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## Original Research

## Effectiveness of Manual Ventilation in Intubated Helicopter Emergency Services—Transported Trauma Patients

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## A B S T R A C T

**Background:** Helicopter Emergency Medical Services agencies frequently transport intubated patients to definitive care. No evidence exists to determine the type of ventilation in this population. Practice varies amongst programs from bag-valve-mask to mechanical ventilation.

**Study Objective:** Evaluate the effectiveness of bag-valve ventilation in intubated trauma patients. We hypothesized manual ventilation provides adequate support to maintain physiologic ETCO<sub>2</sub>.

**Methods:** From June to December 2015, twenty patients were enrolled in this prospective, observational study. Included were endotracheally intubated trauma patients transported by this HEMS program. Excluded were interfacility transports, non-scene calls, and patients with supraglottic devices. ETCO<sub>2</sub> was recorded every 30 seconds during the flight. As a descriptive pilot study, power was not considered.

**Results:** 20 patients provided over 500 cumulative minutes of manual ventilation data. The percentage of cumulative time spent with adequate oxygen saturations was 83.6%. The percentage of cumulative time spent with adequate ETCO<sub>2</sub> was 48.7%, with 34.6% of time spent under and 16.7% above this range.

**Conclusion:** Manual ventilation maintained a physiologic ETCO<sub>2</sub> only 16.7% of the time. Significant variability existed, resulting in intermittent hypoxia and hyperventilation. Prior research linked such events to increased morbidity and mortality. Further studies are warranted to compare manual against mechanically ventilated patients.

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Helicopter emergency medical service (HEMS) agencies are frequently called to trauma scenes for patients with extensive injuries who are likely to benefit from expedited transport to definitive care at a level 1 or level 2 trauma center. These patients most often require intubation, with guidelines recommending ventilation at physiologic end-tidal carbon dioxide (ETCO<sub>2</sub>).<sup>1–3</sup> To our knowledge, no professional recommendations have been made regarding the best method of ventilation to achieve this goal, and no large randomized controlled trials exist that investigate this. Current practice varies between manual bag valve ventilation and mechanical ventilation. Without validated evidence, it appears convenience and

anecdotal experience may dictate this decision in the prehospital setting, particularly with HEMS.

Manual ventilation with a bag valve device is dynamic, simplistic, and inexpensive and saves valuable transport time with its ease of setup. However, manual ventilation is dependent on a human operator, who may be distracted or inexperienced and is subject to numerous external influences. Such factors may limit effectiveness.

Alternatively, a mechanical ventilator will provide ventilation that is consistent, precise, automatic, and highly customizable while also freeing the medical provider to perform other tasks. However, the logistics, cost, and complexity of mechanical ventilation can be prohibitive. Furthermore, the flight time from a scene to a hospital is often relatively short, with an average air transport time of 8 to 10 minutes. The time required to initiate mechanical ventilation, which may be up to 10 minutes, may cause an unnecessary delay in care, potentially resulting in poorer outcomes.

Our goal was to evaluate the effectiveness of manual ventilatory support, specifically in a population of prehospital intubated trauma patients. Our hypothesis is that manual control of ventilation will

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provide adequate support to maintain a physiologic  $\text{ETCO}_2$  between 35 and 45 mm Hg.

## Methods

This research represents a prospective, observational, proof of concept study. A convenience sample of data over 7 months, from June 2015 to December 2015, was collected. We enrolled 20 patients who were transported to various level 1 and level 2 trauma centers in our service area. Institutional review board approval was obtained from the Medical College of Wisconsin, Milwaukee, WI.

Our HEMS fleet has 3 bases that service southeastern Wisconsin and Illinois. We transport approximately 900 patients annually, which is approximately 1 flight per base per day. Approximately 35% of flights are trauma scene calls, with patients transported to the closest American College of Surgeons–verified level 1 or level 2 trauma center. Each aircraft is staffed with a critical care nurse and critical care paramedic, with emergency medicine residents and emergency medical services fellows occasionally flying as crewmembers.

Inclusion criteria for the study were limited to patients with traumatic mechanisms of injury who were endotracheally intubated on scene and transported by helicopter. Excluded patients included any interfacility transports, nonscene calls, and any patient ventilated with a supraglottic device.

$\text{ETCO}_2$  monitoring was accomplished with a ZOLL ProPac (Protocol Systems Inc, Beaverton, OR) programmed to collect vital signs at 30-second intervals for the duration of the transport. Physiologic  $\text{ETCO}_2$  of 35 to 45 mm Hg was determined to be normal for this study. Printouts of the vital signs were added to the electronic patient care record. Flight crews collected additional information on demographics and mechanism, but information such as name, address, birth date, and other identifiers was not abstracted. As a convenience sample and descriptive pilot study, there were no considerations of power or a targeted enrollment number. We enrolled all patients who met the inclusion criteria during the study period.

## Results

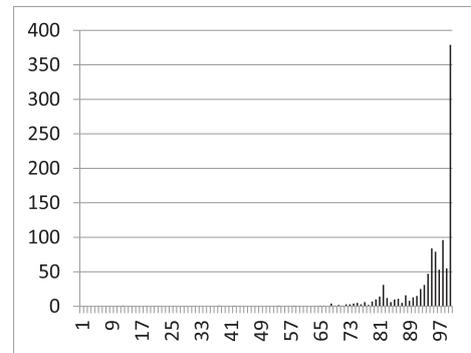
Cumulatively, our data consisted of 1,466 time points, which represented the recorded  $\text{ETCO}_2$  every 30 seconds over 733 minutes of manual ventilation. Regarding demographics, patient ages ranged from 19 to 79 years old, with a mean of 49 years. Notably, the group of ages 40 to 60 years old represented 45% of our study group. There were 16 men and 4 women.

In regard to mechanism, all 20 cases were blunt trauma injuries. The vast majority represented road collisions, with 8 motor vehicle and 7 motorcycle collisions. For the remainder, 3 cases represented falls, 1 was a plane crash, and 1 was a pedestrian struck by an automobile. Additionally, the majority of our patients had some component of head injury. There were 11 patients with scalp lacerations and 6 with visible skull deformities.

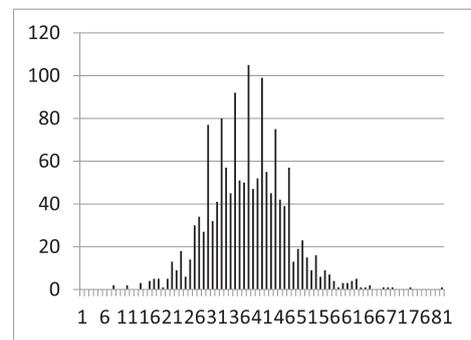
We found that 83.6% of our data points were adequately oxygenated, defined as partial pressure of oxygen  $\geq 90\%$  (Fig. 1). Compared with capnography, 48.7% of our data points were within the physiologic range of  $\text{ETCO}_2$  (ie, between 35 and 45, Fig. 2). Otherwise, 34.6% of the time was spent below the range goal and 16.7% was spent above.

## Discussion

The main finding of our data pertains to ventilation, with a minority of the time points collected spent within the range of physiologic  $\text{ETCO}_2$ . A disproportionate percentage of patients were hypocapnic, with hypocapnia occurring more than twice as often as hypercapnia. This finding of prehospital hypocapnia is consistent with similar studies and has been attributed primarily to hyperventilation.<sup>4,5</sup> The same phenomenon of inadvertent hyperventilation with manual ventilation has been shown more robustly in intrahospital transport.<sup>6–8</sup>



**Figure 1.** A bar graph of oxygenation; the x-axis represents partial pressure of oxygen, and the y-axis represents cumulative time points.



**Figure 2.** A bar graph of ventilation; the x-axis represents  $\text{ETCO}_2$ , and the y-axis represents cumulative time points.

This is a critical problem because hyperventilation and the resulting hypocarbia have been linked to numerous negative physiologic effects, including increased intrathoracic pressure, decreased venous return, decreased coronary perfusion, decreased cardiac output, decreased cerebral perfusion, brain cell hypoxemia, loss of cerebrovascular autoregulation, and decreased survival.<sup>5,9–12</sup>

Our data show that appropriate oxygenation is provided most of the time, but many would argue that adequate oxygenation 83.6% of the time is simply not acceptable. The instances of hypoxia could be explained by significant lung injuries because all patients in this study group suffered blunt trauma resulting in intubation. Our data do not seem to suggest a problem with oxygenation but rather a problem with ventilation.

Explaining hypocapnia can be challenging because  $\text{ETCO}_2$  measurement is dependent on multiple concurrent physiologic parameters. Ventilation, metabolism, and perfusion all play important roles in  $\text{ETCO}_2$  measurement. Accordingly, hypocapnia cannot be attributed to poor ventilation alone. Furthermore, poor ventilation in the setting of trauma may be caused by a pneumothorax, pulmonary hemorrhage, or an obstructed endotracheal tube and should not be solely indicative of poor manual ventilation. In the same way, perfusion may be compromised in the setting of significant traumatic hemorrhage, contributing to measured hypocarbia.

Looking at each patient care record individually, there appeared to be a smaller subset of cases that disproportionately contributed to hypocarbia. Three cases accounted for 37% of recorded hyperventilation, with each being hypocarbic over 90% of the time. Of further interest, the 5 most hemodynamically unstable patients accounted for 65% of hypocarbic data points. That being said, 80% of the patients had a single  $\text{ETCO}_2$  recorded under 25 mm Hg. This number has consistently been used in the literature as a determination of severe hyperventilation.<sup>4,13,14</sup> Although a subset of patients accounted for

the majority of hyperventilation, 16 of the 20 patients did have a single recorded  $\text{ETCO}_2$  reading below 25 mm Hg, indicating hyperventilation may be a pervasive problem.

In most cases, flight paramedics were manually delivering breaths under the primary guidance of oxygenation with a secondary consideration of ventilation and  $\text{ETCO}_2$ . HEMS care occurs in very tight quarters, and airway management is often the sole focus of the flight paramedic. Therefore, if he or she needs to assist the flight nurse with patient care, the bag valve mask would need to be set down, interrupting the cycle of ventilation. The harmful effects of hypoxia appear to be much more published and popularized than those of hypocarbia. Perhaps part of the problem is a lack of awareness. Along these lines, it was concerning that possibly hypoxia, and the resulting hyperventilation, was a large contributor to the marked hypocarbia. When controlled for hypoxia by eliminating all time points with partial pressure of oxygen < 90%, we found that only 24% of our data was marked with hypocapnia, much less than the 35% previously recorded. However, this again only represents a portion of observed hypocarbia.

There seems to be a large percentage of time where there is no obvious central cause for hyperventilation-induced hypocarbia. Perhaps this stems from the “adrenaline rush” of a resuscitation and helicopter transport, resulting in more frequent and forceful bagging, as has been suggested in other studies of hyperventilation.<sup>4,5,15</sup> Manual resuscitation shows a large variation in the tidal volume delivered.<sup>16</sup> A relationship between professional category, grip strength of the hand keeping the mask, and ventilation performance has been shown to cause hyperventilation in all health care providers.<sup>17</sup> Therefore, one must alter the technique for the manual ventilator to provide adequate ventilatory support. One potential alteration would be to prepare the ventilator before arrival on scene. It has been reported that it could take up to 10 minutes to set up the ventilator and associated circuits, but with proper training, this could be accomplished in less than 1 minute. En route to the scene, the ventilator could be turned on and programmed with settings regarding ventilator status, age, and mode along with basic parameters for assist control with positive end-expiratory pressure. The ventilator could then be placed in standby mode and adjusted according to patient condition. Some patients may be so critical that time should not be taken to set up the ventilator, but this should be the minority, not the majority. Regular training should occur in any service that uses ventilators so preparing the ventilator with the expectation of use will correct manual ventilation deficiencies.

There are several important limitations of this study. One limitation is the small sample size. As a pilot study, only 20 patients were enrolled. In addition, there was little geographic variation because most subjects were in southeastern Wisconsin. The demographic data show many subjects were middle-aged adult men. Our population of critically ill trauma patients has physiologic parameters that may differ significantly from less ill or nontrauma patient populations. The sample size, combined with the demographics, would limit how generalizable these results are to a broader population. Another major limitation of this observational study is that we did not control for variables that may have affected the physiologic parameters measured. For example, although we did not specifically look at the assisted ventilatory rate, a previous study has shown this to be elevated in prehospital environments and has attributed high rates as the primary cause of hypocarbia.<sup>4,5,15</sup> There were no statistical or experimental controls or comparisons for the effect of the ventilator rate or other potential confounders, such as underlying lung disease or other comorbidities on the measured values. Finally, the outcome data could have been beneficial, but because patients were transported to several different trauma centers, this was not a feasible option in this study.

## Conclusion

We conclude that although manual ventilation via a bag valve mask has been shown to provide adequate ventilator support, in this study, the practitioner does not. Previous studies have shown that adequate ventilation of adults is even possible with a smaller, pediatric-sized bag valve mask.<sup>18</sup> When considering hypoxia and other outliers, we found that hyperventilation-induced hypocarbia is pervasive, which is consistent with multiple previous studies. Therefore, in order to ensure adequate support, practitioners must adjust their technique. Clinical practice guidelines exist for mechanical ventilation, and with a general knowledge of respiratory mechanics and technology, appropriate ventilatory care can be provided to these critical patients and may even improve outcomes.<sup>19</sup> Mechanical ventilation consistently delivers ventilations, which can quickly be adjusted for patient condition. Although the austere environment of HEMS may not be ideal for ventilator use, a well-trained provider can properly use the ventilator for critically injured trauma patients.

The next step in evaluating this phenomenon would be to collect comparative data from mechanically ventilated patients. Additionally, data on patient outcomes could be a valuable addition. Given prior implications for the harmful effects of hyperventilation, further research is needed on this topic.

## References

- Walsh BK, Crotwell DN, Restrepo RD. Capnography/capnometry during mechanical ventilation: 2011. *Respir Care*. 2011;56:503–509.
- Alson RL, Campbell JE. International Trauma Life Support for Prehospital Care Providers. 6th ed Upper Saddle River, NJ: Pearson Education; 2008.
- Brain Trauma Foundation Writing Team. Guidelines for prehospital management of traumatic brain injury. 2nd edition. *Prehosp Emerg Care*. 2007;12 (suppl 1):S1–S52.
- Thomas SH, Orf J, Wedel SK, Conn AK. Hyperventilation in traumatic brain injury patients: inconsistency between consensus guidelines and clinical practice. *J Trauma*. 2002;52:47–52.
- Aufderheide TP, Lurie KG. Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation. *Crit Care Med*. 2004;32: S345–S351.
- Braman SS, Dunn SM, Amico CA, Millman RP. Complications of intrahospital transport in critically ill patients. *Ann Intern Med*. 1987;107:469–473.
- Gervais HW, Eberle B, Konietzke D, Hennes HJ, Dick W. Comparison of blood gases of ventilated patients during transport. *Crit Care Med*. 1987;15:761–763.
- Hurst JM, Davis Jr K, Branson RD, Johannigman JA. Comparison of blood gases during transport using two methods of ventilatory support. *J Trauma*. 1989;29: 1637–1640.
- Cheifetz IM, Craig DM, Quick G, et al. Increasing tidal volumes and pulmonary overdistention adversely affect pulmonary vascular mechanics and cardiac output in a pediatric swine model. *Crit Care Med*. 1998;26:710–716.
- Bullock R. Hyperventilation. *J Neurosurg*. 2002;96:157–159.
- Muizelaar JP, Marmarou A, Ward JD, et al. Adverse effects of prolonged hyperventilation in patients with severe head injury: a randomized clinical trial. *J Neurosurg*. 1991;75:731–739.
- Manley GT, Hemphill JC, Morabito D, et al. Cerebral oxygenation during hemorrhagic shock: perils of hyperventilation and the therapeutic potential of hypoventilation. *J Trauma*. 2000;48:1025–1032.
- Tyburnski JG, Collinge JD, Wilson RF, Carlin AM, Albarán RG, Steffes CP. End-tidal  $\text{CO}_2$ -derived values during emergency trauma surgery correlated with outcome: a prospective study. *J Trauma*. 2002;53:738–743.
- Tobias JD, Lynch A, Garrett J. Alterations of end-tidal carbon dioxide during the intrahospital transport of children. *Pediatr Emerg Care*. 1996;12:249–251.
- 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;56:808–814.
- Lee HM, Cho KH, Choi YH, Yoon SY, Choi YH. Can you deliver accurate tidal volume by manual resuscitator? *Emerg Med J*. 2008;25:632–634.
- Khoury A, Sall FS, De Luca A, et al. Evaluation of bag-valve-mask ventilation in manikin studies: what are the current limitations? *Biomed Res Int*. 2016; 2016:4521767.
- 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;21:74–78.
- Girardeau RP. In-depth overview of mechanical ventilation. *JEMS*. 2015;40(3). Accessed February 16, 2019. <https://www.jems.com/articles/print/volume-40/issue-3/features/depth-overview-mechanical-ventilation.html>.