Airway and ventilation management strategies for hemorrhagic shock. To tube, or not to tube, that is the question!

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ABSTRACT: Many standard trauma management guidelines advocate the early use of endotracheal intubation (ETI) and positive pressure ventilation as key treatment interventions in hemorrhagic shock. The evidence for using these airway and ventilation strategies to manage a circulation problem is unclear. The potentially harmful effects of drug-assisted intubation and positive pressure ventilation include reduced cardiac output, apnea, hypoxia, hypocapnea (due to inadvertent hyperventilation), and unnecessarily prolonged on-scene times. Conversely, the beneficial effects of spontaneous negative pressure ventilation on cardiac output are well described. Few studies, however, have attempted to explore the potential advantages of a strategy of delayed intubation and ventilation (together with a policy of aggressive volume replacement) in shocked trauma patients. Given the lack of evidence, the decision making around how, when, and where to subject shocked trauma patients to intubation and positive pressure ventilation remains complex. If providers choose to delay intubation, they must have the appropriate skills to safely manage the airway and recognize the need for subsequent intervention. If they decide to perform intubation and positive pressure ventilation, they must understand the potential risks and how best to minimize them. We suggest that for patients with hemorrhagic shock who do not have a compromised airway and who are able to maintain adequate oxygen saturation (or mentation if monitoring is unreliable), a strategy of delayed intubation should be strongly encouraged. (J Trauma Acute Care Surg. 2018;84: S77–S82. Copyright © 2018 Wolters Kluwer Health, Inc. All rights reserved.)

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The presurgical management of life-threatening hemorrhage is one of the greatest challenges in the treatment of patients with traumatic injuries. During the initial assessment, providers must identify and treat time-critical life or limb-threatening injuries in order of priority. A structured approach is widely used in which airway management comes second only to the management of visible catastrophic hemorrhage. At this stage of resuscitation care, many providers resort to the “known”: intubation and positive pressure ventilation to secure the airway and manage ventilation of patients in hemorrhagic shock. This would seem to be treating a “C” (circulatory) problem with an “A” (airway) solution. We describe the reasoning behind using these advanced airway and ventilation management techniques to treat patients with hemorrhagic shock and discuss whether these interventions may have an adverse impact on patient outcomes.

PRESURGICAL INTUBATION AND VENTILATION IN HEMORRHAGIC SHOCK

Hemorrhage is known to be the greatest single cause of potentially preventable death on the battlefield. The increased awareness of the role of hemorrhage control in battlefield trauma management has had a profound effect on doctrine, training, and equipment with consequent impact on survival rates. Providers are taught to focus on the rapid control of hemorrhage and to manage the airway by conventional means, including securing a definitive airway by surgical techniques (tracheotomy) or ETI.

Many treatment guidelines suggest that the placement of an endotracheal tube by rapid intubation is a key component of the management of hemorrhagic shock in trauma. The perils of using anesthesia in shocked trauma patients have been known for many years, with one author even suggesting in 1943 that in war surgery, “intravenous anaesthesia is also an ideal method of euthanasia.” While the accuracy of Halden’s data has subsequently been questioned, it does highlight that there have been concerns for many years about the risks of using drug-assisted intubation and positive pressure ventilation in patients with hemorrhagic shock.

Why Do We Want to Intubate Patients?

In patients with direct airway injury or obstruction, there is clearly an urgent need to open and maintain the airway. This can safely be provided in most cases using simple airway opening maneuvers and adjuncts. When these strategies fail, or there is
significant airway injury, many civilian emergency medicine service (EMS) providers resort to drug-assisted intubation to secure the airway. In the military environment, there is good evidence that prehospital providers have high success rates with securing a definitive airway using surgical techniques at this stage of airway care.8–10 When, however, advanced providers and resources are available far forward (usually on evacuation platforms or at Role 2 hospital facilities), then patients may also undergo drug-assisted ETI for a number of other indications. One of the most common reasons to perform intubation is the theoretical concern that patients with a reduced level of consciousness may be unable to protect their own airway. The evidence behind the widely accepted standard that patients with a Glasgow Coma Score (GCS) of 8 or less must be intubated is poor.11 Emergency airway interventions are also routinely performed in the prehospital arena for significant breathing problems (respiratory distress), circulation problems (hemorrhagic shock), disability problems (low GCS or combative, agitated head-injured patients), and other reasons such as pain management (multiple distressing injuries and amputations). Reviews of recent practice describe the many perceived indications to perform intubation but not the evidence behind them.12,13 Whatever the indications, the potential negative impact on a patient with hemorrhagic shock must not be forgotten.

The decision when to undertake this potentially dangerous intervention in these challenging and sometimes hostile environments requires experience, skill, and judgment; and there is evidence that outcomes are influenced by the level of experience of the provider.14 As in many other areas of medicine, it is maybe harder to decide when not to perform an intervention than it is to actually undertake that intervention. Deciding not to perform intubation and ventilation in the presence of hemorrhagic shock requires the associated skills to safely manage such patients by using alternative strategies. These may include management of agitated patients with the safe use of sedation agents such as ketamine, or even placement of surgical airways to allow spontaneous ventilation (using local anesthetic techniques in conscious patients with significant airway injury).

In shocked trauma patients, ETI represents an attempt to maintain a patent airway and maximize the tissue delivery of oxygen to the tissues. Below a critical level of oxygen delivery, an incurred oxygen debt begins to accumulate with associated rise in lactate and eventual irreversible cellular damage.15 Fick’s equation (Fig. 1) demonstrates that oxygen delivery is directly proportional to hemoglobin concentration, oxygen saturation, and cardiac output; and hence, all efforts must be made to maximize these values during resuscitation. This is especially true when delays in definitive surgical control of hemorrhage are involved. Indeed, hemoglobin must be retained and losses replaced. Intubation and positive pressure ventilation represent an attempt to maximize oxygen saturation but at what cost to cardiac output and hence oxygen delivery?

### Adverse Effects of Drug-Assisted Intubation and Positive Pressure Ventilation

Drug-assisted intubation and subsequent positive pressure ventilation carry many well-described risks, especially to the patient in shock. In a retrospective database review of 444 trauma patients undergoing intubation on arrival in a Canadian tertiary trauma center over a 15-year period, 161 patients (36.3%) experienced postintubation hypotension, suggesting that this procedure is not without risk of impact on cardiac output.16 Another study of 2,403 patients who underwent emergency tracheal intubation in the emergency department found that 41 patients (1.7%) had a postintubation cardiac arrest within 10 minutes of the procedure. Systolic hypotension before intubation, defined as a systolic blood pressure of 90 mm Hg or less, was independently associated with postintubation cardiac arrest (odds ratio, 3.67 [95% confidence interval, 1.58–8.55], \( p = 0.01 \)).17 This highlights the importance of volume resuscitation for these patients. It also emphasizes the fact that airway interventions and positive pressure ventilation should not be the standard response for these patients, but instead treating the shock state with blood product replacement and hemostasis.

There is a wide choice of sedating agents used to assist performing presurgical ETI, but for patients with significant traumatic injury, many providers opt for ketamine given its safety profile and proven efficacy in remote and austere settings.18 Etomidate is also widely used in the United States, as it has a favorable hemodynamic profile in shocked patients, but has been withdrawn from use in many countries owing to concerns about adrenal suppression. While many other sedating agents are available, almost all carry a significant risk of provoking hypotension in the presence of hemorrhagic shock.19 Although ketamine is widely used as the first-line sedation agent for shocked patients, there have been case reports of deaths with its use.20 In vitro, ketamine has a negatively inotropic effect; but in vivo, this is thought to be outweighed by endogenous catecholamine release.21,22 It is postulated that the deaths associated with ketamine administration for induction in these patients may have occurred due to pre-existing catecholamine depletion, although the adverse effects of positive pressure ventilation may have also contributed. One study of the potential hypotensive effects of ketamine in patients undergoing prehospital rapid sequence intubation (RSI) demonstrated that while only 2% of patients with a low shock index (<0.9) became hypotensive following ketamine administration, a far larger proportion of patients (26%) with a high shock index (≥0.9) developed hypotension.23

Neuromuscular blocking agents are routinely given as part of the regime of agents for RSI, and these also carry significant

\[
\text{DO}_2 = 1.34 \times \text{Hb} \times \text{SaO}_2 \times \text{CO}
\]

\( \text{DO}_2 \) (oxygen delivery), \( \text{Hb} \) (haemoglobin concentration), \( \text{SaO}_2 \) (oxygen saturation), \( \text{CO} \) (cardiac output)

**Figure 1.** Fick’s Equation.
risks in patients with hemorrhagic shock. Paralysis renders the patient apneic, which will cause the partial pressure of carbon dioxide (Pco2) to rise until the patient is ventilated. The resulting respiratory acidosis will exacerbate any existing metabolic acidosis due to the hemorrhagic shock state. Furthermore, any patient who becomes apneic is at immediate risk of hypoxemia until ventilation is re-established. Studies have shown that intubation and repeated laryngoscopy attempts can carry significant risk of hypoxemia and cardiac arrest.

Positive pressure ventilation has long been known to decrease cardiac output. Raised intrathoracic pressure during inspiration associated with the positive pressure of ventilation reduces the already compromised venous return, right ventricular output, and pulmonary blood flow and hence reduces cardiac output. In expiration, the intrathoracic pressure decreases to allow venous return, right ventricular output, and pulmonary blood flow. Furthermore, there is evidence from animal studies that hyperventilation in the presence of hemorrhagic shock, particularly in the presence of associated traumatic brain injury (TBI). Hyperventilation reduces Pco2, which in turn causes cerebral vasodilatation, hence reducing cerebral perfusion. Furthermore, there is evidence from animal studies that hyperventilation is not only unnecessary but also contributes to a reduction in cardiac output.

A further, often unrecognized complication of intubation in the presence of hemorrhagic shock is the time that it takes to prepare for and deliver this intervention. Patients with life-threatening hemorrhage that has not been successfully managed by direct compression have a time critical need for damage control surgery (or other interventions) that require urgent transport to an appropriate medical treatment facility. Intubation may delay that process.

These potentially harmful effects of drug-assisted intubation and positive pressure ventilation are summarized in Table 1.

### OUTCOMES

We are not aware of any published randomized controlled trials comparing intubation against conservative airway management strategies for the presurgical management of trauma patients with hemorrhagic shock. Available evidence is based largely on retrospective database reviews that seek to review the recorded outcomes in patients who received intubation and compare with those patients who did not receive the intervention (or extrapolation from other scenarios and medical conditions). Some studies include patients who underwent ETI without the use of drugs, while others include drug-assisted or RSI. One retrospective database review compared trauma patients who underwent ETI before arrival in hospital with those who were intubated upon arrival in the emergency department (ED). Patients with a GCS of less than 8 and an injury severity score of greater than 16 were included, these being considered as surrogates for inability to maintain an airway or being more likely to be hypovolemic. Patients who were intubated in the field were reported to be more likely to be hypotensive upon arrival in ED and had worse survival, but the cause of this was unclear. Prehospital vital signs were not recorded. While the authors concluded that this showed an association between prehospital ETI and poor outcomes, it is clear that this association may be due to the fundamental differences between the two population groups compared. Patients who can be intubated in the field by paramedics without the use of drugs were more likely to be more severely injured and hence have worse outcomes. A recent systematic review and meta-analysis comparing mortality rates of adult trauma patients undergoing prehospital ETI to those undergoing ED ETI showed higher mortality rates after prehospital ETI (although the authors noted that the overall quality of evidence is very low). A further retrospective database review has also suggested an association between field intubation and higher mortality specifically for trauma patients with hemorrhagic shock. In this study, the authors identified 552 adult trauma patients who received massive transfusion on arrival at hospital. Sixty-three of these patients (11%) underwent field intubation before arrival in hospital, with the remaining 489 (89%) not undergoing intubation before hospital. The group that underwent field intubation had lower GCS, lower median systolic blood pressure, and higher median injury severity score. While it would seem that the two groups were fundamentally different, the authors attempted to control for this with the use of multivariate regression analysis and concluded that field intubation may be associated with higher mortality in this group of patients with hemorrhagic shock requiring massive transfusion. Critics suggest, however, that the statistical methods used are unlikely to control for the significant differences between the two groups and that from these data, it is impossible to attribute the higher mortality to the effect of intubation and positive pressure ventilation alone.

These findings suggest that it may be impossible in retrospective studies to decide whether poor outcomes are due to the intubation and ventilation process itself or the injuries for which the providers decided that the patient required this intervention. Suggestion of harm is found in one review of moderately injured patients who underwent intubation but who at subsequent review were felt not to have required that intervention. In this retrospective trauma registry review, patients who were intubated but who were only moderately injured (GCS ≥ 13, maximum Abbreviated Injury Scale score for any one region ≤3, no packed cells given in ED) were matched with similarly injured patients who were not intubated. The results demonstrated that the intubated

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**TABLE 1. Potential Pitfalls of Drug-Assisted Intubation and Positive Pressure Ventilation in Hemorrhagic Shock**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Potential Adverse Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuromuscular blocking agents</td>
<td>Apnea, hypoxemia, respiratory acidosis</td>
</tr>
<tr>
<td>Sedation agents</td>
<td>Hypotension, respiratory depression, hypoxemia</td>
</tr>
<tr>
<td>Intubation attempts</td>
<td>Hypoxemia, unrecognized oesophageal placement of endotracheal tube</td>
</tr>
<tr>
<td>Positive pressure ventilation</td>
<td>Reduced cardiac output, hypothermia,</td>
</tr>
<tr>
<td>Inadvertent hyperventilation</td>
<td>Cerebral vasodilatation</td>
</tr>
</tbody>
</table>
patients spent longer at scene, had more volume replacement, more coagulation derangement and lower hemoglobin concentra-
tions than the nonintubated patients. With all its limitations, this may be one of the few publications that address the negative
effect of unnecessary intubations.

Animal studies currently provide the only available pro-
spective evidence for comparison of airway and ventilation man-
agement strategies in hemorrhagic shock. One study used a swine
model of exsanguinating hemorrhage to explore the potential
benefits of spontaneous ventilation compared with positive pres-
sure ventilation in the presence of hemorrhagic shock. This
study found that spontaneously ventilating subjects maintained
cardiac output and body temperature at higher levels than those
receiving positive pressure ventilation. Such studies would
seem to suggest that in hemorrhagic shock, a strategy of conser-
ervative airway management that allows spontaneous ventilation
might protect patients from the risks of impaired cardiac output
associated with positive pressure ventilation, provided that the
airway is patent and the patient is not managed with any sedation
agents that cause respiratory depression.

There may also be a potential beneficial role of negative
pressure created by inspiratory resistance. One study of human
volunteers subjected to an artificial shock state demonstrated
that the use of an impedance threshold device in spontaneously
breathing subjects delayed the onset of cardiovascular col-
lapse. This would seem to support that a strategy of deferring
intubation and positive pressure ventilation in hemorrhagic
shock states may have a protective effect on cardiac output.

Head Injury

The initial care of patients with both hemorrhagic shock
and head injury presents particular challenges in the presurgical
environment. It may be impossible to discern whether a patient
has a low GCS as a result of direct brain injury or as a conse-
quence of hemorrhagic shock. Hence, strategies to manage the
critically injured patient with hemorrhagic shock and a reduced
GCS must ensure the optimum management of any potential asso-
ciated brain injury. Any advanced airway interventions must
have a minimal effect on cerebral perfusion and intracranial
pressure and must not cause unnecessary delays in the transport
of the patient. The use of drug-assisted intubation and positive
pressure ventilation has significant potential to do harm in the
presence of TBI. It has been shown that a single excursion of
blood pressure below 90 mm Hg systolic is independently asso-
ciated with a more than doubling of mortality in TBI with re-
peated episodes associated with an up to eightfold increase in
mortality. A single episode of oxygen saturation below 90% was
also reported to be independently associated with at least
doubling of mortality in TBI, while the combination of both
hypoxia and hypotension has been described as associated with
a sixfold increase in mortality in TBI. Endotracheal intuba-
tion can be extremely challenging in the prehospital environ-
mant; and in this stressful situation, EMS providers have frequently
been observed to hyperventilate patients following intubation.
This is known to cause hypocapnea, which in turn produces poten-
tially harmful vasoconstriction in the brain. Hyperventilation
in patients with TBI following RSI has been shown to more than
double mortality. However, for patients who do have severe
TBI, there is some evidence that prehospital RSI may be associ-
ated with improved neurological outcome.

DISCUSSION

While the use of presurgical intubation and positive pres-
sure ventilation in the management of patients with hemorrhagic
shock is widespread, the evidence behind the use of these airway
and breathing interventions to address a circulation problem is
unclear. Furthermore, the adverse effects of intubation, particu-
larly in patients with hemorrhagic shock, have a sound physio-
logical basis and are well described. Hence, although there is
often certainty that a given patient with hemorrhagic shock will
need to be intubated to achieve surgical control of hemorrhage,
the timing of this procedure is unclear. An important analogy is
the deliberate delay in the induction of anesthesia for the patient
with a leaking abdominal aortic aneurysm until appropriate hemo-
static resources are available. Although few vascular anesthesi-
thets would ever contemplate initiating positive pressure ventilation
in the prehospital setting or even the ED for a shocked patient with
a leaking abdominal aortic aneurysm, trauma patients with similar
hemodynamic compromise are often subjected to intubation and
positive pressure ventilation in these settings, with occasionally
lethal results. The timing and location of intubation for all pa-
ients with hemorrhagic shock must be carefully considered. De-
ivering rapid intubation skills into the prehospital arena, where
most preventable deaths occur, requires significant investment
in training, equipment, and skills to manage the very few patients
who may succumb to airway obstruction and who are already
often managed successfully by relatively inexperienced providers
using basic airway techniques and surgical cricothyroidotomy. It
must not be forgotten that most preventable trauma deaths occur
owing to hemorrhage and that damage control resuscitation teams
must put the management of hemorrhage at sufficiently high pri-
ority that complex, time-consuming, and potentially dangerous
solutions to airway problems are not used when far simpler stra-
tegies are likely to be effective. If indicated, intubation under such
circumstances should be performed in conjunction with aggres-
sive blood product administration to mitigate the considerable
risks of the procedure.

Thus, although decision making is complex, providers
must know when not to deploy this skill as much as when they
should use it. The possible time delays that this intervention
may cause must be acknowledged. Advanced providers must
be trained not only in the techniques of intubation and positive
pressure ventilation but also in the other measures that may allow
safe deferral of these interventions. The importance of simple air-
way management techniques must be emphasized and strategies
taught to avoid premature use of neuromuscular blocking agents
and positive pressure ventilation. Providers must be taught the
clinical skills and provided with appropriate equipment (pulse
oximetry and capnography) to monitor unintubated patients and
facilitate early identification of airway or ventilatory failure. Even
when advanced providers and equipment are available either in the field or on arrival in a medical treatment facility,
these providers must then be fully aware of the hazards of drug-
assisted intubation and positive pressure ventilation, particularly
for patients with hemorrhagic shock. Knowledge of the hypoten-
sive effects of induction agents, risks of respiratory acidosis due
to apnea during laryngoscopy, dangers of multiple intubation attempts, impairment of cardiac output resulting from positive pressure ventilation, and effects of hyperventilation, particularly in patients who may have TBI, must be emphasized. Providers must be prepared to consider other management strategies that minimize these risks, including rapid evacuation of the casualty (with or without using simple airway management techniques) while monitoring the casualty and the oxygen saturation.

CONCLUSION

There is no good quality prospective evidence to support the use of prehospital intubation for the management of patients with hemorrhagic shock. Available evidence even includes evidence of harm for such patients who were intubated and for those who did not need ETI (or when the intervention could have been postponed until the arrival to the hospital) but received this treatment. Similarly, there is a paucity of evidence of the effects of not intubating patients with severe hemorrhagic shock who traditionally have been considered to warrant this intervention. Animal studies confirm the physiologic advantages of not performing positive pressure ventilation in the presence of hemorrhagic shock and, where feasible, spontaneous ventilation should be considered to maintain cardiac output and hence maximize tissue oxygen delivery and negative pressure ventilation. This will require adaptation of the clinical practice guidelines, education, and training, but mostly requires appreciation of the substantial detrimental effects that intubation and positive pressure ventilation have in bleeding casualties. Whenever possible, spontaneous ventilation should be preferred over drug-assisted intubation and positive pressure ventilation. We suggest that for patients with hemorrhagic shock who do not have a significant airway injury and who are able to maintain adequate oxygen saturation (or mentation, in absence of reliable monitoring), a strategy of delayed intubation should be strongly encouraged.

AUTHORSHIP

G.S. suggested the review. A.J.H. undertook the initial literature review and wrote the first draft of the manuscript. E.G. created the initial outline, assisted with the first draft, and oversaw subsequent critical revisions of the manuscript. All authors contributed equally to further literature review, critical revisions, and writing of the final manuscript.

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DISCLOSURE

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REFERENCES


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