

Prehospital Hyperventilation After Brain Injury: A Prospective Analysis of Prehospital and Early Hospital Hyperventilation of the Brain-Injured Patient

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Abbreviations:

ABG = arterial blood gas
CBF = cerebral blood flow
GCS = Glasgow Coma Scale
ICP = intracranial pressure
ISS = Injury Severity Score
NTDB = National Trauma Data Bank
TBI = traumatic brain injury
PaCO₂ = systemic arterial carbon dioxide tension

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Abstract

Background: The Brain Trauma Foundation's *Guidelines for the Management of Severe Head Injury* state that the use of prophylactic hyperventilation after traumatic brain injury (TBI) should be avoided because it can compromise cerebral perfusion. The objective of this study was to assess the prevalence of unintentional hyperventilation.

Methods: A prospective evaluation of all intubated trauma patients with a diagnosis of TBI was performed. Patients with signs of impending herniation were excluded.

Results: Forty patients were included in the study. The average Glasgow Coma Scale (GCS) was 6.3. Of these, 28 patients (70%) were unintentionally hyperventilated. Eleven (39%) of the hyperventilated patients died or were discharged in a persistent vegetative state. Of the remaining 12 patients who experienced normal ventilation, three patients (25%) died or were discharged in a vegetative state ($p = ns$) (Table 1).

Conclusion: Hyperventilation was common after TBI. However, patients ventilated to a normal PaCO₂ were significantly more acidotic. Prehospital personnel should undergo educational training after development of strict ventilation protocols for patients suffering TBI.

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Introduction

Elevated intracranial pressure (ICP) is known to be associated with poor outcome after traumatic brain injury (TBI).¹ Prior to the publication of the *Guidelines for the Management of Severe Head Injury* in 1995,² aggressive hyperventilation and prolonged hypocapnia (PaCO₂ = 25-30 mmHg) had been the standard of care for management of elevated ICP associated with TBI.

In 1995, the American Association of Neurological Surgeons and the Congress of Neurological Surgeons, with support from the Brain Trauma Foundation, published the above guidelines.² These guidelines state that the use of prophylactic

hyperventilation therapy during the first 24 hours after severe TBI should be avoided because it can compromise cerebral perfusion at a time when cerebral blood flow is reduced. Hyperventilation is defined as a PaCO₂ ≤ 35 mmHg. Additional recommendations state that chronic or prolonged hyperventilation therapy should be avoided in the absence of increased ICP. At University of Wisconsin-Madison, trauma protocols prohibit the use of hyperventilation in the absence of signs of impending cerebral herniation.

The hypothesis of this study was that, despite protocols to the contrary, hyperventilation remains a

n	Age (years)	Blunt TBI		ISS	GCS	Craniotomy	
		n	(%)			n	(%)
40	35	39	(97.5)	31.4 ±12.13	6.3 ±0.6	4	(10)

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Table 1—Demographics of study population (mean ±1 standard deviation) (n = number, TBI = traumatic brain injury, ISS = Injury Severity Score, GCS = Glasgow Coma Scale Score)

Group	n	(%)	PaCO ₂ (mm Hg)	Minute Ventilation (l/min)	pH (units)	Base Excess (mEq/L)
Hyperventilation (PaCO ₂ ≤35 mmHg)	28	(70)	28.6 ±4.7	10.82 ±2.45	7.39 ±0.1	-6.5
Normal Ventilation (PaCO ₂ >35 mmHg)	12	(30)	41.4 ±5.1	9.50 ±1.67	7.22 ±0.3	-6.5
<i>p</i> -value (Wilcoxon rank)			0.0001	ns	0.0013	0.9871

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Table 2—Minute levels of ventilation and acid-base variable of the hyperventilation and normal ventilation groups (mean ±1 standard deviation, n = number)

common practice in the initial management of patients with a TBI. The goal of this prospective study was to evaluate the prevalence of hyperventilation in the prehospital and early hospital management of patients with TBI.

Methods

The Trauma Coordinator prospectively evaluated 50 consecutive intubated trauma patients with a diagnosis of TBI based on the prehospital report or the initial emergency department (ED) evaluation.

There were no changes in patient protocols during the study period. Likewise, prehospital and emergency department personnel, including treating physicians, were not aware that data were being collected. A standardized data collection sheet was utilized that included demographic data, mechanisms of injury, respiratory data, and arterial blood gas analysis (ABG). Hyperventilation was defined as a PaCO₂ ≤35 mmHg.

Patients with unilateral dilation, of a pupil or other signs of impending brain herniation were excluded, as were patients without an arterial blood gas (ABG) analysis within eight hours after injury. Minute ventilation levels were calculated from the initial ventilator settings used when the first arterial blood gas sample was obtained.

Statistical analysis included Wilcoxon rank sums and Student's *t*-test. A *p*-value of <0.05 was considered statistically significant.

Results

The medical records of 50 consecutive patients with TBI were reviewed. Ten patients were excluded, including four who were hyperventilated for signs of impending brain herniation and six who had no ABG sampled within eight

hours of injury. Thus, the records of 40 patients were available for analysis. The average age in the sample population was 35 years (Table 1). Of the 40 patients, 39 had sustained blunt trauma to the head. The neurological status of the patients was significantly impaired as indicated by the mean of the initial values for the Glasgow Coma Scale score of 6.3 ±0.6 (mean ±1 standard deviation). Four of the patients (10%) required a craniotomy. Most of the patients had multiple injuries as indicated by the average of the Injury Severity Scores of 31.4 ±12.13.

Patients were grouped on the basis of their values for PaCO₂ into hyperventilation and normal level of ventilation groups for further analysis (Table 2). Twenty-eight patients (70%) had been hyperventilated with PaCO₂ values ≤35 mmHg (mean PaCO₂ = 28.6 ±4.7 mmHg), and 12 patients had normal values for PaCO₂ (mean = 41.4 ±5.1 mmHg). The difference was statistically significant (*p* = 0.0001). The mean levels of minute ventilation were 10.82 ±2.45 liters/minute for the hyperventilation group and 9.50 ±1.67 l/minute for the normal group. The differences did not reach statistical significance. Both groups developed metabolic acidosis. The mean values for base deficit were the same (6.5 mEq/l), and the values did not reach statistical significance (*p* = 0.9871). Thus, the mean values for arterial pH for the hyperventilated group were in the normal range (7.39 ±0.1) while the normal group was quite acidotic (pH = 7.22 ±0.3; *p* = 0.0013).

The hyperventilated group had less severe injuries than did the normal group (28.6 ±10.7 vs. 37.8 ±12.9), but more of the patients in the hyperventilated group either died or remained in a vegetative state (11 vs. 3, or 39% vs. 25%) (Table 3). These differences did not reach statistical significance.

Group	n	(%)	ISS	Died or Persistent Vegetative State	
Hyperventilation	28	(70%)	28.6 ± 10.7	11	(39%)
Normal Ventilation	12	(30%)	37.8 ± 12.9	3	(25%)
<i>p</i> - values (Wilcoxon rank)			0.05	ns	

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Table 3—Outcomes (Mean ±standard deviation; n = number; ISS = Injury Severity Score)

Discussion

Despite protocols to the contrary, hyperventilation of patients with a TBI is common in both the prehospital and early hospital setting. In this study, 70% of the patients were unintentionally hyperventilated (PaCO₂ range = 14–35mmHg). Presumably, this occurred prior to the patients' being placed on a mechanical ventilator, as evidenced by similar minute ventilation levels between groups. During prehospital transport and the initial hospital phases of trauma resuscitation, ventilation is performed using a manual bag-valve device. Unintentional hyperventilation may occur due to operator-dependent variations in tidal volume and respiratory rate while "bagging" the patient. Unintentional hyperventilation during manual ventilation has been shown to occur in adults³ and children⁴ during intra-hospital transport of ventilator-dependent intensive care unit patients. In addition, hyperventilation has occurred in children with closed head injuries transported by helicopter.⁵

The data indicate that hyperventilation occurs when cerebral blood flow (CBF) may be critically compromised. Previously, the rationale for hyperventilation was based on the premise that hyperventilation would reduce intracranial pressure (ICP) due to cerebral vasoconstriction. Based on observations from Wolff in the 1930s,⁶ low arterial carbon dioxide tension was found to decrease cerebral blood flow through arterial vasoconstriction. Since the 1950s, physicians have used acute hyperventilation to lower ICP when the ICP was elevated above normal levels.^{7–10} Although no randomized trials have demonstrated improved outcomes associated with hyperventilation after TBI, it became the standard of care for more than 40 years.

In the early 1990s, several authors began questioning the use of hyperventilation in victims of TBI. Using advanced imaging techniques and invasive monitoring, cerebral blood flow in a patient with TBI could be quantified. These studies have shown that in both human and animal subjects, TBI leads to dramatic decreases in CBF to the point of ischemia.^{11–17} This reduction in CBF occurs rapidly following the injury, and is most profound during the first 24 hours.¹¹ Hyperventilation further decreases CBF by hypocapnea-induced vasoconstriction. This further reduction in CBF may cause ischemic neuronal tissue to infarct, leading to worsened brain injury¹⁵ and increased cerebral edema, and paradoxically, may further increase ICP. Thus, contrary to widely held beliefs, hyperventilation may not lower ICP.

In 1991, [Muizelaar] and colleagues published the only

randomized, controlled study to date that compared hyperventilation with normal ventilation in TBI patients.¹¹ They demonstrated significantly worse outcomes at three and six months post-injury in those treated with hyperventilation when compared with normocapneic patients.

Although not the focus of this study, the data failed to show a statistically significant difference in outcome after traumatic brain injury between patients who were acutely hyperventilated versus those who were not. This inability to demonstrate statistical significance may be explained by the sample population size or chosen endpoints. However, the difference in Injury Severity Score (ISS) between groups was statistically significant. This may have led to a bias towards mortality in the normal ventilation group with its statistically significantly higher ISS. The mortality rate of the normally ventilated group is lower than expected, given the ISS mean value of 37. The National Trauma Data Bank (NTDB) has reported mortality rates greater than 35% with ISS of 37.¹⁸ The lack of hyperventilation in the normal ventilation group may have resulted in the decreased mortality for its given ISS when compared with the NTDB mortality rates. The improved outcome for the given ISS in this group of multiple injury patients is likely multifactorial and was not specifically addressed by this study.

Alternatively, the benefits of normal ventilation on cerebral blood flow may be outweighed by the negative effects of systemic acidosis. Patients ventilated to a normal PaCO₂ were significantly more acidotic than were those in the hyperventilation group. The significance of this acidosis and its relation to patient outcome are unknown.

Educational programs should be developed for both prehospital and emergency department personnel to review the risks of hyperventilation in the management of patients with traumatic brain injury. Ventilation protocols restricting the use of prophylactic hyperventilation following severe TBI should be developed and adherence monitored.

Conclusions

This study has demonstrated that hyperventilation of patients with TBI remains common in the prehospital and early hospital setting. The likely reason for this is the variability in tidal volumes delivered with an adult bag-valve mask. The unintentional hyperventilation during manual ventilation may be corrected with the use of end-tidal CO₂ monitoring. Studies in both adults and children have shown correlation between end-tidal and arterial CO₂.^{19–20} and monitoring equipment is available that is compact and simple enough for use in the prehospital setting.

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