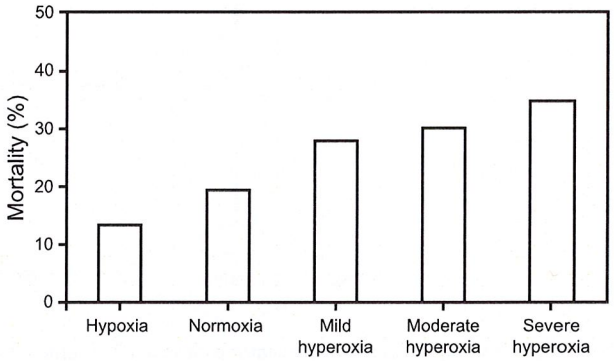


Fig. 2. Mortality across oxygenation subgroups. Hypoxia, P_{aO_2} < 60 mm Hg; normoxia, P_{aO_2} 60–120 mm Hg; mild hyperoxia, P_{aO_2} 121–200 mm Hg; moderate hyperoxia, P_{aO_2} 201–300 mm Hg; severe hyperoxia, P_{aO_2} >300 mm Hg. From Reference 7, with permission.

Summary and Recommendations

As demonstrated in this review, mechanical ventilation in the prehospital and emergency department settings (1) influences how the ventilator is managed after ICU admission, and (2) impacts patient outcome. Providers in these arenas, therefore, should strive to achieve the most-appropriate and safe ventilator settings on an individual patient level. Interfacility transfer of patients who are hypoxemic to higher levels of care (ie, a facility with extracorporeal membrane oxygenation capability) is feasible and safe, despite risks of deterioration and desaturation to the patient. In the prehospital environment, strong consideration should be given to avoidance of adult bag-valve-masks in all patients to avoid the dangers of hyperventilation and hypocapnia as well as the delivery of unnecessarily large V_T values. When possible, a transport ventilator should be used or the adult bag-valve-mask should be replaced with a pediatric-sized bag-valve-mask to minimize delivery of V_T that exceed

lung-protective ventilation targets.[44] Hypocapnia can be avoided by titration of ventilation based on end-tidal capnometry to reduce the risk of hyperventilation. Despite a paucity of patient-centered outcome data, we agree with previous recommendations to use a disposable, adjustable PEEP valve when providing bag-mask ventilation, titrating PEEP dosing to patient oxygen saturation.

For the vast majority of patients who receive mechanical ventilation in the prehospital or emergency department setting, we recommend that lung-protective V_T (6–8 mL/kg PBW) be the default approach. It should also be noted that data from large academic medical centers demonstrated that ~8% of patients on mechanical ventilation in the emergency department have acute lung injury.[3,74] Therefore, dosing V_T closer to the 6 mL/kg PBW end of the range as an initial approach may serve to improve the outcome in this cohort. To avoid hyperoxia, as opposed to the traditional approach of administering F_{IO_2} of 1.0 at the initiation of mechanical ventilation, we recommend starting at 0.3–0.4 and only titrating up when needed, and in combination with PEEP. To streamline care, we recommend bundled ventilator protocols to help achieve implementation of best practices, and recommend a team approach, with heavy involvement from respiratory therapy. The lung-protective ventilation protocol used successfully in the LOV-ED study is displayed in Figure 1.

Although we recommend the effective implementation of protocols to reduce the unnecessary practice variability that surrounds postintubation mechanical ventilation, this does not replace the clinical decision making at the bedside with respect to dynamic ventilator adjustments. The implementation of a lung-protective ventilation protocol has proven safe and feasible, and is associated with improved outcome in patients on mechanical ventilation. However, it is not appropriate for all patients with acute respiratory failure (ie, life-threatening acidemia, expiratory flow limitation, and intrinsic PEEP [asthma, COPD]).[75,76] Although high minute ventilation is often used to reduce P_{aCO_2} transiently in the setting of acute brain herniation, maintenance of normocapnia is recommended in patients with brain injury.[77]

Protocols in patients with and without ARDS allow for set frequency adjustments up to 30–35 breaths/min[36,78]; In most patients, this does not result in clinically important increases in intrinsic PEEP and can typically maintain normocapnia.[79] This method has been shown to be safe in patients with brain injury and gives providers the flexibility to titrate ventilation to achieve appropriate P_{aCO_2} levels while providing lung-protective V_T.[80] Further, lung-protective ventilation in the setting of brain injury is well tolerated physiologically and is associated with improved outcomes.[81] Therefore, the presence of brain injury should NOT preclude clinicians from attempting to use lung-protective ventilation. Finally, among the most important findings of this review was that there is a relative paucity of literature in the realm of prehospital and emergency ventilation. Given the importance of this topic, we believe that this is an area that is ripe for further study.

REFERENCES

1. Fuller BM, Mohr NM, Dettmer M, Kennedy S, Cullison K, Bavolek R, et al. Mechanical ventilation and acute lung injury in emergency department patients with severe sepsis and septic shock: an observational study. Acad Emerg Med 2013;20(7):659-669.
2. Gajic O, Frutos-Vivar F, Esteban A, Hubmayr RD, Anzueto A. Ventilator settings as a risk factor for acute respiratory distress syndrome in mechanically ventilated patients. Intensive Care Med 2005; 31(7):922-926.
3. Hou PC, Elie-Turenne MC, Mitani A, Barry JM, Kao EY, Cohen JE, et al.; US Critical Illness and Injury Trials Group: Lung Injury Prevention Study Investigators (USCIITG-LIPS 1). Towards prevention of acute lung injury: frequency and outcomes of emergency department patients at-risk: a multicenter cohort study. Int J Emerg Med 2012;5(1):22.
4. Fuller BM, Mohr NM, Drewry AM, Carpenter CR. Lower tidal volume at initiation of mechanical ventilation may reduce progression to acute respiratory distress syndrome: a systematic review. Crit Care 2013;17(1):R11.
5. Wilcox SR, Seigel TA, Strout TD, Schneider JI, Mitchell PM, Marcolini EG, et al. Emergency medicine residents' knowledge of mechanical ventilation. J Emerg Med 2015;48(4):481-491.
6. Wilcox SR, Strout TD, Schneider JI, Mitchell PM, Smith J, Lutfy-Clayton L, et al. Academic emergency medicine physicians' knowledge of mechanical ventilation. West J Emerg Med 2016;17(3):271-279.
7. Page D, Ablordeppey E, Wessman BT, Mohr NM, Trzeciak S, Kollef MH, et al. Emergency department hyperoxia is associated with increased mortality in mechanically ventilated patients: a cohort study. Crit Care 2018;22(1):9.
8. Fuller BM, Mohr NM, Miller CN, Deitchman AR, Levine BJ, Castagno N, et al. Mechanical ventilation and ARDS in the ED: a multicenter, observational, prospective, cross-sectional study. Chest 2015; 148(2):365-374.
9. Stephens RJ, Ablordeppey E, Drewry AM, Palmer C, Wessman BT, Mohr NM, et al. Analgosedation practices and the impact of sedation depth on clinical outcomes among patients requiring mechanical ventilation in the emergency department: a cohort study. Chest 2017; 152(5):963-971.
10. Bhat R, Goyal M, Graf S, Bhooshan A, Teferra E, Dubin J, Frohna B. Impact of post-intubation interventions on mortality in patients boarding in the emergency department. West J Emerg Med 2014; 15(6):708-711.
11. Slutsky AS, Ranieri VM. Ventilator-induced lung injury. N Engl J Med 2013;369(22):2126-2136.
12. Al Ghouleh I, Khoo NK, Knaus UG, Griendling KK, Touyz RM, Thannickal VJ, et al. Oxidases and peroxidases in cardiovascular and lung disease: new concepts in reactive oxygen species signaling. Free Radic Biol Med 2011;51(7):1271-1288.
13. Becker LB. New concepts in reactive oxygen species and cardiovascular reperfusion physiology. Cardiovasc Res 2004;61(3):461-470.
14. Ranieri VM, Suter PM, Tortorella C, De Tullio R, Dayer JM, Brienza A, et al. Effect of mechanical ventilation on inflammatory mediators in patients with acute respiratory distress syndrome: a randomized controlled trial. JAMA 1999;282(1):54-61.

15. Protti A, Cressoni M, Santini A, Langer T, Mietto C, Febres D, et al. Lung stress and strain during mechanical ventilation: any safe threshold? Am J Respir Crit Care Med 2011;183(10):1354-1362.
16. Protti A, Andreis DT, Milesi M, Iapichino GE, Monti M, Comini B, et al. Lung anatomy, energy load, and ventilator-induced lung injury. Intensive Care Med Exp 2015;3(1):34.
17. Cressoni M, Cadringher P, Chiurazzi C, Amini M, Gallazzi E, Marino A, et al. Lung inhomogeneity in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2014;189(2):149-158.
18. Gattinoni L, Marini JJ, Pesenti A, Quintel M, Mancebo J, Brochard L. The "baby lung" became an adult. Intensive Care Med 2016; 42(5):663-673.
19. Gattinoni L, Pesenti A. The concept of "baby lung". Intensive Care Med 2005;31(6):776-784.
20. Helmerhorst HJF, Schouten LRA, Wagenaar GTM, Juffermans NP, Roelofs JJTH, Schultz MJ, et al. Hyperoxia provokes a time- and dose-dependent inflammatory response in mechanically ventilated mice, irrespective of tidal volumes. Intensive Care Med Exp 2017; 5(1):27.
21. Cavassani SS, Junqueira VB, Moraes JB, Luzo KK, Silva CM, Barros M, et al. Short courses of mechanical ventilation with high-O2 levels in elderly rat lungs. Acta Cir Bras 2011;26(2):107-113.
22. Li LF, Liao SK, Ko YS, Lee CH, Quinn DA. Hyperoxia increases ventilator-induced lung injury via mitogen-activated protein kinases: a prospective, controlled animal experiment. Crit Care 2007;11(1): R25.
23. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult. 1. N Engl J Med 1972;287(14):690-698.
24. Dreyfuss D, Soler P, Basset G, Saumon G. High inflation pressure pulmonary edema. Respective effects of high airway pressure, high tidal volume, and positive end-expiratory pressure. Am Rev Respir Dis 1988;137(5):1159-1164.
25. Webb HH, Tierney DF. Experimental pulmonary edema due to intermittent positive pressure ventilation with high inflation pressures. Protection by positive end-expiratory pressure. Am Rev Respir Dis 1974;110(5):556-565.
26. Muscedere JG, Mullen JB, Gan K, Slutsky AS. Tidal ventilation at low airway pressures can augment lung injury. Am J Respir Crit Care Med 1994;149(5):1327-1334.
27. Determann RM, Royakkers A, Wolthuis EK, Vlaar AP, Choi G, Paulus F, et al. Ventilation with lower tidal volumes as compared with conventional tidal volumes for patients without acute lung injury: a preventive randomized controlled trial. Crit Care 2010;14(1): R1.
28. Serpa Neto A, Cardoso SO, Manetta JA, Pereira VG, Espósito DC, Pasqualucci Mde O, et al. Association between use of lung-protective ventilation with lower tidal volumes and clinical outcomes among patients without acute respiratory distress syndrome: a meta-analysis. JAMA 2012;308(16):1651-1659.
29. Futier E, Constantin JM, Paugam-Burtz C, Pascal J, Eurin M, Neuschwander A, et al.; IMPROVE Study Group. A trial of intraoperative low-tidal-volume ventilation in abdominal surgery. N Engl J Med 2013;369(5):428-437.
30. Licker M, Diaper J, Villiger Y, Spiliopoulos A, Licker V, Robert J, Tschopp JM. Impact of intraoperative lung-protective interventions in patients undergoing lung cancer surgery. Crit Care 2009;13(2): R41.
31. Michelet P, D'Journo XB, Roch A, Doddoli C, Marin V, Papazian L, et al. Protective ventilation influences systemic inflammation after esophagectomy: a randomized controlled study. Anesthesiology 2006; 105(5):911-919.
32. Fuller BM, Page D, Stephens RJ, Roberts BW, Drewry AM, Ablordeppey E, et al. Pulmonary mechanics and mortality in mechanically ventilated patients without acute respiratory distress syndrome: a cohort study. Shock 2018;49(3):311-316.
33. Gajic O, Dara SI, Mendez JL, Adesanya AO, Festic E, Caples SM, et al. Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation. Crit Care Med 2004; 32(9):1817-1824.
34. Yilmaz M, Keegan MT, Iscimen R, Afessa B, Buck CF, Hubmayr RD, et al. Toward the prevention of acute lung injury: protocol-guided limitation of large tidal volume ventilation and inappropriate transfusion. Crit Care Med 2007;35(7):1660-1666, quiz 1667.
35. Needham DM, Yang T, Dinglas VD, Mendez-Tellez PA, Shanholtz C, Sevransky JE, et al. Timing of low tidal volume ventilation and intensive care unit mortality in acute respiratory distress syndrome. A prospective cohort study. Am J Respir Crit Care Med 2015;191(2): 177-185.
36. Fuller BM, Ferguson IT, Mohr NM, Drewry AM, Palmer C, Wessman BT, et al. Lung-Protective Ventilation Initiated in the Emergency Department (LOV-ED): a quasi-experimental, before-after trial. Ann Emerg Med 2017;70(3):406-418.e4.
37. Fuller BM, Ferguson IT, Mohr NM, Drewry AM, Palmer C, Wessman BT, et al. A quasi-experimental, before-after trial examining the impact of an emergency department mechanical ventilator protocol on clinical outcomes and lung-protective ventilation in acute respiratory distress syndrome. Crit Care Med 2017;45(4):645-652.
38. Sjoding MW, Gong MN, Haas CF, Iwashyna TJ. Evaluating delivery of low tidal volume ventilation in six ICUs using electronic health record data. Crit Care Med 2019;47(1):56-61.
39. Fuller BM, Mohr N, Skrupky L, Mueller K, McCammon C. Emergency department vancomycin use: Dosing practices and associated outcomes. J Emerg Med 2013;44(5):910-918.
40. Wang HE, Mann NC, Mears G, Jacobson K, Yealy DM. Out-of-hospital airway management in the United States. Resuscitation 2011; 82(4):378-385.
41. Wilcox SR, Saia MS, Waden H, Frakes M, Wedel SK, Richards JB. Mechanical ventilation in critical care transport. Air Med J 2016; 35(3):161-165.
42. Stoltze AJ, Wong TS, Harland KK, Ahmed A, Fuller BM, Mohr NM. Prehospital tidal volume influences hospital tidal volume: a cohort study. J Crit Care 2015;30(3):495-501.
43. Weiss SJ, Ernst AA, Jones R, Ong M, Filbrun T, Augustin C, et al. Automatic transport ventilator versus bag valve in the EMS setting: a prospective, randomized trial. South Med J 2005;98(10):970-976.
44. Siegler J, Kroll M, Wojcik S, Moy HP. Can EMS providers provide appropriate tidal volumes in a simulated adult-sized patient with a pediatric-sized bag-valve-mask? Prehosp Emerg Care 2017;21(1): 74-78.
45. Turki M, Young MP, Wagers SS, Bates JH. Peak pressures during manual ventilation. Respir Care 2005;50(3):340-344.
46. Weingart SD, Levitan RM. Preoxygenation and prevention of desaturation during emergency airway management. Ann Emerg Med 2012;59(3):165-175.e1.
47. Kroll M, Das J, Siegler J. Can altering grip technique and bag size optimize volume delivered with bag-valve-mask by emergency medical service providers? Prehosp Emerg Care 2019;23(2):210-214.
48. Singh JM, MacDonald RD, Ahghari M. Critical events during land-based interfacility transport. Ann Emerg Med 2014;64(1):9-15.e2.
49. Singh JM, MacDonald RD, Bronskill SE, Schull MJ. Incidence and predictors of critical events during urgent air-medical transport. CMAJ 2009;181(9):579-584.
50. Wilcox SR, Saia MS, Waden H, Genthon A, Gates JD, Cocchi MN, et al. Improved oxygenation after transport in patients with hypoxemic respiratory failure. Air Med J 2015;34(6):369-376.
51. Uusaro A, Parviainen I, Takala J, Ruokonen E. Safe long-distance interhospital ground transfer of critically ill patients with acute se-

vere unstable respiratory and circulatory failure. Intensive Care Med 2002;28(8):1122-1125.
52. Davis DP, Heister R, Poste JC, Hoyt DB, Ochs M, Dunford JV. Ventilation patterns in patients with severe traumatic brain injury following paramedic rapid sequence intubation. Neurocrit Care 2005; 2(2):165-171.
53. Helm M, Hauke J, Lampl L. A prospective study of the quality of pre-hospital emergency ventilation in patients with severe head injury. Br J Anaesth 2002;88(3):345-349.
54. Davis DP, Dunford JV, Poste JC, Ochs M, Holbrook T, Fortlage D, et al. The impact of hypoxia and hyperventilation on outcome after paramedic rapid sequence intubation of severely head-injured patients. J Trauma 2004;57(1):1-8, discussion 8-10.
55. Dumont TM, Visioni AJ, Rughani AI, Tranmer BI, Crookes B. Inappropriate prehospital ventilation in severe traumatic brain injury increases in-hospital mortality. J Neurotrauma 2010;27(7):1233-1241.
56. Warner KJ, Cuschieri J, Copass MK, Jurkovich GJ, Bulger EM. The impact of prehospital ventilation on outcome after severe traumatic brain injury. J Trauma 2007;62(6):1330-1336, discussion 1336-1338.
57. Roberts BW, Karagiannis P, Coletta M, Kilgannon JH, Chansky ME, Trzeciak S. Effects of P_{aCO_2} derangements on clinical outcomes after cerebral injury: a systematic review. Resuscitation 2015;91:32-41.
58. Davis DP, Dunford JV, Ochs M, Park K, Hoyt DB. The use of quantitative end-tidal capnometry to avoid inadvertent severe hyperventilation in patients with head injury after paramedic rapid sequence intubation. J Trauma 2004;56(4):808-814.
59. Easter BD, Fischer C, Fisher J. The use of mechanical ventilation in the ED. Am J Emerg Med 2012;30(7):1183-1188.
60. Needham DM, Bronskill SE, Calinawan JR, Sibbald WJ, Pronovost PJ, Laupacis A. Projected incidence of mechanical ventilation in Ontario to 2026: preparing for the aging baby boomers. Crit Care Med 2005;33(3):574-579.
61. Singer AJ, Thode HC Jr, Viccellio P, Pines JM. The association between length of emergency department boarding and mortality. Acad Emerg Med 2011;18(12):1324-1329.
62. Mullins PM, Goyal M, Pines JM. National growth in intensive care unit admissions from emergency departments in the United States from 2002 to 2009. Acad Emerg Med 2013;20(5):479-486.
63. Cowan RM, Trzeciak S. Clinical review: emergency department overcrowding and the potential impact on the critically ill. Crit Care 2005;9(3):291-295.
64. Derlet R, Richards J, Kravitz R. Frequent overcrowding in U.S. emergency departments. Acad Emerg Med 2001;8(2):151-155.
65. Al-Qahtani S, Alsultan A, Haddad S, Alsaawi A, Alshehri M, Alsolamy S, et al. The association of duration of boarding in the emergency room and the outcome of patients admitted to the intensive care unit. BMC Emerg Med 2017;17(1):34.
66. Cardoso LT, Grion CM, Matsuo T, Anami EH, Kauss IA, Seko L, Bonametti AM. Impact of delayed admission to intensive care units on mortality of critically ill patients: a cohort study. Crit Care 2011; 15(1):R28.
67. Angotti LB, Richards JB, Fisher DF, Sankoff JD, Seigel TA, Al Ashry HS, Wilcox SR. Duration of mechanical ventilation in the emergency department. West J Emerg Med 2017;18(5):972-979.
68. Wilcox SR, Richards JB, Fisher DF, Sankoff J, Seigel TA. Initial mechanical ventilator settings and lung protective ventilation in the ED. Am J Emerg Med 2016;34(8):1446-1451.
69. Fuller BM, Ferguson I, Mohr NM, Stephens RJ, Briscoe CC, Kolomiets AA, et al. Lung-protective ventilation initiated in the emergency department (LOV-ED): a study protocol for a quasi-experimental, before-after trial aimed at reducing pulmonary complications. BMJ Open 2016;6(4):e010991.
70. Kilgannon JH, Jones AE, Shapiro NI, Angelos MG, Milcarek B, Hunter K, et al.; Emergency Medicine Shock Research Network (EMShockNet) Investigators Association between arterial hyperoxia following resuscitation from cardiac arrest and in-hospital mortality. JAMA 2010;303(21):2165-2171.
71. de Jonge E, Peelen L, Keijzers PJ, Joore H, de Lange D, van der Voort PH, et al. Association between administered oxygen, arterial partial oxygen pressure and mortality in mechanically ventilated intensive care unit patients. Crit Care 2008;12(6):R156.
72. Helmerhorst HJ, Schultz MJ, van der Voort PH, Bosman RJ, Juffermans NP, de Jonge E, et al. Self-reported attitudes versus actual practice of oxygen therapy by ICU physicians and nurses. Ann Intensive Care 2014;4:23.
73. de Graaff AE, Dongelmans DA, Binnekade JM, de Jonge E. Clinicians' response to hyperoxia in ventilated patients in a Dutch ICU depends on the level of F_{IO_2}. Intensive Care Med 2011;37(1):46-51.
74. Goyal M, Houseman D, Johnson NJ, Christie J, Mikkelsen ME, Gaieski DF. Prevalence of acute lung injury among medical patients in the emergency department. Acad Emerg Med 2012;19(9):E1011-1018.
75. Stather DR, Stewart TE. Clinical review: mechanical ventilation in severe asthma. Crit Care 2005;9(6):581-587.
76. Leatherman JW, McArthur C, Shapiro RS. Effect of prolongation of expiratory time on dynamic hyperinflation in mechanically ventilated patients with severe asthma. Crit Care Med 2004;32(7):1542-1545.
77. Asehnoune K, Roquilly A, Cinotti R. Respiratory management in patients with severe brain injury. Crit Care 2018;22(1):76.
78. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, Morris A, Schoenfeld D, Thompson BT, Wheeler A. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000;342(18):1301-1308.
79. Hough CL, Kallet RH, Ranieri VM, Rubenfeld GD, Luce JM, Hudson LD. Intrinsic positive end-expiratory pressure in Acute Respiratory Distress Syndrome (ARDS) network subjects. Crit Care Med 2005;33(3):527-532.
80. Asehnoune K, Mrozek S, Perrigault PF, Seguin P, Dahyot-Fizelier C, Lasocki S, et al.; BI-VILI study group. A multi-faceted strategy to reduce ventilation-associated mortality in brain-injured patients. The BI-VILI project: a nationwide quality improvement project. Intensive Care Med 2017;43(7):957-970.
81. Roquilly A, Cinotti R, Jaber S, Vourc'h M, Pengam F, Mahe PJ, et al. Implementation of an evidence-based extubation readiness bundle in 499 brain-injured patients. a before-after evaluation of a quality improvement project. Am J Respir Crit Care Med 2013;188(8): 958-966.

Homeland Security
Science and Technology

Summary

U.S. Department of Homeland Security
SAVER
System Assessment and Validation for Emergency Responders

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions.

Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective assessments and validations on commercial equipment and systems, and provides those results along with other relevant equipment information to the emergency responder community in an operationally useful form. SAVER provides information on equipment that falls within the categories listed in the DHS Authorized Equipment List (AEL).

The SAVER Program is supported by a network of technical agents who perform assessment and validation activities. Further, SAVER focuses primarily on two main questions for the emergency responder community: "What equipment is available?" and "How does it perform?"

For more information on this and other technologies, contact the SAVER Program Support Office.

RKB/SAVER Telephone: 877-336-2752
E-mail: saver@hq.dhs.gov
Website: https://www.rkb.us/saver

Pre-Hospital Ventilators

(AEL reference number 09ME-02-VENT)

Ventilators are positive pressure devices that deliver regulated volumes of air and supplemental oxygen to patients requiring respiratory support. The concentration of air and oxygen can be adjusted as needed with each breath and with the number of breaths per minute. Pre-hospital ventilators are used during emergency response operations and for ground or air transport.

In order to provide responders with information on currently available pre-hospital ventilators, Science Applications International Corporation conducted a comparative assessment of these devices for the System Assessment and Validation for Emergency Responders (SAVER) Program in May 2012. Detailed findings are provided in the *Pre-Hospital Ventilators Assessment Report*, which is available by request at https://www.rkb.us/saver.

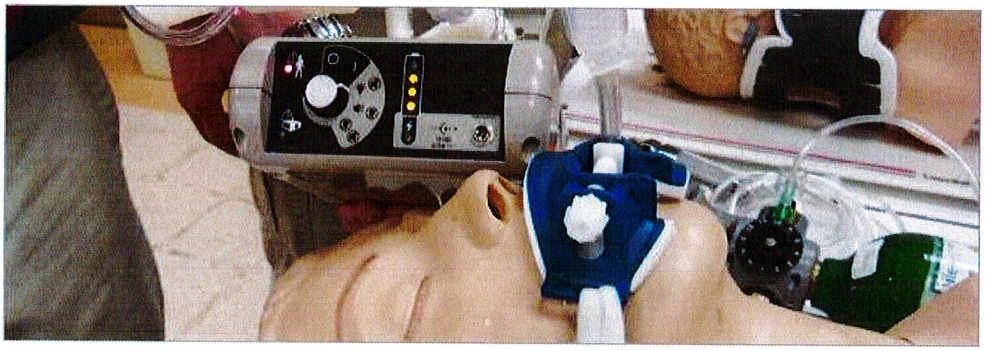
Assessment Methodology

Prior to the assessment, eight emergency medical technicians and paramedics were chosen from various jurisdictions to participate in a focus group. The group identified evaluation criteria and recommended product selection criteria and possible scenarios for assessment.

After identifying evaluation criteria, the focus group assigned each criterion to one of five SAVER categories, and then assigned a weight for its level of importance. Once the criteria were weighted, the five SAVER categories were assigned a percentage value to represent the level of each category's importance relative to the other categories.

Based on focus group recommendations, market research, and system availability, the following pre-hospital ventilators were selected for assessment:

- AutoVent™ 3000, Allied Healthcare Products Inc.;
- Simplified Automated Ventilator (SAVe™), AutoMedx Inc.;
- AEV® Automatic Emergency Ventilator, Impact Instrumentation Inc.; and
- MCV200 Portable Ventilator, Allied Healthcare Products Inc.



Eight responders served as evaluators for this assessment. All evaluators had received Emergency Medical Technician—Intermediate or Paramedic certification or licensure by a national or state agency, and had at least 8 years of professional experience providing advanced adult and pediatric patient airway management.

During the assessment, evaluators rated the pre-hospital ventilators based on evaluation criteria established by the focus group. The assessment was separated into two phases: the specification assessment and the operational assessment. Evaluators assessed the systems based on vendor-provided information during the specification assessment. Hands-on experience using the pre-hospital ventilators during four scenarios served as the basis for the operational assessment. Mannequins were used to simulate adult patients during each of the scenarios.

SAVER Category Definitions
Affordability groups criteria related to life-cycle costs of a piece of equipment or system.
Capability groups criteria related to the power, capacity, or features available for a piece of equipment or system to perform or assist the responder in performing one or more relevant tasks.
Deployability groups criteria related to the movement, installation, or implementation of a piece of equipment or system by responders at the site of its intended use.
Maintainability groups criteria related to the maintenance and restoration of a piece of equipment or system to operational condition by responders.
Usability groups criteria related to the quality of the responders' experience with the operational employment of a piece of equipment or system. This includes the relative ease of use, efficiency, and overall satisfaction of the responders with the equipment or system.

Assessment Results

Table 1 displays the composite assessment scores as well as the category scores for each pre-hospital ventilator. Higher scores indicate a higher rating by evaluators. For specifications, see table 2. The advantages and disadvantages of each pre-hospital ventilator, as identified by evaluators, are listed in table 3. To view how each pre-hospital ventilator scored against the evaluation criteria assigned to the SAVER categories, see table 4.

An analysis of evaluator comments and scores revealed the following common observations concerning the assessed pre-hospital ventilators:

- Evaluators placed a high value on pre-hospital ventilators that are intuitive and easy to use.
- Evaluators expressed a strong preference for pre-hospital ventilators capable of operating in a wide range of environments.
- Evaluators preferred pre-hospital ventilators with dual settings that allow the unit to be used on both adult and pediatric patients.
- Evaluators placed a high value on pre-hospital ventilators that are sensitive to changes in airway pressure.
- Evaluators expressed a strong preference for pre-hospital ventilators that can be easily deployed due to being compact, lightweight, and/or mountable.
- Evaluators preferred pre-hospital ventilators that are reasonably priced and have low maintenance costs.
- Evaluators placed a high value on pre-hospital ventilators that can be easily cleaned.
- Evaluators expressed a strong preference for pre-hospital ventilators that include a warranty.
- Evaluators placed a high value on pre-hospital ventilators that have lengthy run times and reduced charge times.
- Evaluators expressed a strong preference for pre-hospital ventilators that include audio and visual alarms.

Responder agencies considering the purchase of a pre-hospital ventilator should review the detailed findings in the *Pre-Hospital Ventilators Assessment Report* and carefully consider each device's overall capabilities and limitations in relation to their jurisdiction's operational needs. All reports in this series, as well as reports on other technologies, are available in the SAVER section of the Responder Knowledge Base (RKB) website, https://www.rkb.us/saver.

Table 1. Pre-Hospital Ventilator Assessment Results

Product	Composite Score	Affordability (15% Weighting)	Capability (25% Weighting)	Deployability (10% Weighting)	Maintainability (10% Weighting)	Usability (40% Weighting)
AutoVent™ 3000	**3.6**	3.1	3.3	4.3	3.0	4.0
SAVe™	**3.6**	2.9	3.3	4.5	3.0	4.0
AEV®	**3.3**	2.7	3.8	3.2	3.0	3.3
MCV200	**3.0**	2.9	3.3	2.6	2.7	3.0

Table 2. Pre-Hospital Ventilator Specifications[1]

Specifications	AutoVent™ 3000	SAVe™	AEV®	MCV200
Flow rate	16 to 48 L/min	6 L/min	0 to 100 L/min	12 to 36 L/min
Tidal volume	400 to 1,200 mL	600 mL	50 to 1,500 mL	200 to 1,200 mL
FIO_2 (percentages)	100	21, 65, 100	21 to 100	21, 65, 100
Frequency	8 to 20 bpm	10 bpm (preset)	1 to 60 bpm	8 to 20 bpm
Dimensions (L x W x H)	3.5 x 6.0 x 1.8 in.	6.5 x 6.3 x 2.5 in.	8.0 x 12.5 x 4.5 in.	14.5 x 10.3 x 3.5 in.
Weight	1.5 lbs	3.0 lbs	9.5 lbs	17.2 lbs
FDA approval	November 1993	September 2007	April 2011	May 2009

Notes:

1 Information was provided by manufacturers and has not been independently verified by the SAVER Program.

bpm = beats per minute
FDA = U.S. Food and Drug Administration
FIO_2 = fraction of inspired oxygen
H = height
in. = inches
L = length
lbs = pounds
L/min = liters per minute
mL = milliliter
W = width

Table 3. Pre-Hospital Ventilator Advantages and Disadvantages

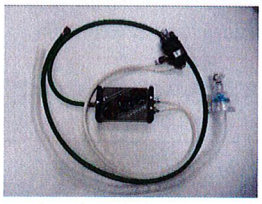
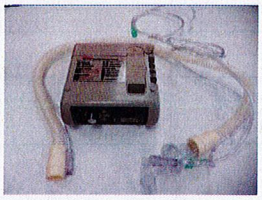
Product	Advantages	Disadvantages
 **AutoVent™ 3000** Composite Score: 3.6	• Can be used on both adult and pediatric patients • Well suited for emergency response and transport • Simplistic use • Minimal training required for use • All pneumatic; no battery or electronic power source required • Rugged, lightweight, and compact • Rugged circuit; difficult to kink • PEEP valve available as an assembly • Reasonable initial cost • Low maintenance costs • Easily deployed	• Labeling of control knobs • Unable to operate without oxygen • Minimal alarms; no low pressure alert or notification • No extended warranty available; no replacement or loaner units provided

Table 3. Pre-Hospital Ventilator Advantages and Disadvantages (Continued)

Product	Advantages	Disadvantages
 **SAVe™** Composite Score: 3.6	• Well suited for pre-hospital response • Simplistic use • Small learning curve • Battery powered with 5.5-hour run time • Will operate without compressed gas • Durable; designed for forward combat life-savers • Automatic shutoff; prevents overpressure or over insufflations • Tactical mode; allows user to turn off audible and visual alarms • Inexpensive initial cost • 1-year warranty; extended warranty available • Loaner units available • Low maintenance costs • Lightweight, compact, portable • Rapid deployment time • Easily decontaminated • No software updates needed	• Fixed ventilator; only for apneic patient • Preset settings; unable to change or customize (e.g., tidal volume, rate, etc.) • Only administers 600 mL; cannot be used on patients weighing less than 100 pounds • 14-hour charge time; slow trickle charge
 **AEV®** Composite Score: 3.3	• Well suited for critical care transport • Capable of operating without a compressed gas source • Sensitive to change in airway pressure • Easy to troubleshoot • 10-hour battery life • High operating temperatures • Audible and visual alarms • Customizable settings • Allows for spontaneous breathing • Extra features (e.g., waveform display, safety features, multi-step processes) • Good in-service training/DVD	• Requires moderate level of training; not an entry level unit • Selector knob slippage • CPAP mode required for manual breath to work • Initial cost • Carrying case not included • Operating manual not included; $27 additional cost • Loaner unit provided based on availability • Maintenance costs • Extended warranty costs • Poor handle; no straps to tie to stretcher
 **MCV200** Composite Score: 3.0	• Operates independently on compressed gas or will operate on battery with room air • Automatically changes to room air if compressed gas is depleted • Audio and visual alarms • Can be used on both adult and pediatric patients • Will accept CBRNE air filter/cartridge; can be used in hazardous environments • Straps included to secure unit to stretcher	• Labels for adult settings should be larger and brighter • Heavy and cumbersome • No security locks; controls easily unintentionally adjusted • Lag time in adjustment knobs • No values on electronic control knobs • Difficult to read color on pressure gauge • No legend on screen; difficult to see in low light • Slow to respond to changes in air pressure • High pressure alarm reads from 0 to 80 psi; only works from 0 to 20 psi; does not alarm between 20 and 80 psi • Straps not attached or durable; can be easily lost • Initial cost

Notes:

CBRNE	=	chemical, biological, radiological, nuclear, and explosive	mL	=	milliliter
CPAP	=	continuous positive airway pressure	PEEP	=	positive end expiratory pressure
DVD	=	Digital Versatile Disc	psi	=	pounds per square inch

Table 4. Pre-Hospital Ventilator Criteria Ratings[1]

KEY Least Favorable → Most Favorable	 AutoVent™ 3000	 SAVe™	 AEV®	 MCV200
Affordability				
Value for cost	◑	◑	◑	◑
Replacement parts costs	◑	◑	◑	◑
Accessory costs	◑	◑	◑	◑
Maintenance costs	◑	◑	◔	◑
Capability				
Decontamination capability	◕	◑	◑	◑
Power supply options	◑	◕	◕	●
System durability	◕	◕	◕	◕
System alarms	◔	◑	◕	◔
Oxygen adjustments	◑	◑	◕	◑
System features	◔	◔	◕	◑
Multifunctional ventilation	◑	◔	●	◑
Initial implementation	◕	●	◑	◑
Equipment compatibility	◑	◕	◕	◕
Deployability				
Ease of transport	◕	●	◑	◔
Ease of site setup	◕	●	◑	◕
Maintainability				
Ease of decontamination	◑	◑	◑	◑
User serviceability	◑	◑	◑	◔
Warranty	◑	◑	◑	◔
Software updates[2]	Not applicable	Not applicable	◑	◕
Usability				
Ease of use	◕	◕	◑	◑
User-friendly controls	◕	◕	◑	◑
Easy-to-read display	◑	◕	◕	◑
Functional component connections	◕	◕	◕	◕

Note:

1 Averaged criteria ratings for each assessed product are graphically represented by colored and shaded circles. Highest ratings are represented by full green circles.

2 This criterion was not assessed for the AutoVent 3000 or the SAVe as it was not applicable. This did not affect the products' final scores.