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14. ABSTRACT

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Comparison of Airway Control Methods and Ventilation Success With an Automatic Resuscitator

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ABSTRACT

Mechanical ventilation in an austere environment is difficult owing to logistics, training, and environmental conditions. We evaluated the ability of professional caregivers to provide ventilatory support to a simulated patient using the Simplified Automated Ventilator (SAVe) with a mask hand attended ventilation, mask with single strap unattended ventilation, and supraglottic airway (King LT) ventilation. All three methods were performed using a SAVe with a set tidal volume of 600ml and respiratory rate of 10 breaths per minute. The simulator consisted of a head and upper torso with anatomically correct upper airway structures, trachea, esophagus, and lung which, also measured the delivered tidal volume, respiratory rate, inspiratory flow, and airway pressures. Volunteers used each airway control method to provide ventilation for 10 minutes in random order. Success of each technique was judged as a mean delivered tidal volume of > 500ml. The major finding of this study was that medical professionals using SAVe resuscitator and the manufacturer supplied face mask with single head strap failed to ventilate the airway model in every case. Keywords: *SAVe, Ventilation, Airway management, Prehospital, Mask Ventilation*

Introduction

Changes in the conduct of military operations have challenged military medicine to reach forward and provide life-saving techniques on the battlefield. One area of interest has been the use of mechanical ventilation. A recent study has shown that the requirement for airway management at the site of wounding particularly with penetrating head injury is associated with significant mortality.[1] Since airway management is typically a precursor to mechanical ventilation, the role of the ventilator is unclear. Traditionally, ventilatory support on the battlefield was accomplished by manual ventilation or not at all. This was in part due to the fact that it was logistically difficult to carry a ventilator and an oxygen source. Additionally, equipment and training to perform endotracheal intubation was not always available.[2,3]

A recent department of defense initiative to develop a simple, small, lightweight ventilator capable of operating from battery without oxygen for use in the battlefield resulted in a product known as the SAVe ventilator. We evaluated the ability of the SAVe to ventilate a model of the head, upper airway, and lungs in the hands of medical professionals using three different techniques of airway management (mask hand ventilation, mask with strap, and king LT supralaryngeal airway).

Device Description

The SAVe simplified automated ventilator (AutoMedx, Germantown, Maryland) is an automatic resuscitator with dimensions of 6.7" x 6.25" x 2.5" weighing 1.4kg. The Model 600 uses an internal air compressor to deliver a preset tidal volume (V_T) of 600ml and a respiratory rate of 10 breaths per minute at an inspiratory time of 2.25 seconds using a constant flow of 16Lpm. The ventilator circuit is a manufacturer-supplied single limb circuit that utilizes a nonrebreathing valve to separate inspired and expired gas. If the patient breathes spontaneously, gas from ambient is drawn in via the nonrebreathing valve; the SAVe ventilator does not have the ability to respond to patient efforts.[4]

Methods

The ability of the SAVe to ventilate a model of the upper airway and lungs (Respi Trainer, Ingmar Medical, Pittsburgh, PA) by medical professionals was evaluated with three different techniques of airway management (hand mask ventilation, mask ventilation with a single head strap and ventilation via the king LT supralaryngeal airway) in a randomized fashion for 10 minutes

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each. The test lung was set to mimic a patient with airway resistance of 5cm H_2O/L/s and lung compliance of 50cm H_2O/L. The medical professionals were registered nurses, registered respiratory therapists, and physicians. All subjects volunteered to participate and signed informed consent documents. During mask ventilation we used the supplied collapsible mask with a single strap provided with the SAVe resuscitator as was purchased by the Department of Defense. We also tested the ability to ventilate the airway using a supralaryngeal airway, the King LT. The King LT (King Systems, Noblesville, IN) is a curved tube with ventilation apertures located between two inflatable cuffs that can be inflated using a single valve/pilot balloon. The distal cuff is designed to seal the esophagus, while the proximal cuff is designed to seal the oropharynx. The proximal end of the tube has a 15mm connector for attachment to standard breathing circuit or resuscitation bag.

The QuickLung Respi Trainer Advance system (IngMar Medical, Pittsburgh, PA) consists of three components. The first component is a lung model (QuickLung), which is a test lung that operates with a combination of springs and orifices to represent a number of different settings for resistance (5, 20, or 50cmH_2O/L/s) and compliance (10, 20, or 50ml/cmH_2O). The second component is the Data Acquisition Module integrated into the mannequin head, which includes an articulated neck that can be moved vertically and a stomach bag connected to a simulated esophagus. If airway pressure exceeds 20cm H_2O, gas can be directed into the stomach, simulating real life clinical scenarios of over ventilating. The Data Acquisition Module measures airway pressure, flow and volume by using the known resistance of the model and the pressure differential across that resistance. Measurements are recorded at 100Hz. The third component is a PC, which receives measurement data via Bluetooth from the Data Acquisition Module and also calculates different performance parameters those parameters are V_t [Tidal volume = (P_{peak}– P_{min})/ Compliance], P_{peak} [the highest value of pressure during a breath], BR (breath rate is the quotient of 60 s and the value of the breath cycle time), and MV (prorated average tidal volume per minute from a sample of two to three breaths).

The Respi Trainer was assembled according to the manufacturer instruction. The SAVe was connected to the mask then held on the Respi Trainer mannequin by the subjects with two hands while maintaining correct airway position for 10 minutes (Figure 1). The same mask was used with the supplied single strap by the clinicians to mask ventilate the Respi Trainer Mannequin after correctly positioning the airway for 10 minutes (Figure 2). Clinicians also used the supralaryngeal airway (King LT) to ventilate the Mannequin using the SAVe for 10 minutes (Fig 3). All three techniques were performed on the ground to simulate a pre-hospital scenario. The data points (tidal volume, peak airway pressure, respiratory rate and minute ventilation) were recorded and stored onto a laptop computer for further analysis.

Figure 1 *Mask hand ventilation*

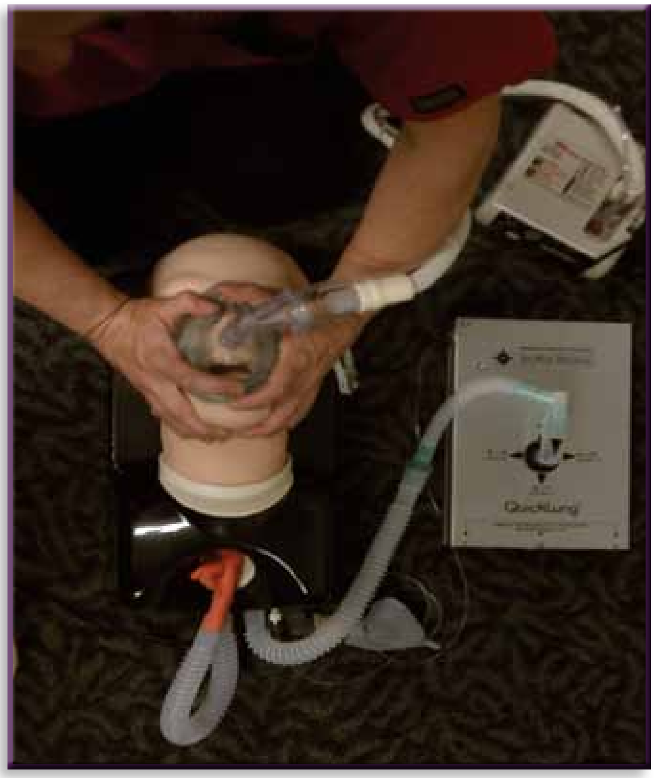


Figure 2 *Mask with single strap ventilation*

Figure 3 *King LT ventilation*

Results

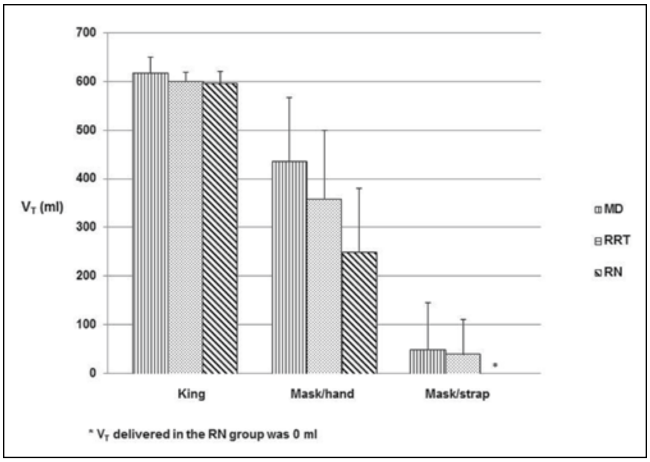
The respiratory rate delivered with all techniques was 10 breaths/min. The V_T varied widely among the three different techniques (Figure 4). None of the 30 subjects could provide an effective tidal volume using the manufacturers supplied mask with single strap strapped to the face. The peak inspiratory pressure was 7.6 ± 3.3cm H_2O for the mask hand ventilation, 0.5 ± 1.4cm H_2O for the mask with strap ventilation, and 13.9 ± 1.3cm H_2O for ventilation with the King LT. The minute ventilation was 3.6 ± 1.7L/min with the mask hand ventilation, 0.13 ± 0.33L/min with the mask with single strap ventilation, and 6.5 ± 0.3 L/min with the King LT.

Comparing the three clinicians groups, the only statistically significant difference ($P \leq 0.05$) was between the MD and RN groups with the delivered V_T using the mask hand technique. Physicians delivered a significantly greater tidal volume (435ml ± 130 vs. 250ml ± 131).

Discussion

The major finding of this study was that medical professionals using the SAVe resuscitator and the manufacturer supplied facemask with single head strap failed to ventilate the model in every case. Ventilation of the model with the SAVe and the King LT supralaryngeal airway achieved the best results in delivering the set tidal volume and the respiratory rate. When subjects held the mask in place with both hands the tidal volume and the respiratory rate delivered varied widely, but was still far superior to those parameters delivered with the mask and single head strap. This variation may be related to differences in subject strength and hand size. After ten minutes of holding the mask in place, all participants expressed some level of hand fatigue.

Figure 4 *Delivered V_T by the three professional groups using the three different ventilation methods*



Previous work by our group[5] found similar results during ventilation of a model of the unprotected airway. These authors found that a ventilator capable of adjustments in flow was better able to compensate for leaks and deliver a more consistent volume. They also demonstrated significantly different volumes of gas forced into the stomach with different ventilation techniques. The highest airway pressure achieved in this study with the SAVe was 15cm H_2O with the King LT. With the mask techniques, airway pressure was < 10cm H_2O in every case. We did not detect gastric insufflation in any of these cases. This is consistent with the model using a simulated esophageal opening pressure of 20cm H_2O. The low flow and leaks around the mask prevented airway pressures from reaching a level that would cause gastric insufflation.

Hess et al[6] evaluated the ability of caregivers to ventilate a model and found that hand size was important in maintaining an effective mask seal. We did not measure hand size in this study, but within the nursing cadre there were significantly more women. This may explain why the physician group (seven men and two women) provided larger tidal volumes than their nursing counterparts (nine women and one man). Our current work supports the report by Hess and colleagues.

After observing the failure of all 30 participants with the current mask with single strap, we evaluated the ability of a mask with an inflatable cushion, which is commonly used in our institution, with 4-tailed head strap to ventilate the model with the SAVe. That resulted in the delivery of the tidal volume and the respiratory rate set on the SAVe with a respiratory rate of 10, tidal volume of 597ml, and peak inspiratory pressure of 13.5cm H_2O and a minute ventilation of 6.5L/min. This method could be an alternative to the mask with the single strap, keeping in mind the issues associated with 4-tailed strap ranging from pressure sores to creating too much pressure leading to gastric distension and increasing the risk of aspiration (Figure 5).

According to our findings the supralaryngeal airway was the best method to deliver the tidal volume and the respiratory rate set on the SAVe. The King LT supralaryngeal airway required minimal training and there were no human variables involved such as hand strength or hand size to alter the tidal volume delivered and/ or the rate at which that tidal volume was delivered. The King LT supralaryngeal airway is also less invasive than the endotracheal tube, which remains the airway of choice in the prehospital setting. Endotracheal tube insertion is a more invasive procedure that requires a higher level of skill and expertise.[1] However, the use of endotracheal tubes has met with varying success in the field.[7-10]

Limitations of our study were a failure of the model to replicate the real life casualty on the battlefield. The relatively clean airway model also fails to simulate the physical appearance of an airway injury and other injuries associated with battlefield trauma. We used fixed compliance of 50ml/cmH2Oand resistance $5cmH_2O/L/s$ that represents a patient with mild to moderate respiratory impairment. There is currently no data regarding the respiratory status of wounded casualties or out of hospital patients at the point of injury. Other variables such as gastric pressure and its impact on the ventilation of casualties and the effect of non-invasive ventilation on air entering the esophagus may also be different in real scenarios.

Figure 5 *Mask with 4-tailed head strap Ventilation*

Conclusions

Compromised airway is the third leading cause of battlefield death, accounting for about 1% of combat deaths.[2,3] The best airway for the injured casualty has yet to be defined. Our data suggest that the use of the SAVe resuscitator without an instrumented airway using the current mask and single head strap is unreliable. Holding the mask in place improves ventilation, but eliminates the advantage of an “automatic” device as it requires the constant attention of a single caregiver. The use of a supralaryngeal airway or improved mask and head strap allows the greatest success. More importantly, the role of a ventilator in an austere environment has yet to be determined. The right person with the right equipment and sufficient training might improve the survival of the casualties with compromised airway on the battlefield; however, that needs to be further studied. The work by Mabry et al. suggests that battlefield injuries, which necessitate and allow airway instrumentation are overwhelmingly fatal.[1] Based on these facts, the role of the mechanical ventilator at the site of wounding needs to be addressed considering the utility of the device and the additional weight and footprint. This decision should be data driven.

The term “far forward” is a term from conventional force-on-force conflicts. The example being World War II, where there was a definite “forward” and a definite “rear”. In the conflicts in which the U.S. is currently or recently engaged (Afghanistan and Iraq), there is no forward per se, and there is correspondingly no rear. Anywhere outside small arms range of a U.S. base is “forward”, even the inside of a U.S. base is within enemy range. Consider the term “austere” as a possible alternative. Even then, there aren’t that many places in Afghanistan or Iraq that are much more than a few minutes flight time, or even drive time for that matter, away from a fixed U.S. facility that had first world level medical support. The paper should either focus its context specifically on medical personnel who actually do work in austere environments (i.e. Special Operations personnel in operations like the Village Support Operations (VSO) in Afghanistan, or JCETs in Central/South

America), or it should broaden the paper to address ventilation in all circumstances where "hands free" ventilatory support is needed.

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Disclosure

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Chief Rodriquez entered the Air Force in September 1983. He has deployed to Operations DESERT SHIELD, DESERT STORM, IRAQI FREEDOM, ENDURING FREEDOM and CONUS Disaster Response.

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Warren C. Dorlac, MD, FACS is an Associate Professor of Surgery at the University of Cincinnati. He is an active member of the Division of Trauma and Surgical Critical Care. He has recently assumed the role as the Chief of the Acute Care Surgery Service. Colonel (Ret) Dorlac served on active duty with the USAF for 26 years with his last military assignment being the Director, Center for Sustainment of Trauma and Readiness Skills (C-STARS) Cincinnati, The University Hospital, Cincinnati, OH and volunteer Associate Professor of Surgery, Department of Surgery, University of Cincinnati from August 2007 to November 2011. In addition, he served as the Trauma Consultant to the USAF Surgeon General from 2008 through 2011. In 2009 he deployed as the Central Command (CENTCOM) Joint Theater Trauma System Director where he oversaw trauma care in Iraq and Afghanistan. In his prior assignment, he was the Trauma Medical Director at the Landstuhl Regional Medical Center (LRMC), Landstuhl, Germany. He provided comprehensive general, trauma and critical care surgery expertise at the only tertiary referral center treating OPERATION ENDURING FREEDOM and OPERATION IRAQI FREEDOM casualties from CENTCOM and referrals from EUCOM. His additional duties included Critical Care Air Transport Team member, Acute Lung Team member and an Advanced Trauma Life Support course instructor. Dr. Dorlac has led an instrumental role in DoD trauma training as well as international trauma training with multiple countries to include South Africa, Chile, Colombia, El Salvador, Hungary, and the Czech Republic.

Colonel Jay A. Johannigman, MD is Mobilization Assistant to the Command Surgeon, AMC as well as the Director of the Division of Trauma and Surgical Critical Care at the University of Cincinnati. Col Johannigman is a Professor of Surgery and has been awarded Fellowship, in both the American College of Surgeons and the Society of Critical Care Medicine. He has completed a Fellowship in Trauma and Surgical Critical Care and holds the certificate of additional qualifications in Surgical Critical Care. Col Johannigman serves as the Region V Chief for the American College of Surgeons Committee on Trauma and is a member of the American Association for the Surgery of Trauma, the Eastern Association for Trauma, the Western Trauma Association and the Committee for Tactical Combat Casualty Care. His academic curriculum vitae include 81 peer-reviewed publications, 17 book chapters, and over one-hundred abstract presentations. Colonel Johannigman received his medical degree at Case Western University. He completed his Surgical Residency as well as a Fellowship in Trauma and Surgical Critical Care the University of Cincinnati. He was commissioned in the Air Force Reserves in 1979. Colonel. Johannigman has been deployed on four separate tours to southern Iraq.

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