A prospective study of the quality of pre-hospital emergency ventilation in patients with severe head injury

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Background. Pre-hospital endotracheal intubation for the purpose of controlled ventilation may prevent secondary brain injury in patients with severe head injury. In view of the limited monitoring devices utilized in the pre-hospital setting, little is known about the ‘quality’ of controlled ventilation initiated in the pre-hospital setting.

Methods. Included in this prospective study were 122 trauma patients with severe head injury (abbreviated injury scale score ≥3). In all cases, the pre-hospital treatment included endotracheal intubation in the field. Upon hospital admission, and maintaining the same ventilation mode and setting initiated in the pre-hospital setting, arterial blood gas samples were taken.

Results. ‘Optimal’ oxygenation (pO2 >100 mm Hg) was achieved in 85.2% and ‘adequate’ ventilation (pCO2 35–45 mm Hg) in 42.6% of the patients upon hospital admission. ‘Optimal’ oxygenation as well as ‘adequate’ ventilation was achieved in 37.7% of the study population. Hypoxaemia (pO2 <60 mm Hg) was observed in 2.5%, hypercapnia (pCO2 >45 mm Hg) in 16.4%, and hypocapnia (pCO2 <35 mm Hg) in 40.9% of the study patients. The incidence of hypocapnia was significantly more frequent in polytraumatized patients. Hypocapnia as well as hypercapnia was significantly more frequent in patients with associated pulmonary contusion.

Conclusions. Endotracheal intubation and controlled ventilation of the lungs initiated in the pre-hospital setting do not guarantee optimal oxygenation and ventilation in patients with severe head injury.

Br J Anaesth 2002; 88: 345–9

Keywords: intubation, tracheal; complications, trauma; ventilation

Accepted for publication: November 18, 2001

Independently, but especially in conjunction with hypotension, hypoxaemia and hypocapnia as well as hypercapnia are recognized as major extracranial variables influencing outcome in severely head injured patients. Early definitive control of the airway by endotracheal intubation and controlled ventilation should reduce the likelihood of hypoxaemia, hypocapnia, and hypercapnia and may prevent secondary brain injury. Recent studies have demonstrated a significantly improved outcome for patients with severe head injury who were treated with endotracheal intubation and controlled ventilation before transfer to hospital. Furthermore, when endotracheal intubation and controlled ventilation was initiated before hospital transfer mortality was significantly reduced in those patients with ‘good’ compared with those with ‘poor’ respiratory therapy (25 vs 61%). In view of less sophisticated ventilator and the limited ability to monitor oxygenation and ventilation in the pre-hospital setting, the ‘quality’ of ventilation initiated in the field is uncertain. We studied the effect of endotracheal intubation and artificial ventilation initiated in the field on arterial PO2 (pO2) and arterial PCO2 (pCO2) in patients with severe head injury.

Patients and methods

We performed a prospective study of trauma patients with severe head injury admitted to the Federal Armed Forces Medical Center, Ulm—a regional trauma centre—from January 1, 1998, to December 31, 1999. Severe head trauma was defined as head or neck Abbreviated Injury Scale (AIS) score of 3 or more. All patients included in the study had their trachea intubated and ventilation of their lungs controlled in the field with the intention to prevent hypoxaemia as well as hypocapnia and hypercapnia.
Endotracheal intubation as well as controlled ventilation was conducted according to the current treatment procedure for the Emergency Medical Services of Ulm County, Germany. In this context, immediately after endotracheal intubation the lungs are ventilated using a manually operated ventilation bag (AMBU-Mark III®, Ambu, Friedburg, Germany), connected to an oxygen demand valve (Dräger, Oxydem®, Dräger, Lübeck, Germany), assuring a fraction of inspired oxygen ($F_{IO2}$) of 1.0. After the correct position of the tracheal tube is confirmed and secured, further pre-hospital artificial ventilation is maintained automatically by a volume constant portable emergency ventilator (Dräger Oxylog®). The ventilator settings used are a tidal volume of 10 ml kg$^{-1}$ of estimated body weight, respiratory weight of 10 min$^{-1}$ and an $F_{IO2}$ of 1.0. During pre-hospital treatment, all patients were continuously monitored by pulse oximetry. Upon hospital admission and maintaining the ventilator settings initiated in the field, arterial blood gas samples were taken.

Table 1 Mechanism of injury within the study population

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>No. (%) of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road accident</td>
<td>92 (75.4)</td>
</tr>
<tr>
<td>Home accident</td>
<td>15 (12.2)</td>
</tr>
<tr>
<td>Sports accident</td>
<td>8 (6.6)</td>
</tr>
<tr>
<td>Homicide/suicide</td>
<td>3 (2.5)</td>
</tr>
<tr>
<td>Working accident</td>
<td>4 (3.3)</td>
</tr>
</tbody>
</table>

Fig 1 Blood gas analysis within the total study collective ($n=122$) upon hospital admission (box-and-whisker plots).

Recorded data included physical characteristics, mechanism of injury, AIS, Injury Severity Score (ISS)\(^10\), arterial blood gas analysis (pH, base excess, $P_{aO2}$, and $P_{aCO2}$) upon hospital admission and vital signs upon hospital admission.

All recorded data were collected concurrently and entered into a relational database management system (Microsoft Access, Microsoft Corporation, Redmond, WA, USA) based on the Trauma Registry of the German Society of Trauma Surgery.\(^11\)

‘Optimal’ oxygenation upon hospital admission was defined as a $P_{aO2}$ greater than 100 mm Hg and ‘adequate’ ventilation as $P_{aCO2}$ 35–45 mm Hg; hypoxaemia was defined as a $P_{aO2}$ less than 60 mm Hg, hypocapnia as a $P_{aCO2}$ less than 35 mm Hg, and hypercapnia as a $P_{aCO2}$ greater than 45 mm Hg.\(^12\)–\(^14\) In order to evaluate the potential influence of age, haemodynamic instability, severe chest injury, or a high injury severity on oxygenation and ventilation, we stratified the study population. Old age was defined as greater than 60 yr of age,\(^15\) haemodynamic instability as a systolic arterial pressure upon hospital admission of less than 90 mm Hg, and severe chest trauma as the presence of pulmonary contusion. Pulmonary contusion was diagnosed by computer tomography, which was conducted on every study patient during the initial in-hospital phase of resuscitation. High injury severity was defined as the presence of polytrauma.\(^16\)
**Statistical methods**

All values in the tables and figures are expressed as mean (SEM) unless otherwise indicated. Each variable was tested for differences between groups by Student’s t test or chi-squared analysis where appropriate. Statistical significance was set at \( P < 0.05 \). Statistical analysis was performed using specialized statistical software (Almo<sup>ã</sup> version 5.0; K. Holm, University of Graz, Austria).

**Results**

Out of 127 trauma victims with associated head injury, five patients were excluded from the study, because of failure to obtain an arterial blood gas sample before the ventilator settings were changed upon hospital admission; therefore, 122 trauma patients (93 male, 29 female, age 37 (21) [range 8–89] yr, ISS 25 (15)) were enrolled into the study. All patients sustained blunt trauma; the detailed analysis of the mechanism of the injury is presented in Table 1.

Subsequent patient evaluation and chest radiogram performed upon admission to the hospital confirmed there were no oesophageal or endobronchial intubations. The results of the arterial blood gas analysis (pH, base excess, \( P_{\text{aO}} \), and \( P_{\text{aCO}} \)) upon hospital admission are presented in Figure 1.

In Table 2 the results concerning ‘optimal’ oxygenation and ‘adequate’ ventilation in the study population are presented.

‘Optimal’ oxygenation upon hospital admission was achieved in 85.2% of the study population, ‘adequate’ ventilation in 42.6% upon hospital admission. Only 37.7% of the study population had been ‘optimally’ oxygenated as well as ‘adequately’ ventilated.

The results concerning the incidence of ‘non-optimal’ oxygenation, hypoxaemia, hypocapnia and hypercapnia within the study population are presented in Table 3.

There were only three cases (2.5% of the total study population) of hypoxaemia upon hospital admission and in all these cases severe extensive pulmonary contusion was present. The majority of the patients with inadequate ventilation upon hospital admission had been hyperventilated (Table 3). The incidence of hypocapnia was significantly more frequent in polytraumatized patients. Hypocapnia as well as hypercapnia was significantly more frequent in patients with associated pulmonary contusion.

**Discussion**

The pre-hospital phase seems to be the most critical period in determining the ultimate outcome after traumatic brain injury. Critical to the outcome are rapid interventions to prevent secondary brain damage. Fundamental goals of the resuscitation of head injured patients are the restoration of oxygenation and ventilation and the restoration of circulating blood volume and arterial pressure. In this context, various studies have demonstrated that endotracheal intubation and controlled ventilation in the field, signifi-

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**Table 2** ‘Optimal’ oxygenation and ‘adequate’ ventilation upon hospital admission within the study population (n=122). HI, head injury; SAP, systolic arterial pressure

<table>
<thead>
<tr>
<th>Group</th>
<th>Optimal oxygenation ((P_{\text{aO}} &gt;100 \text{ mm Hg})) (no. (%) of patients)</th>
<th>Adequate ventilation ((P_{\text{aCO}} 35–45 \text{ mm Hg})) (no. (%) of patients)</th>
<th>Optimal oxygenation + adequate ventilation ((P_{\text{aO}} &gt;100 \text{ mm Hg} + P_{\text{aCO}} 35–45 \text{ mm Hg})) (no. (%) of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total study population ((n=122))</td>
<td>104 (85.2)</td>
<td>52 (42.6)</td>
<td>46 (37.7)</td>
</tr>
<tr>
<td>Isolated HI ((n=38))</td>
<td>32 (84.2)</td>
<td>16 (42.1)</td>
<td>14 (36.8)</td>
</tr>
<tr>
<td>Polytrauma ((n=68))</td>
<td>55 (80.9)</td>
<td>31 (45.6)</td>
<td>26 (38.2)</td>
</tr>
<tr>
<td>Pulmonary contusion ((n=50))</td>
<td>40 (80.0)</td>
<td>20 (40.0)</td>
<td>17 (34.0)</td>
</tr>
<tr>
<td>SAP &lt;90 mm Hg ((n=9))</td>
<td>7 (77.8)</td>
<td>4 (44.4)</td>
<td>4 (44.4)</td>
</tr>
<tr>
<td>Age &gt;60 yr ((n=18))</td>
<td>12 (66.7)</td>
<td>7 (38.9)</td>
<td>5 (27.8)</td>
</tr>
</tbody>
</table>

**Table 3** Incidence of ‘non-optimal’ oxygenation, hypoxaemia, hypo- and hypercapnia upon hospital admission within the study population \((n=122)\) HI, head injury; SAP, systolic arterial pressure. *Significant at \( P < 0.05 \) by chi-squared test

<table>
<thead>
<tr>
<th>Group</th>
<th>Hypoxaemia ((P_{\text{aO}} &lt;60 \text{ mm Hg})) (no. (%) of patients)</th>
<th>‘Non-optimal’ oxygenation ((P_{\text{aO}} 60–100 \text{ mm Hg})) (no. (%) of patients)</th>
<th>Hypocapnia ((P_{\text{aCO}} &lt;35 \text{ mm Hg})) (no. (%) of patients)</th>
<th>Hypercapnia ((P_{\text{aCO}} &gt;45 \text{ mm Hg})) (no. (%) of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total study collective ((n=122))</td>
<td>3 (2.5)</td>
<td>15 (12.3)</td>
<td>50 (40.9)</td>
<td>20 (16.4)</td>
</tr>
<tr>
<td>Isolated HI ((n=38))</td>
<td>0 (0.0)</td>
<td>5 (13.2)</td>
<td>17 (44.7)</td>
<td>2 (5.3)</td>
</tr>
<tr>
<td>Polytrauma ((n=68))</td>
<td>2 (2.9)</td>
<td>9 (13.2)</td>
<td>21 (30.9)*</td>
<td>14 (20.6)*</td>
</tr>
<tr>
<td>Pulmonary contusion ((n=50))</td>
<td>3 (6.0)</td>
<td>6 (12.0)</td>
<td>14 (28.0)*</td>
<td>15 (30.0)*</td>
</tr>
<tr>
<td>SAP &lt;90 mm Hg ((n=9))</td>
<td>0 (0.0)</td>
<td>2 (22.2)</td>
<td>3 (33.3)</td>
<td>2 (22.2)</td>
</tr>
<tr>
<td>Age &gt;60 yr ((n=18))</td>
<td>0 (0.0)</td>
<td>5 (27.8)</td>
<td>8 (44.4)</td>
<td>2 (11.1)</td>
</tr>
</tbody>
</table>
stantly improves outcome in patients with severe head injury, so that it is now a generally accepted therapeutic measure in the pre-hospital management of these patients. However, the results of a number of studies20–22 indicate that the ‘quality’ of such a pre-hospital-initiated controlled ventilation has to be improved. In this study the ‘quality’ of the pre-hospital-initiated controlled ventilation was determined by an arterial blood gas analysis upon hospital admission, which means at the end of the pre-hospital management. Therefore, our results simply reflect the endpoint of a pre-hospital-initiated controlled ventilation.

In only 37.7% of the study population, ‘optimal oxygenation’ as well as ‘adequate’ ventilation was achieved after pre-hospital-initiated endotracheal intubation and artificial ventilation upon hospital admission. A detailed review of study findings identified that this is not so much connected with ‘oxygenation’ but primarily results from ‘ventilation’ problems. Upon hospital admission ‘hypoxaemia’ was evident in only three (2.5%) cases and these three patients had severe chest trauma with extensive bilateral pulmonary contusions. In a similar study20 conducted in 1989 where none of the patients were monitored by pulse oximetry and only one in three of the patients received an $F_{O_2}=1.0$, the proportion of patients who upon hospital admission had ‘hypoxaemia’ was 25%.

An ongoing problem is the pre-hospital control of ‘ventilation’. We were only able to meet the desired goal of ‘normoventilation’ in 42.6% of the cases. In the majority of cases (40.9%), the emergency physician unintentionally hyperventilated the lungs, whereas hypoventilation only occurred in 16.4% of cases. Kehrberger and colleagues20 came to a similar conclusion. Hyperventilation may aggravate cerebral ischaemia20,22 and, therefore, should be avoided during the pre-hospital phase.13 This especially applies to patients with ‘polytrauma’, who in our study were more often unintentionally hyperventilated. These patients additionally are at risk of hypotension, a major determinant in the outcome from severe head injury.16

The ‘quality’ of pre-hospital-initiated ventilation seems to be influenced mainly by the less sophisticated ventilation devices used in the pre-hospital setting in comparison with the in-hospital setting. In the case of manual ventilation using a self-inflating manual resuscitator (i.e. AMBU®-bag) with an additional oxygen supply, it is not possible to measure minute volume; the ‘quality’ of ventilation depends on the experience and skill of the person ‘squeezing’ the bag.23,24 Most of the automatic emergency ventilators allow the ventilatory frequency and minute volume to be set but only some of them (i.e. Oxylog 2000®) measure these preset variables. A number of studies23,25,26 have shown, that in nearly all commonly used automatic emergency ventilators, the delivered minute volume differs by up to ±20% from the preset minute volume.

Pulse oximetry has proved useful in the detection of hypoxia in the pre-hospital setting.3 On the other hand there is still no reliable, as well as practical, method for monitoring and controlling ‘ventilation’ in the pre-hospital setting. Blood gas analysis, the gold standard, seems not to be a practical method for the pre-hospital setting. The use of capnography as a non-invasive as well as continuous monitoring method for controlling ‘ventilation’ is limited in hypovolaemic patients or patients with severe lung contusion.3,27

Without any doubt, endotracheal intubation and controlled ventilation in the field improves the outcome in patients with severe head injury.4–7 However, our data document that endotracheal intubation and controlled ventilation in the field do not guarantee ‘optimal’ oxygenation and ‘adequate’ ventilation in patients with severe head injury. In order to optimize the pre-hospital respiratory therapy in such trauma victims, additional respiratory monitoring is necessary.

Acknowledgements

The authors would like to thank Kenneth M. Sutin, MD, Assistant Professor of Clinical Anesthesiology and Clinical Surgery from the Department of Anesthesiology, Bellevue Hospital Center, New York University School of Medicine, New York, USA for his extraordinary support in the study and in preparing this publication.

References

6 Winchell RJ, Hoyt DB. Endotracheal intubation in the field improves survival in patients with severe head injury. Arch Surg 1997; 132: 592–7
The American Association of Neurological Surgeons and the Brain Trauma Foundation. *Guidelines for the Management of Severe Head Injury: The Use of Hyperventilation in the Acute Management of Severe Traumatic Brain Injury*. The American Association of Neurological Surgeons and the Brain Trauma Foundation, Chicago, 1995; 105


Kehrberger E, Hörtling H. Blutgasanalysen nach präklinischer kontrollierter Beatmung durch den Notarzt. Der Notarzt 1990; 5: 2–4


