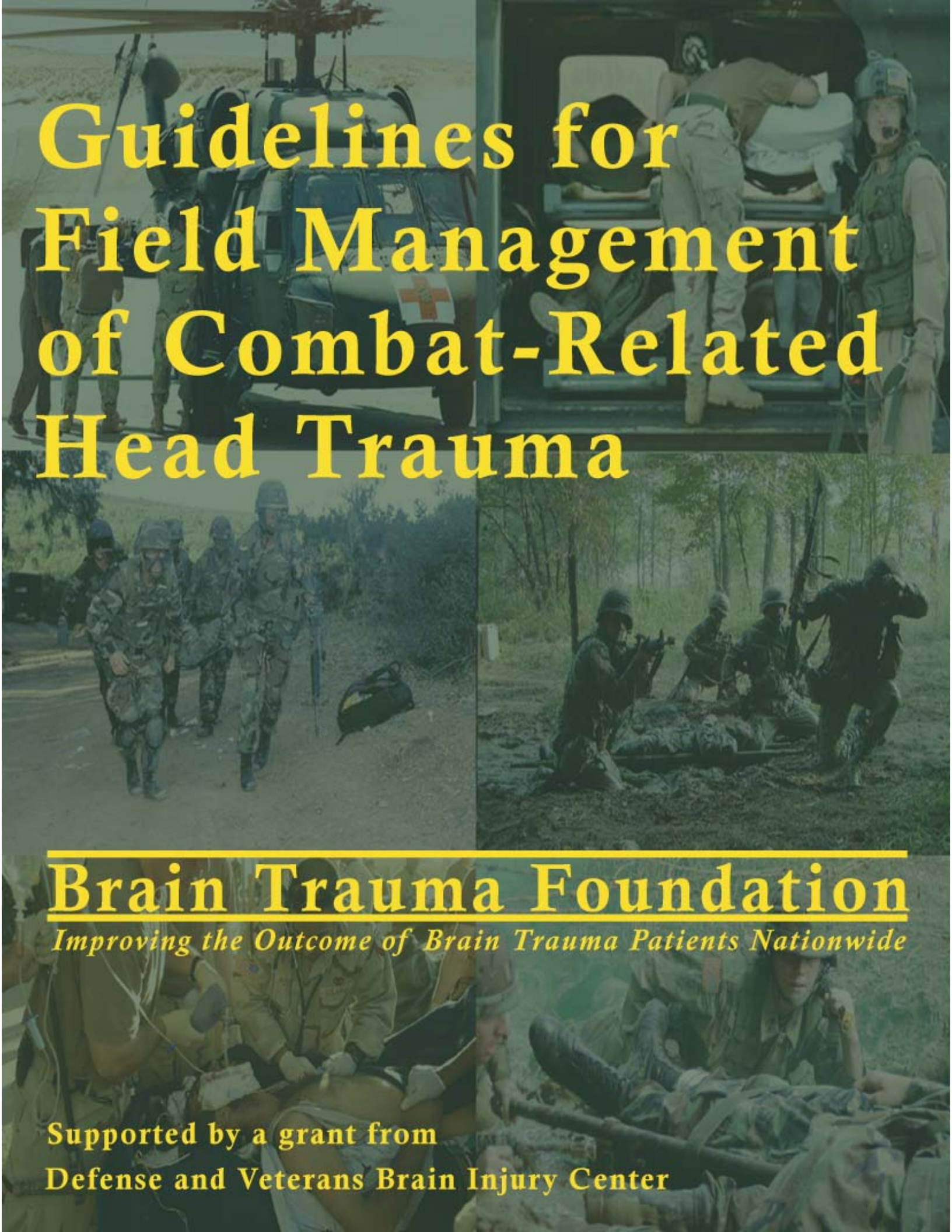

Guidelines for Field Management of Combat-Related Head Trauma

Brain Trauma Foundation

Improving the Outcome of Brain Trauma Patients Nationwide

Supported by a grant from
Defense and Veterans Brain Injury Center

GUIDELINES FOR THE FIELD MANAGEMENT OF COMBAT-RELATED HEAD TRAUMA

Brain Trauma Foundation
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GUIDELINES FOR THE FIELD MANAGEMENT OF COMBAT-RELATED HEAD TRAUMA

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DISCLAIMER OF LIABILITY

The information contained in the *Guidelines for the Field Management of Combat-Related Head Trauma*, which reflects the current state of knowledge at the time of completion (November 2005), is intended to provide accurate and authoritative information about the subject matter covered. Because there will be future developments in scientific information and technology, it is anticipated that there will be periodic review and updating of these Guidelines. These Guidelines are distributed with the understanding that the Brain Trauma Foundation is not engaged in rendering professional medical services. If medical advice or assistance is required, the services of a competent physician should be sought. The recommendations contained in these Guidelines may not be appropriate for use in all circumstances. The decision to adopt a particular recommendation contained in these Guidelines must be based on the judgment of medical personnel, who take into consideration the facts and circumstances in each case and on the available resources.

INTRODUCTION: *FIELD MEDICINE IN THE FORWARD AND TACTICAL ENVIRONMENT*

There are many unique aspects of providing medical care in the combat environment. The vast majority of the considerations covered also apply to providing care for the neurologically injured. This chapter will review some of the major issues related to providing combat care with emphasis on neurological injury and illness. While a majority of the chapter will focus on the difficulties inherent in this environment, the final portion will discuss some advantages.

As the following chapters will outline, the majority of available recommendations are extrapolated from civilian data. In some instances, it will be obvious that the best civilian data have direct application to military scenarios. In others, it will be equally obvious that the best available civilian recommendation is impractical at best, and potentially threatening to life or mission accomplishment at worst. We have attempted to discriminate between the two as often as possible, based on the available military-specific literature and personal experience. Ultimately, it will be the decision of the individual medic and/or the unit chain of command as to whether a particular diagnostic or therapeutic maneuver can be implemented. The general direction we have taken with our recommendations is that the best-known community standard should be implemented whenever possible.

The recommendations in the following chapters are based on the best available data, and the authors maintained a patient-driven focus during development. In other words, each recommendation was created based upon the best care possible for the patient, in spite of the fact that tactical limitations may prevent this level of care from actually being available to all patients at all times. It should also be noted that guidelines such as these are quite different than protocols developed by medical facilities or military units. Protocols should be generated locally to give very specific directions as to how individual providers are to act in a variety of situations. Guidelines such as these are intended to serve as a starting point for the development of facility-specific protocols.

Patient-driven guidelines can and, we feel, should also drive educational and technological development. Once the “best possible” care is defined, it is incumbent upon trainers and developers to make that care available as far forward as possible. For instance, if it is proven that monitoring tissue oxygenation saves lives, it becomes important to provide combat medics with a practical means of doing so.

Factors that create limitations in the level of medical care available in the combat environment include the overall tactical scenario, physiologic parameters associated with combat, and logistics. Our ability to develop standards for optimal management is, as will be seen in the following chapters, limited by a lack of scientific data. The majority of the recommendations provided are extrapolated from civilian data. While many of these recommendations will be both practical and applicable, the ability of the individual medic to provide this care may be limited.

There are numerous tactical considerations that can impact medical care. Noise and light discipline will restrict a complete history and physical examination. Individual unit mobility and the availabil-

ity of casualty evacuation assets can delay movement of a seriously wounded casualty to the next level of care. Rapid movement of a tactical unit may prevent casualty assessment or implementation of a care plan. The inability to secure an area under heavy fire can hamper care plans or prevent resupply. Chemical, biological, or nuclear contamination may have a significant impact on the neurologic system. Additionally, presence of these agents precludes effective examination and limits care due to the donning of chemical protective gear by both patient and provider.

While the medic is clearly responsible for providing medical care, it is important to remember that the overall tactical scenario is dictated by the chain of command. Communication between medics and the chain of command will improve both casualty care and accomplishment of the mission. The chain of command must be kept informed of the needs of the patients, including evacuation priorities, resupply requirements, and movement restrictions, to name only a few. The medic must also be kept informed of the battlefield limitations influencing all of the above. It cannot be overemphasized how important this type of communication becomes in a hostile environment, nor how important it is to develop these lines of communication and relationships prior to entering a combat zone. Training exercises should be realistic and should include medical care scenarios within the tactical plan.

Multiple issues within the combat environment affect human physiology. Regardless of whether the battle is taking place in a hot or cold environment, dehydration is common. The ability of the body to compensate for fluid loss associated with wounding may be compromised if the casualty is severely dehydrated before injury. The stress of combat leads to increased anxiety and an increase in circulating catecholamines. This can be protective, but also may result in changes in mental status that make neurologic assessment more difficult. The psychological effects of heavy combat may also result in acute stress reactions, creating a casualty who is disoriented, incoherent, or mute. Exposure to high velocity blast can result in a transient loss of consciousness, deafness, or visual dysfunction secondary to globe deformation, retinal injury, or traumatic iridoplegia. It is important to remember that interpretation of the scoring on the Glasgow Coma Scale may be influenced by some of these issues in the hyperacute setting. Triage decisions should take this into account. The Glasgow Coma Scale is extremely important for assessment and continued monitoring of neurologic status, but it is important to keep in mind that its usefulness as a prognostic indicator is limited.

Logistical support varies greatly depending on the location of the medical provider. The independent duty corpsman aboard ship may have hundreds or thousands of pounds of supplies and equipment at his or her disposal, whereas the medic with a small unit traveling on an independent reconnaissance patrol for several weeks will only have what can be carried, or in the best of circumstances, resupplied as needed. Any type of resupply may also be a challenge. In the absence of ground or aerial resupply, several casualties may rapidly deplete available bandages, fluids, and medications. Tactical considerations such as speed of unit movement, intensity of enemy engagement, weather, terrain, and visibility all may work together to create an impossible situation for resupply.

All of these individual components affect the practicality of providing high-level care to a neurologically wounded servicemember. In this type of environment, where decisions must be made about casualty movement on the battlefield, casualty evacuation, distribution of limited resources, and many other parameters, experience matters. Years of medical training and experience, even outside a combat environment, can give the medic the knowledge to be able to adapt to multiple patient scenarios in varying environments while providing the best possible care.

Although there are many limitations, it should not be assumed that all aspects of neurologic trauma care in the combat environment are negative. First and foremost, the dedication of all medics to saving casualties is extraordinarily high. While there is clearly much heroism seen in the provision of trauma care in the civilian setting, an overriding principle taught to providers is to avoid becoming a casualty. In the military, the mandate to leave no one behind creates a level of confidence in the warrior and a level of fearlessness in the medic that has not been routinely duplicated in the civilian setting. From a physiologic standpoint, there are few populations where the medical providers can uniformly expect an extremely high level of physical fitness, psychological preparedness, and compliance with therapeutic recommendations. Finally, the long and glorious history of battlefield medics has created a situation where the level of cooperation from the chain of command and from fellow service members is unique. This advantage allows the medic to leverage the resources of the entire unit when practical to assist in the care of the wounded.

We have no doubt that the medics of the future will continue to serve in the time-honored tradition of the medics of the past. It is our hope that this course will highlight current recommendations with regard to the care of the neurologically injured patient. We wish safety and success to each and every one of you.

METHODOLOGY: *GUIDELINE DEVELOPMENT RATIONALE AND PROCESS*

In order to create an evidence-based document relevant to the field treatment of brain injury, the literature was searched for each topic for publications on brain injury that pertained to the prehospital or austere environment. From the comprehensive literature searches, articles were selected which were relevant to the field management of traumatic brain injury (TBI) and utilized human data. Articles with outcomes related to morbidity and mortality were preferred. In establishing a literature base for recommendations, we generally only include publications that involve human subjects. However, in these Guidelines, we have included some publications that involve training with mannequins given that such training is an accepted practice in assessing competency for EMT certification. Additional studies were, in general, referenced only as a part of background discussion. The prehospital literature was heavily utilized; military literature was used where it was available.

Each chapter follows the same format:

I. Conclusions or Recommendations (for Treatment chapters only)
   A. Standards
   B. Guidelines
   C. Options
II. Overview
III. Search Process
IV. Scientific Foundation
V. Summary
VI. Key Areas for Future Investigation
VII. Evidence Table
VIII. References

Section I describes the conclusions the authors formulated from the literature. For the chapters on assessment, which included prognosis studies, the authors summarized the evidence rather than made recommendations. Thus, their findings are listed as "Conclusions" for any diagnostic or prognostic assessment and as "Recommendations" where the end result is a specific treatment or set of treatment options. Section VII in each chapter provides a brief analysis of the literature that supports the conclusions or recommendations, whereas Section VIII references a more extensive list of studies.

The Guidelines follow the recommendations of the Institute of Medicine (IOM) Committee to Advise the Public Health Service on Clinical Practice Guidelines[1] outlined below:

1. There should be a link between the available evidence and the recommendations.

2. Empirical evidence should take precedence over expert judgment in the development of guidelines.

3. The available scientific literature should be searched using appropriate and comprehensive search terminology.

4. A thorough review of the scientific literature should precede guideline development.

5. The evidence should be evaluated and weighted, depending on the scientific validity of the methodology used to generate the evidence.

6. The strength of the evidence should be reflected in the strength of the recommendations, reflecting scientific certainty (or lack thereof).

7. Expert judgment should be used to evaluate the quality of the literature and to formulate guidelines when the evidence is weak or nonexistent.

8. Guideline development should be a multidisciplinary process, involving key groups affected by the recommendations.

The American Medical Association (AMA) and many specialty societies, including the American Association of Neurological Surgeons (AANS) and the American Academy of Neurology (AAN), have further formalized this process by designating specific relationships between the strength of evidence and the strength of recommendations.[2–4] Evidence is indexed into several classes.

Class I evidence is derived from the strongest studies of therapeutic interventions (randomized controlled trials) in humans. Used to support treatment recommendations of the highest order, they are called practice **standards**.

Class II evidence consists of comparative studies with less strength (nonrandomized cohort studies, randomized controlled trials with significant design flaws, and case-control studies) that are used to support recommendations called **guidelines**.

Class III evidence consists of other sources of information, including case series and anecdotal or descriptive studies that support practice **options**.

Standards, guidelines, and options reflect a high, moderate, or unclear clinical certainty, respectively, as indicated by the scientific evidence available. The overall term for all of the recommendations is **practice parameters**, or more commonly and what we called here, practice guidelines.

In partnership with the Evidence-based Practice Center (EPC) of Oregon Health & Science University (OHSU), a rigorous protocol for classification of evidence was adopted by the Brain Trauma Foundation (BTF) for all of its guidelines endeavors. Criteria for classification of evidence based on study design and quality are in Table 1.

Table 1. Criteria for Classification of Evidence

Class of Evidence	Study Design	Quality Criteria
I	Good quality randomized controlled trial (RCT)	Adequate random assignment method. Allocation concealment. Groups similar at baseline. Outcome assessors blinded. Adequate sample size. Intention-to-treat analysis. Follow-up rate ≥ 85%. Differential loss to follow-up. Maintenance of comparable groups.
II	Moderate or poor quality RCT	Violation of one or more of the criteria for a good quality RCT.[1]
II	Good quality cohort	Blind or independent assessment in a prospective study, or use of reliable data in a retrospective study.[2] Non-biased selection. Follow-up rate ≥ 85%. Adequate sample size. Statistical analysis of potential confounders.[3]
II	Good quality case-control	Accurate ascertainment of cases. Nonbiased selection of cases/controls with exclusion criteria applied equally to both. Adequate response rate. Appropriate attention to potential confounding variables.
III	Moderate or poor quality cohort	Violation of one or more criteria for a good quality cohort.[1]
III	Moderate or poor quality case-control	Violation of one or more criteria for a good quality case-control.[1]
III	Case series, databases, or registries	

[1]Assessor needs to make a judgment about whether one or more violations are sufficient to downgrade Class of study based upon the topic, the seriousness of the violation(s), their potential impact on the results, and other aspects of the study. Two or three violations do not necessarily constitute a major flaw. The assessor needs to make a coherent argument why the violation(s) either do or do not warrant a downgrade.

[2]Reliable data are concrete data such as mortality or re-operation.

[3]Publication authors must provide a description of robust baseline characteristics, and control for those that are unequally distributed between treatment groups.

The authors of these guidelines, entitled *Guidelines for the Field Management of Combat-Related Head Trauma*, represented a multidisciplinary group consisting of neurosurgeons, trauma surgeons, neurointensivists, and paramedics from both the civilian and the military sectors. They were selected for their expertise in TBI, combat medicine, or military medical education. All the military authors had recent combat experience. Each author independently conducted a MEDLINE or comparable search, reviewed and evaluated the literature for their assigned topics, then cooperated in formulating the Guidelines during several work sessions aimed at completing understandable and applicable recommendations based on the best evidence available. The template for these Guidelines was the first edition of the *Guidelines for Prehospital Management of Traumatic Brain Injury* developed by BTF in 1999–2000.

The *Guidelines for the Field Management of Combat-Related Head Trauma* covers three main areas: assessment, treatment, and triage and transport decisions. A consensus assessment and treatment algorithm is included to provide an overview of all these aspects of management. At several points during the development process, a review team comprised of representatives of the armed services medical "school houses," military neurosurgery and trauma surgery, and military medic instruction evaluated the document, and their comments were delivered to the authors. Several draft documents were produced and evaluated before this document was finalized and published.

The Brain Trauma Foundation of New York City managed the guidelines project under a grant from the Defense and Veterans Brain Injury Center (DVBIC) through the Henry M. Jackson Foundation for the Advancement of Military Medicine, Inc. DVBIC is a collaboration between the Department of Defense and the Department of Veterans Affairs. Its mission is to serve active duty military, their dependents, and veterans with TBI through state-of-the-art medical care, innovative clinical research initiatives, and educational programs. The Brain Trauma Foundation, founded in 1986, is a not-for-profit organization dedicated to improving the outcome of traumatic brain injured patients. It achieves its mission through evidence-based guidelines development, the education and training of medical personnel, quality improvement programs, and clinical research.

In 1995, BTF brought together a team of neurosurgeons from around the country to develop the first evidence-based guidelines for neurotrauma care. The *Guidelines for the Management of Severe Traumatic Brain Injury* was developed according to procedures set forth by the American Medical Association. The Guidelines cover specific treatments and the areas of care specifically related to the acute, intensive care phase of injury. Today, these Guidelines are approved by the American Association of Neurological Surgeons and endorsed by the Congress of Neurological Surgeons, the World Health Organization Neurotrauma Committee, and the New York State Department of Health, among others. In addition, the Guidelines appear in the American College of Surgeons handbook *Resources for Optimal Care of the Injured Patient*.

BTF has also developed *Guidelines for the Surgical Management of Traumatic Brain Injury*, addressing key topics in the acute neurosurgical management of TBI related to indications, technique and timing of operative procedures. The Guidelines are revised and updated approximately every five years. BTF has promoted the Guidelines nationally and internationally through lectures, presentations, the hands-on training of medical professionals, and distance learning.

It is understood that military operations take place in a wide range of physiological and logistical environments. The ability of the combatant to survive injury is heavily dependent on the circumstances of that injury. The goal of these Guidelines is to provide dispassionate analysis of the known benefits and risks of therapies available to the brain injured patient in the field. In this way, these Guidelines strive to be a resource and a tool for the combat medic, physician, commanding officer, and logistician who must then make the tough "on the ground" therapeutic, tactical, and logistical decisions that will ultimately result in optimum care for the injured combatant.

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ASSESSMENT: *OXYGENATION AND BLOOD PRESSURE*

I. CONCLUSIONS

A. Hypoxemia and hypotension are two considerable factors associated with poor prognosis in severe traumatic brain injury (TBI) patients in the prehospital setting.

B. All reasonable efforts should be made to avoid hypoxemia and hypotension in the brain injured casualty. Reasonable efforts will be dictated by situation, available resources, and the tactical situation.

1. Hypoxemia should be prevented in the brain injured casualty. Pulse oxymetry should be instituted as soon as possible along the chain of evacuation. Low oxygenation should be addressed as soon as it is practical to do so along the chain of evacuating.
2. Hypotension should be avoided. Blood pressure should be measured as soon as possible along the chain of evacuation. Fluid resuscitation should be instituted for patients with systolic pressure < 90 as soon as resources and the tactical situation allow.

II. OVERVIEW

Hypoxemia, as evidenced by apnea, cyanosis, saturations < 90% or a PaO_2 < 60 mm Hg, and hypotension, as evidenced by as a single episode of systolic blood pressure < 90 mm Hg, have been shown to be among the top five predictors of poor outcome in patients with TBI. It is therefore felt to be appropriate to identify and address these conditions as soon as available resources and the tactical situation allow.

Recognizing that assessment and treatment modalities may not be readily available in the forward military environment, the following is but a guide to the level of care that is recommended within certain tactical and operational limitations:

A. *Combat Medic/Tactical Assessment*: Determine patency of airway and note any obstruction. Ask the patient to speak. Look at the patient's chest and observe breathing motion. Feel for carotid and radial pulses. Mental status is very useful in assessing non-comatose patients since inadequate oxygenation and blood pressure may also alter mental status.

B. *Evacuation Assessment:* Measure oxygenation with SPO_2 monitor. Measure BP and record. When possible, place a BP monitoring device.

C. *Battalion Aid Station Assessment:* If possible, measure oxygenation with SPO_2 monitor. When equipment is not available, assess patient as recommended for first responder. Measure BP and record. When equipment is not available, feel for carotid and radial pulses.

D. *Forward Surgical Assessment*: Measure oxygenation with SPO_2 monitor. Measure BP with BP monitoring device.

III. SEARCH PROCESS

MEDLINE was searched from 1966 to 2005 using the following search terms: "head injury" or "traumatic brain injury" and "airway" or "hypoxemia" or "hypotension" or "oxygenation assessment" or "blood pressure assessment" or "field assessment of oxygenation and blood pressure." References from the book, *Guidelines for Prehospital Management of Traumatic Brain Injury*, chapter on "Assessment: Oxygenation and Blood Pressure" were also reviewed. Some studies of in-hospital patients with severe head injury and hypotension were used to corroborate out-of-hospital hypotension studies.

IV. SCIENTIFIC FOUNDATION

Assessment of Oxygenation

The concept of secondary injury is fundamental to understanding the management of TBI. Hypoxia has long been known to be a significant source of secondary brain injury. Significant Class III data have validated the concept that patients with an oxygen saturation < 90% have significantly worse outcome than patients whose oxygen saturations are > 90%.[1,2] It should be emphasized that this recommendation is based on epidemiological data.

While it has never been demonstrated that improving blood oxygen saturation in the field improves outcome, a significant body of clinical research seems to support the assertion that this should be so. Knowing that blood oxygen saturation is > 90% is a long way from knowing anything about oxygen delivery to the brain. While the brain's general susceptibility to hypoxia is understood in general terms, the unique susceptibility of the injured brain to hypoxia is very poorly understood.

It is well known that the brain has very little cellular or tissue oxygen reserve and so is highly dependent on timely delivery of oxygen via the circulation. In general, the brain can only survive for 7 minutes without oxygen before the threat of irreversible cellular damage becomes very high. The cellular physiology of this process has been investigated, as have the biochemical consequences of low oxygen availability and ATP depletion in nerve cells. Nerve cells, glial cells, and cerebral vascular endothelium all appear to have unique susceptibilities to low oxygen tension, and so it is not surprising that patients with low oxygen saturation in the blood after injury may fair worse.[3] It appears that the injured brain is even more susceptible to hypoxia than the healthy brain, but this assertion remains untested by all but epidemiological data.

Clinical studies in humans have demonstrated that patients with less oxygen delivered to their brain after injury appear to have worse outcomes.[4,5]

One method for assessing the adequacy of the brain's oxygen delivery is to measure how much oxygen the brain uses. This can be estimated by knowing the oxygen content of the blood entering the cranial vault, the systemic oxygen content, and then measuring the content of the blood leaving the cranial vault, which is done by placing a sensor or sampling catheter high in the jugular vein. By subtracting the oxygen content of the blood leaving the head from the content of the blood entering the head, a rough estimate of the brain oxygen utilization can be obtained. The resulting number is known as the AVO2 difference.

This number reflects the balance between the oxygen delivered to the brain and the metabolic activity, and therefore the oxygen demand, of the brain. A metabolically active brain will require more oxygen and more delivery of oxygen than a quiet brain. The brain will be injured when this demand is not met. The AVO2 difference really assesses if brain demand is being met.

The AVO2 difference is useful, but some estimates of the adequacy of oxygen delivery to the brain can be made by simply measuring the saturation of blood leaving the brain in the jugular bulb, the $SjvO_2$. Most patients have saturations of 55–69% in blood leaving the brain. Studies have shown that patients with jugular saturations < 50% have worse outcomes.[6,7]

The real issue, however, is cerebral tissue oxygen tension. This can be measured via cerebral tissue oxygen monitoring. Normal cerebral tissue oxygen pressures, $PbrO_2$, are approximately 32 mm Hg. Studies have shown that patients whose $PbrO_2$ is allowed to dip to 15 or lower do significantly worse. Elegant work has stratified patients into groups with episodes of progressively lower brain tissue oxygen pressures, with increasingly poorer outcomes as the brain tissue oxygen pressure is allowed to go lower and the time the brain stays at these suppressed levels increases.[4] Some brain tissue data has suggested that hypoxic brain injury is cumulative, that periods of recovery between episodes of hypoxia do not erase the negative effect of the hypoxia and that in fact, multiple brief episodes of hypoxia can be as damaging as a single prolonged hypoxic event.

Assessment of Blood Pressure

The assessment of blood pressure follows much the same logic as that for assessment of oxygen. The ultimate problem appears to be the delivery of adequate supplies of oxygen and other substrate to the brain after injury. For adequate supplies of oxygen to reach the brain, the blood must be well oxygenated, the saturations give some indication of this, and cerebral blood flow must be adequate. While systemic blood pressure is a poor way to assess cerebral blood flow, it is not unreasonable to assume that patients with low systemic blood pressure are at higher risk for low cerebral blood flow and so should be at higher risk for poor outcomes.

In fact, good epidemiologic data has demonstrated that patients with low systolic pressure have poorer outcomes from head injury than patients who are not permitted to have their systolic blood pressure dip below 90 mm Hg.[1,2,8–15] Again, this argument is an epidemiological one as is the selection of 90 mm Hg as a cutoff for poor outcomes. This level was simply selected and it turned out that patients whose blood pressure was below 90 mm Hg did worse. If there is a better cutoff value or what that value might be is unknown.

Manley et al.[16] have given us some insight into the dynamics of oxygen delivery in an animal model. He looked at brain tissue oxygen pressures during hemorrhagic shock. He showed how brain tissue oxygen pressure declined as oxygen delivery was compromised by hypovolemia due to bleeding. The hypothesis is that patients with low oxygen saturation in their blood and low systemic blood pressure are at higher risk for low oxygen delivery to the cerebral parenchyma after injury and so are at higher risk for subsequent hypoxic and ischemic injury. Good Class III epidemiology seems to confirm this suspicion.[1–3,9–15,17]

In his analysis of the prospectively collected National Trauma Coma Data Bank data, Chesnut et al.[1] looked at the impact of hypoxemia, defined as apnea, cyanosis, saturations < 90% or a PaO_2 < 60 mm Hg, and hypotension, defined as a single episode of systolic blood pressure < 90 mm Hg on outcome. Each was in the top five independent predictors of poor outcome.

A smaller Class III study from Australia also found the hypotension and hypoxemia were significant predictors of mortality.[8] An interesting prehospital study from Italy looked at arterial saturation in the field in 50 patients and found a significant association between arterial saturation and outcome.[2]

Table A. Outcome by Secondary Insult at Time of Arrival at Traumatic Coma Data Bank Hospital for Mutually Exclusive Insults[a]

			Outcome (%)		
Secondary Insult	**N (patients)**	**% of Total Outcome**	**Good or Moderately Disabled**	**Severely Disabled or Vegetative**	**Dead**
Total cases	699	100	43	20	37
Hypoxemia[b]	78	11	45	22	33
Hypotension[b]	113	16	26	14	60
Neither	456	65	51	22	27
Both	52	8	6	19	75

[a]Adapted from Chesnut,[1] 1993
[b]Hypoxemia PaO_2 < 60 mm Hg; hypotension: SBP < 90 mm Hg

A single episode of hypotension was associated with a doubling of mortality and an increased morbidity when compared with a matched group of patients without hypotension (Table A). Notably, the TCDB study defined hypotension and hypoxemia as a single reported incidence that meets the definition of each and does not require a protracted duration for secondary insult.

V. SUMMARY

Patients with hypoxemia or hypotension have poorer outcomes from TBI than patients who avoid these conditions. It would therefore seem appropriate to correct these conditions as soon as resources and tactical situation allow.

A structured and prioritized approach to combat casualties is important because it enables a clear assessment process for the medic to follow. We acknowledge the Advanced Trauma Life Support Course™ of the Committee on Trauma of the American College of Surgeons.[19] The course prioritizes airway before breathing and breathing before blood pressure and these strategies have been adopted worldwide. Other accepted methodological approaches to the comprehensive assessment and management of the TBI patient can be found in various sources.[20] Standardized assessments are crucial to the appropriate assessment and then subsequent proper management of casualties in the forward area.

VI. KEY ISSUES FOR FUTURE INVESTIGATION

1. Prospective evaluation of assessment tools.
2. What is the optimum threshold for systolic blood pressure resuscitation?
3. Are there better field resuscitation end points?
4. What is the optimum oxygen saturation in the field?

VII. EVIDENCE TABLE

Chesnut,[1] 1993

Description of Study: A prospective study of 717 severe head injury patients admitted consecutively to four centers investigated the effect on outcome of hypotension (systolic blood pressure [SBP] < 90 mm Hg) occurring from injury through resuscitation.

Classification: III

Conclusions: Hypotension was a statistically independent predictor of outcome. A single episode of hypotension during this period doubled mortality and also increased morbidity. Patients whose hypotension was not corrected in the field had a worse outcome than those whose hypotension was corrected by time of emergency department arrival.

Fearnside,[8] 1993

Description of Study: A prospective study of 315 severe head injury patients admitted consecutively to a single-center investigated prehospital and inhospital predictors of outcome.

Classification: III

Conclusions: Hypotension (SBP < 90 mm Hg) occurring at any time during a patient's course independently predicts worse outcome.

Gentleman,[9] 1992

Description of Study: A retrospective study of 600 severe head injury patients in three cohorts evaluated regarding the influence of hypotension on outcome and the effect of improved prehospital care in decreasing its incidence and negative impact.

Classification: III

Conclusions: Improving prehospital management decreased the incidence of hypotension but its impact on outcome in patients suffering hypotensive insults maintained as a statistically significant, independent predictor of poor outcome. Management strategies that prevent or minimize hypotension in the prehospital phase improves outcome from severe head injury.

Gopinath,[4] 1999

Description of Study: $SjvO_2$ and $PbtO_2$ were successfully monitored in 58 patients with severe head injury. The changes in $SjvO_2$ and $PbtO_2$ were compared during ischemic episodes.

Classification: III

Conclusions: Both monitors provide complimentary information, and neither monitor alone identifies all episodes of ischemia. The best strategy for using these monitors is to take advantage of the unique features of each monitor. $SjvO_2$ should be used as a monitor of global oxygenation; but $PbtO_2$ should be used as a monitor of local oxygenation, ideally with the catheter placed in an area of the brain that is vulnerable to ischemia but that may be salvageable with appropriate treatment.

Hill,[10] 1993

Description of Study: Retrospective study of the prehospital and emergency department resuscitative management of 40 consecutive multi-trauma patients. Hypotension (SBP ≤ 80 mm Hg) correlated strongly with fatal outcomes. Hemorrhagic hypovolemia was the major etiology of hypotension.

Classification: III

Conclusions: Improving the management of hypovolemic hypotension is a major potential mechanism for improving the outcome from severe head injury.

Jeffreys,[11] 1981

Description of Study: A retrospective review of hospital records of 190 head injury patients who died after admission. Hypotension was one of the four most common avoidable factors correlated with death.

Classification: III

Conclusions: Early hypotension appears to be a common and avoidable cause of death in severe head injury patients.

Kohi,[12] 1984

Description of Study: A retrospective evaluation of 67 severe head injury patients seen over a 6-month period was correlated with 6-month outcome. For a given level of consciousness, the presence of hypotension resulted in a worse outcome than would have been predicted.

Classification: III

Conclusions: Early hypotension increases the mortality and worsens the prognosis of survivors in severe head injury.

Kokoska,[18] 1998

Description of Study: A retrospective review of 72 pediatric patients (ages 3 months–14 years) with regard to hypotensive episodes and outcome. Hypotensive episode was defined as a blood pressure reading of less than the fifth percentile for age that lasted longer than 5 minutes.

Classification: III

Conclusions: Prehospital, ED, and ICU hypotensive episodes were significantly associated with poor outcome.

Miller,[13] 1982

Description of Study: 225 severe head injury patients were prospectively studied with respect to the influence of secondary insults on outcome. Hypotension (SBP < 95 mm Hg) was significantly associated with increased morbidity and mortality. The predictive independence of hypotension in comparison with other associated factors, however, was not investigated.

Classification: III

Conclusions: Strong statistical relationship between early hypotension and increased morbidity and mortality from severe head injury.

Miller,[17] 1978

Description of Study: 100 consecutive severe head injury patients were prospectively studied with respect to the influence of secondary insults on outcome (report of first 100 patients in subsequent report of 225 patients [vide supra]). Hypotension (SBP < 95 mm Hg) associated with a trend (not statistically significant) toward worse outcome in entire cohort; the trend met statistical significance for patients without mass legions. Seminal report relating early hypotension to increased morbidity and mortality. Influence of hypotension on outcome was not analyzed independently from other associated factors.

Classification: III

Conclusions: First prospective report implicating early hypotension as a major predictor of increased morbidity and mortality from severe head injury.

Obrist,[7] 1984

Description of Study: Cohort study of 31 patients with severe TBI in whom the effect of aggressive hyperventilation on ICP, CBF, and arteriovenous difference in oxygen content ($AVdO_2$) was examined.

Classification: III

Conclusions: Hyperventilation had a much more direct effect on CBF reduction (29 of 31 patients) than it did on ICP reduction (15 of 31 patients). Aggressive hyperventilation in 10 patients ($PaCO_2$) of 23.2 ± 2.8 mm Hg) led to $AVdO_2$ values of 10.5 ± 0.7 vol% and CBF values of 18.6 ± 4.4ml/100 g/min.

Pigula,[14] 1993

Description of Study: 58 children (< 17 years old) with severe head injuries were prospectively studied for the effect of hypotension (SBP < 90 mm Hg) on outcome. An episode of hypotension decreased survival fourfold. This finding was confirmed in a concomitant analysis of the effect of hypotension on outcome in 509 patients in the National Pediatric Trauma Registry. Hypotension appeared to eliminate any neuroprotective mechanisms normally afforded by age.

Classification: III

Conclusions: The detrimental effects of hypotension (SBP < 90 mm Hg) on outcome appear to extend to children.

Robertson,[6] 1989

Description of Study: 51 patients who were comatose due to head injury, subarachnoid hemorrhage, or cerebrovascular disease. CBF was measured daily for 3–5 days, and in 49 patients CBF was measured every 8 hours for 5–10 days after injury.

Classification: III

Conclusions: These studies suggest that reliable estimates of CBF may be made from $AVdO_2$ and AVDL measurements, which can be easily obtained in the intensive care unit.

Stocchetti,[2] 1996

Description of Study: A prospective study of data collected at the accident scene from 50 severely head-injured patients rescued by helicopter. Instead of classifying blood pressure or oxygen saturation measurements as above or below a certain threshold, systolic blood pressure was classified as < 60 mm Hg, 60–80 mm Hg, 81–99 mm Hg, or > 99 mm Hg, and arterial oxygen saturation measured via pulse oximeter was classified as < 60%, 60–80%, 81–90%, or > 90%. Patients with lower blood pressure or oxygen saturation fared worse than those with higher values.

Classification: III

Conclusions: Low prehospital blood pressures or oxygen saturations are associated with worse outcomes. Arterial oxygen saturation of 80% or lower was associated with a 47% mortality compared with 15% mortality when oxygen saturation was greater than 80%.

Valadka,[5] 1998

Description of Study: Forty-three severely head-injured patients who were not obeying commands on presentation or whose condition deteriorated to this level shortly after admission had intracerebral placement of Licox (n = 39) or Paratrend (n = 4) PO2 probes during craniotomy or in the intensive care unit.

Classification: III

Conclusions: Both the Licox and Paratrend probes functioned well in room air and in the Level I control. However, in the zero-oxygen solution, the Paratrend probes gave an average reading of 7.0 ± 1.4 torr (0.9 ± 0.2 kPa), compared with 0.3 ± 0.3 torr (0.04 ± 0.04 kPa) for the Licox probes. Analysis of the $PbtO_2$ monitoring data suggested that the likelihood of death increased with increasing duration of time at or below a $PbtO_2$ of 15 torr (2.0 kPa) or with the occurrence of any $PbtO_2$ values of ≤ 6 torr (≤ 0.8 kPa).

Winchell,[15] 1996

Description of Study: From a trauma registry of 1013 patients, 157 patients with severe anatomic head injury (i.e., Head and Neck Abbreviated Injury Scale Score of 4 or 5) were identified. These included 88 patients with Glasgow Coma Scale score > 8. The 157 patients had a total of 831 episodes of systolic hypotension (< 100 mm Hg) while in the ICU. The total number and the average daily number of hypotensive events were independent predictors of death in the ICU.

Classification: III

Conclusions: Transient hypotensive (systolic BP < 100 mm Hg) episodes in the ICU are associated with a significantly worse outcome. Mortality rose from 9–25% in patients who had 1–10 hypotensive episodes and in 35% in patients with > 10 episodes.

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ASSESSMENT: *GLASGOW COMA SCALE SCORING AND ASSESSMENT OF PUPILS*

I. CONCLUSIONS

A. Data are insufficient to support a treatment standard for Glasgow Coma Scale (GCS) scoring and pupil assessment in patients with severe traumatic brain injury (TBI) incurred in combat.

B. Measuring GCS score and assessing pupils:

1. How to measure:
   The GCS score and pupil assessment should be determined by direct clinical examination.
2. Who should measure:
   a. The far forward first medical provider (medic) should obtain the first score. At each echelon of care, the primary medical care provider should be responsible for measuring the GCS and assessing the pupils.
   b. Competence in measuring the GCS and assessing the pupils should be maintained.
3. When to measure:
   a. The GCS and pupils should be measured as soon as tactically possible.
   b. At regular intervals, the GCS and pupils should be reassessed, in addition to measuring GCS before transport to the next echelon of care and after arrival at the higher echelon.

C. For acute pupillary dilation, brain herniation should be considered and appropriate intervention instituted (see Treatment section). However, patients exposed to chemical agents or explosive blast may experience iridoplegia, which is not indicative of herniation.

II. OVERVIEW

The Glasgow Coma Score was developed by Teasdale and Jennett[1] in 1974 as a means by which to quantitatively describe the level of consciousness of patients who had suffered TBI. Since then, it has gained wide civilian use and is applied most appropriately as a measure of severity of TBI. While the GCS directly measures the depth of coma through a battery of metrics, practitioners are able to use depth of coma as a proxy for severity of injury.[2] The GCS is an inexpensive highly reliable method of recording and reporting the neurologic state of TBI patients. In the civilian sector, a wide variety of health care providers are trained to perform this test.

Clinical examination of pupils is an important aspect of neurologic assessment. Pupil assessment is defined as each pupil's size at baseline and each pupil's response to direct light stimulation. It can be performed easily and quickly, and results are objective. Asymmetry between the sizes of the two pupils in the same patient can be indicative of severe brain dysfunction.[3] Among patients suffering from TBI, pupil dilation and paralysis of pupillary constriction when stimulated by light is associated with poor clinical outcome.[4,5] Further, in the acute clinical setting, these can also be indicative of brain herniation.[3]

The GCS score and pupillary exam is taught to every military medical care provider. It is part of the core curriculum for 91W advanced medics. It is also part of the Advanced Trauma Life Support (ATLS) course of the American College of Surgeons.[6] ATLS certification is a requirement of all military physicians, regardless of specialty. Although each medical officer is not required to maintain ATLS certification, they must have taken and passed the course at least once in their career.

The retention of the GCS among military physicians is poor.[7] The retention among combat medics in the field is unknown. However, one can assume that without regular refresher courses, retention will also be poor.

The usefulness of a quantitative clinically relevant measure of head injury severity, such as the GCS, cannot be understated. In the setting of head injury, using simple methods, such as examination of the pupils, to make early diagnosis of brain dysfunction and herniation can be lifesaving. Military medical providers have to make triage decisions. Triage is perhaps the most important function a medic on the battlefield can perform. Triage is the basis of who gets medical care, who gets evacuated, with what priority and by what means. Unlike the civilian sector, the sickest patients do not typically get priority. A measure of head injury severity like GCS is particularly helpful in enabling the first provider to be able to make these difficult decisions.

Both the GCS and abnormal pupillary function are not intended for and thus do not identify mild TBI, nor are they intended for making a definitive disposition regarding long term outcome. Studies of military patients from Operation Iraqi Freedom and Operation Enduring Freedom suggest that a significant portion of combat casualties may have mild TBI without a history of loss of consciousness or awareness. Numerous troops complain of nausea, vertigo, frequent headache, and loss of appetite and sleep at weeks and months after returning from deployment. Not all of these troops had abnormal GCS scores in theater or several days and weeks post injury.[8] A TBI casualty can have a GCS score of 15 and have marked impairment of mental status. GCS is probably most helpful in the acute phase of assessment and intervention, but a more functional score should be utilized for further care and definitive dispositions. Additionally, in a 2005 publication, Davis et al.[9] found that GCS values have the limited ability to predict severity of injury and length of stay in the intensive care unit. However, there is a statistically significant correlation between Head AIS and GCS score.

III. SEARCH PROCESS

The search engine PubMed was used. The time period was 1980 to 2005. The queries were based on the terms “head injury,” “military,” “GCS,” “pupils” and “pupillary response.” Changing the terms to “brain injury,” “TBI,” “loss of consciousness,” and “combat” did not identify any other articles. Queries using “GCS” and “performance” and “first providers” and “military” and “pupils” yielded no articles. Changing the terms to “medic,” “retention,” and “combat” did not identify any other articles. Review of the bibliography of identified articles also did not identify any other pertinent articles.

IV. SCIENTIFIC FOUNDATION

Medical care on the modern battlefield remains dangerous and chaotic. The modern combat medic is a highly skilled first provider who works under austere conditions. The ability to con-

duct meaningful research under these conditions is very difficult, and thus has not been done. The conclusions are extrapolated from the civilian sector and also from studies conducted at higher echelons of care. This too is problematic. Civilian EMT paramedics have significantly more medical training than combat medics. Civilian EMTs have continued refresher training, to which, in theater of war, medics do not have access. Civilian paramedics are able to use more medical resources, some of which have significant implications on the GCS score, such as artificial airways and mechanical ventilation; neither are presently available on the battlefield. For these reasons, the prognosis of a civilian casualty will be better than that of a military patient with the same GCS score.

The mechanisms of military head injury are different than those of civilians. In combat, many military head injury patients suffer penetrating head injury from fragments.[10–13] Civilian patients rarely do. Another battle etiology is exposure to explosive blast.[14] Although a closed head injury, the similarity of blast-induced neuropathophysiology with civilian closed head injury from blunt impact or acceleration-deceleration, such as from motor vehicle crashes, is unknown. Even gunshot wounds are different in military and civilian patients. Gunshot wounds incurred in battle are typically from high velocity rifle bullets whereas civilian patients usually suffer gunshot wounds from low velocity handgun rounds.[12,13,15–18]

Basing prehospital conclusions on studies conducted at the hospital is intrinsically flawed. The medical care and resources at a military hospital are vastly superior to what is available to a combat medic in the field. Thus, GCS and pupillary function may not have the same prognostic value.

Military Prehospital GCS Score and Patient Outcome

No studies have been published validating the GCS score in the prehospital far forward combat casualty care setting. Also, there are no military specific studies published that determined the efficacy of the GCS score in determining severity of head injury from the types of head wounds incurred in combat.

Military Prehospital Pupil Assessment and Patient Outcome

No studies have been published validating the pupil assessment in the prehospital far forward combat casualty care setting. Also, there are no published studies that determined the efficacy of pupil assessment in determining or prognosticating severity of head injury from the types of head wounds incurred in combat.

Military Hospital GCS Score and Patient Outcome

GCS score at time of admission to the military surgical hospital is shown to be predictive of severity of head injuries incurred in battle. Aarabi (1990) conducted a retrospective analysis of 435 Iran-Iraq War (1980–88) military patients. GCS score was assigned by the neurosurgeon at the time of admission to the Iranian hospital. There was a positive correlation between GCS and good outcome.[19] Of patients who had admission GCS scores of 13–15, 6% died and 52.2% survivors had focal neurological deficits at discharge. This contrasts with patients with admission GCS scores of 3–5, among whom 65% died and 100% of survivors had focal neurological deficits at discharge. Brandvold et al.[20] performed a retrospective study of 116 military patients who had suffered TBI during hostile actions in Lebanon from 1982–1985. Of these, 67 were Israeli

and 46 could be followed after hospital discharge. GCS score correlated with mortality and clinical outcome. For patients with GCS scores of 3 to 4, 80% died; with GCS scores of 5–12, 12% died; and with GCS scores of 13–15, only 6% died. Using the Glasgow Outcome Scale (GOS), of the patients who presented with GCS scores of 3–4, the few survivors were all Grades III and IV. For those with GCS scores of 5–8, many were Grades III and IV but an increasing number of patients were Grades I and II. If the GCS score was 9–15, almost all patients were Grades I and II.

Admission GCS score on time of arrival at a Yugoslav military hospital is also predictive of survival. Turina et al.[21] studied 43 war TBI Yugoslavian military patients. The GCS was higher among survivors as was the War Head Injury Score (WHIS), 11 and 14 respectively. The converse was true for nonsurvivors, in whom the mean GCS score was 4 and WHIS 7.

GCS is shown to be predictive of mortality from traumatic cerebral aneurysm following battle-related penetrating brain injury. Aarabi (1995) completed a study of 1306 Iran-Iraq War military patients who had suffered TBI. Of these, 19 had traumatic cerebral aneurysms. Of patients with traumatic cerebral aneurysms and GCS scores of 5–8, 84% died. In contrast, in spite of having aneurysm, those who had GCS scores of 9–15, only 6.6% died.[22]

However, GCS was not found to be predictive of risk of CNS infection following war-related TBI. Aarabi et al. (1998) published a study of 964 Iran-Iraq War military patients with penetrating brain injuries. GCS was assigned at the time of admission to the Iranian hospital. There was no correlation between GCS and prevalence of CNS infection.[23]

In a study of debridement of combat-related head wound, the GCS score also was not found to be predictive of outcome in military TBI patients. Amirjamshidi et al.[24] reported a study of 99 Iran-Iraq War military patients who had suffered fragment-penetrating brain injuries. GCS was assigned at admission to an Iranian hospital. The primary intention of the study was to study the effect of wound debridement on clinical outcome. Patients ranged in GCS scores from 8–14. Within this range, the GCS score did not correlate with clinical outcome.

Civilian Prehospital GCS Score and Patient Outcome

The reliability and clinical benefit of civilian sector prehospital GCS scoring has been reviewed. The Brain Trauma Foundation's *Guidelines for Prehospital Management for Traumatic Brain Injury* recommends it for this use.[25]

Civilian Prehospital Pupil Assessment and Patient Outcome

The reliability and clinical benefit of civilian sector prehospital pupil assessment has been reviewed. Again, the Brain Trauma Foundation's *Guidelines for Prehospital Management for Traumatic Brain Injury* recommends it for this use.[26]

GCS Score and Pupil Assessment for Military Patients Suffering from Penetrating Head Injury

To date, there are no published studies validating the use of GCS or pupil assessment for determining the severity of brain injury from U.S. military relevant mechanisms of brain injury, such as fragment or high velocity bullets.

GCS Score and Pupil Assessment for Civilian Patients Suffering from Penetrating Head Injury

The reliability and clinical benefit of GCS scoring and pupil assessment for civilian penetrating head injuries has been reviewed. The *Guidelines for Management of Penetrating Head Injuries* recommends it for this use.[27]

Reliability of Prehospital Scoring

The reliability of GCS scoring by U.S. military medical providers is poor. In a prospective study by Riechers et al.[7], 90 military physicians were tested on their knowledge of the GCS score. In spite of 87% having had completed ATLS training that included GCS, less than 15% were able to accurately describe each aspect of the score. Poor performance correlated with time since training and with infrequency of GCS use. There is, however, civilian data that show that GCS values have the limited ability to predict severity of injury and length of stay in the intensive care unit. They did find that there is a statistically significant correlation between Head AIS and GCS score.[9] The use of reference aids as a means of improving performance was not studied.

V. SUMMARY

Glasgow Coma Scale (GCS) scoring and assessment of pupils should be done in every patient with suspected TBI. The first provider should obtain these measurements as soon as possible, at regular intervals thereafter and before and after transport. Worsening of either should initiate appropriate treatment interventions (see Treatment section).

No Class I evidence is available on which to base conclusions for these parameters. There are very limited numbers of studies conducted on the battlefield of any level on which to determine this. Studies performed in the civilian sector were reviewed in order to evaluate the situation. There are no data from the U.S. military indicating the reliability of the GCS or pupillary response to light as a reliable indicator of the severity of head injury incurred in battle. In the civilian sector, Class II data from civilian victims suffering from traumatic head injury does demonstrate GCS's reliability, particularly with repeated scoring and improvement or deterioration of the score over time. Class II data from civilian patients demonstrate pupil assessment as a useful method for prognosticating poor outcome and as a diagnostic indicator of brain dysfunction, including herniation.

VI. KEY ISSUES FOR FURTHER INVESTIGATION

A number of issues require study to evaluate the usefulness of the GCS score and pupillary response to identify and grade military relevant TBI.

1. What is the reliability of the GCS and/or pupil function obtained by combat medics?
2. How well do GCS and/or pupil function correlate with TBI such that these scores have implications for return to duty?
3. Far forward medical providers have limited medical supplies. The decision to commit these supplies to any given patient must be done with the intent to provide maximum benefit to the most patients. Can GCS and/or pupil assessment be used to prognosticate TBI in the military medical care system, particularly as it pertains to committing limited medical resources?

4. Alternative methods of determining severity of TBI have been proposed. These need rigorous evaluation through well-conducted prospective studies. Can GCS and/or pupil function be used as a triage tool under current military medical care guidelines for evacuation to higher levels of care?
5. Are the GCS score and/or pupil function reliable indicators of severity of injury when patients have compromised airways or ventilatory capability but cannot be intubated and mechanically ventilated with supplemental oxygen?
6. Medical care under battlefield conditions generally means how to treat at the minimal acceptable level. This is done in an effort to maximize the number of patients that can be treated for the longest period of time with the fewest available medical resources. Thus for military medical providers, a rational guide to how little therapy an injured patient can tolerate is useful. Can the GCS score be used as a goal of resuscitation under austere limited resource conditions?
7. Should GCS be modified or a new TBI scoring method be developed that is specific for the military combat environment?

VII. EVIDENCE TABLE

Aarabi,[19] 1990

Description of Study: This is a retrospective study of 435 Iran-Iraq War military patients who were admitted to a military hospital after suffering head injury. GCS score was assigned on admission.

Classification: III

Conclusions: Findings reveal a positive correlation between clinical outcome and admission GCS score. Of those who died, 75% had an admission GCS score ≤ 8.

GCS	Focal Neurological Deficit	Mortality
13–15	52%	6%
9–12	88%	25%
6–8	91%	57%
3–5	100%	65%

Aarabi,[22] 1995

Description of Study: This is a retrospective study of 1306 Iran-Iraq military patients who had suffered TBI. Of these, 19 patients were identified as have traumatic cerebral aneurysm. GCS score was obtained on admission to the hospital.

Classification: III

Conclusions: GCS score < 8 was found to correlate with mortality.

GCS	Mortality
9–15	7%
5–8	84%

Aarabi,[23] 1998

Description of Study: This is a retrospective study of 964 Iran-Iraq military patients who had suffered head injury. GCS score was obtained on admission to the hospital.

Classification: III

Conclusions: Findings reveal that there is no correlation between GCS and CNS infection.

Brandvold,[20] 1990

Description of Study: This is a retrospective study of 113 Lebanon Conflict military patients. Of these, 46 Israeli patients were followed. GCS score was obtained on admission to the hospital.

Classification: III

Conclusions: GCS score was shown to correlate with outcome as measured by the GOS and survival.

GCS	Mortality
13–15	6%
5–12	12%
3–4	80%

VIIa. DESCRIPTION OF THE STUDIES ACCORDING TO THE CLASSIFICATION CRITERIA

GCS Predictive Strength in Military Patients

First Author	Number of patients	Prospective/ Retrospective	Class	Where	Outcome Measure	When	Blinded	Multivariate
Amirjamshidi[24]	99	Retrospective	III	Iran Med Center	Return to work	Admission, 8 years post discharge	N	N
Aarabi, 1990[19]	435	Retrospective	III	Iran Military Hospital	Mortality, neurologic outcome	---	N	N
Aarabi, 1995[22]	19	Retrospective	III	Iran Military Hospital	Mortality with traumatic cerebral aneurysm	Admission	N	N
Aarabi, 1998[23]	964	Retrospective	III	Iran Military Hospital	Risk of CNS infection	Admission	N	N
Brandvold[20]	46	Retrospective	III	Israeli Hospital	Mortality	Admission	N	N
Turina[21]	43	Prospective	III	Croatian Military Hospital	Survival	Admission	N	N

GCS Knowledge

First Author	Number of patients	Prospective/ Retrospective	Class	Where	Who	Outcome Measure	When	Blinded	Multivariate
Riechers[7]	90	Pro	III	US Military Hospital	Physicians	Accuracy	2004	Y	Y

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TREATMENT: *AIRWAY, VENTILATION, AND OXYGENATION*

I. RECOMMENDATIONS

A. Standards

Data are insufficient to support a treatment standard for airway, ventilation, and oxygenation management techniques in the out-of-hospital or tactical environment.

B. Guidelines

Routine or prophylactic hyperventilation is not recommended and should be avoided.

C. Options

1. Airway management is crucial for the TBI patient and oxygen tension should be monitored and maintained at a $SaO_2 \geq 90$. When the assessment indicates an obstructed airway, the management depends on the skills of the health care provider.
2. Adequacy of ventilation is measured by pCO_2 or to a lesser degree of accuracy by end tidal carbon dioxide ($EtCO_2$) measurement. Endotracheal intubation (ETI) by an experienced provider using direct laryngoscopy (DL) is accepted as the optimal method of airway control. There is evidence that the Intubating Laryngeal Mask Airway (ILMA®), the Combitube®, and the Fiberoptic Intubation device (FI) may be useful for the less experienced care giver.
3. While a chest radiograph is the traditional way to confirm endotracheal tube placement, there is evidence that the Self-Inflating Bulb (SIB) device and/or measurement of $EtCO_2$ (except in a cardiac arrest situation) are useful tools for confirming placement along with auscultation of the chest (when the environment would allow and when chest radiography is not an option).
4. Hyperventilation should only be done if patients are exhibiting signs of cerebral herniation such as posturing with asymmetric or bilateral dilated pupils. If done, hyperventilation is defined as 20 breaths per minute for adults. Hyperventilation should be discontinued as soon as signs of herniation normalize.

II. OVERVIEW

While primary and secondary hypoxia and both hypo- and hypercapnea have been strongly associated through multiple studies with increased morbidity and mortality of patients suffering traumatic brain injury,[1–11] it is less clear how to prevent hypoxia or hyper- and hypocarbia in the head injured patient.[12] This is especially true in the out-of-hospital setting. Active monitoring of SaO_2 and $EtCO_2$ have been shown to help. The use of positive pressure ventilations with or without endotracheal intubation may be associated with adverse effects secondary to increased interthoracic pressures. Therefore, lower tidal volumes and longer expiratory times may be needed than is current standard practice.

High FIO_2 will compensate to maintain PaO_2 but $PaCO_2$ may suffer. Securing of the airway solely to prevent aspiration has lately been questioned, but there may be many other indications

to isolate the airway in the battle injured patient. Patients with a Glasgow Coma Scale (GCS) score ≤ 9 should be intubated if possible.[13] Endotracheal intubation in the prehospital setting has itself been associated with both improved outcome and harmful side effects. The sum of these studies seems to point to skill of the practitioner as the key difference in patient outcome. Therefore, endotracheal intubation, while still the gold standard of airway management, presents dangers in unpracticed hands. An increasing number of studies correlate education time and intubation experience to success and outcome. Higher success rates with medication-assisted intubation may be negated if tube migration cannot be monitored, prevented, or corrected.

For the purposes of discussing advanced airway management in the far forward environment, it is important to note that there exist many different levels of practitioner and many levels of care that are rendered on the battlefield. Equipment logistics, initial and sustainment training opportunities, and local medical treatment authorizations for non-credentialed providers are among the differences that may account for varying treatments provided to similar patients across the levels of care.

III. SEARCH PROCESS

A literature search from 1970 to 2005 was conducted using the terms "airway" or "oxygenation" or "intubation" or "advanced airway," and "prehospital care" or "EMS" or "emergency medical services," and "traumatic head injury" or "traumatic brain injury" or "TBI." Reference to the *Guidelines for Prehospital Management of Traumatic Brain Injury* chapter "Treatment: Airway, Ventilation, and Oxygenation" was also made. That process of literature review produced 187 references, 26 of which were directly relevant to outcome analysis and clinical orientation.

IV. SCIENTIFIC FOUNDATION

The amount of scientific evidence available in the medical literature regarding airway, ventilation, and oxygenation management in the tactical or combat arena is meager. We therefore used the civilian hospital, prehospital, and aeromedical literature to help us with our recommendations.

Hsiao et al.[13] demonstrated a correlation between GCS score and the need for intubation in the field or within 30 minutes of ED arrival, and correlated the need for intubation and GCS score with positive CT scan findings indicative of TBI. This retrospective evaluation included patients with a GCS ≤ 13 as measured in the ED, as well as patients who were intubated in the field and had a GCS scored by the field medical providers. Of note, the lowest reported field GCS was used for this study. GCS scores grouped patients as follows: 3–5, 6–7, 8–9, and 10–13. Patients with the lowest GCS scores had the highest need for emergent intubation (in the field or ED) and had the highest number of positive CT scans. Hsiao concluded that patients with a GCS ≤ 9 are candidates for aggressive airway management, including intubation and use of pharmacologic agents, if needed.

While endotracheal intubation is widely considered the definitive method of prehospital airway management, there are several studies that examined the use of other airway devices to successfully manage the airway. In a prospective simulation of emergency resuscitation, Dorges et al.[14] showed success of placement with other airway devices. Forty-eight apneic patients were successfully intubated with various advanced airway devices including LMA's, Combitubes®, and cuffed orotracheal airways. All patients in this study were successfully ventilated using bag-valve mask tech-

nique subsequent to successful placement of the airway adjunct. This trial showed that paramedics could successfully use these alternatives for successful placement and management of the airway.

Another 1997 study examined the use of the Upsherscope® to help facilitate intubation versus the traditional method of direct laryngoscopy.[15] Fridrich and his colleagues did not find the Upsherscope® to be of greater benefit than direct laryngoscopy. However, Langeron et al.[16] found that use of the Intubating Laryngeal Mask Airway (ILMA®) did have some benefit to successful placement of an endotracheal airway. This prospective randomized study examined 100 patients with at least one difficult airway intubation criteria. Time to intubation, hypoxic events, and success of intubation were all compared with a fiberoptic intubation (FIB) group. Similarly high success rates were obtained in both the ILMA® and FIB groups: 94% versus 92%. There was no significant difference between time to intubation and the number of attempts for each group. The one important significant difference to note was a more frequent incidence of adverse events in the FIB group: 18% versus 0%, $P < 0.05$.

Biswas et al.[17] also examined the use of the ILMA®, but in the lateral position. Under general anesthesia, 82 adult patients were intubated using the ILMA® while they were placed in either the left or right lateral position. 86% of patients were intubated on the first attempt, and the remaining were all intubated on the second attempt. He concluded that the ILMA® is a useful alternative to the FIB. It is also a good option for intubating non-supine patients that could be encountered in the far forward environment.

Deibel et al.[18] analyzed the performance of airway management skills of EMS personnel and emergency department physicians using mannequins. These trials were performed under simulated confined space scenarios. Time to successful intubation was examined and determined in the three groups: endotracheal intubation, Combitube®, and LMA. Time to successful ventilation for each adjunct was 70 seconds, 51.3 seconds, and 43.2 seconds, respectively, showing that the Combitube® and LMA are viable alternatives to endotracheal intubation. Not only are the LMA and ILMA® good alternatives for experienced airway providers, but for less experienced technicians as well. Choyce et al.[19] examined their uses and determined that both adjuncts are good options for use in less experienced medical personnel.

The performance of endotracheal intubation under emergency situations has a higher mortality and increased incidence of complications compared to non-emergency situations. Schwartz et al.[20] prospectively examined in-hospital emergency intubations in 297 patients. Patients undergoing emergency endotracheal intubation had a higher incidence of aspiration, pneumothorax, and mortality.

An Israeli study by Ben Abraham et al.[21] investigated the potential causes of failure by combat medical officers in securing the airway of a multiple injury patient. In examining 250 soldiers, it was found that most had uncomplicated airways and that difficult intubations were unlikely to be associated with anatomical causes. Complicated tactical scenarios and efficient skills of the providers were identified as the most important factors that contribute to in-field failures to secure airway control.

It has long been thought that skills performance declines without practice, use and/or re-training. In a 2000 prospective randomized controlled trial, Kovacs et al.[22] trained a group of 84 students in endotracheal intubation. These participants had no prior training or experience in advanced airway management. Time to successful intubation was measured and used as the benchmark for successful performance. Skills performance did indeed decline over time as measured at 16, 25, and 40 weeks post initial training. Therefore, it is advisable that personnel performing endotracheal intubation have refresher training in these advanced skills.

Aside from proper skill performance and technique, personnel performing intubations should always confirm placement of the endotracheal tube. The auscultation of breath sounds in the lung fields and the absence of sounds over the epigastrum have long been clinical methods of confirming endotracheal tube placement. However, the use of other placement confirmation devices is important to the overall treatment of the intubated patient. Several groups have looked at confirmation devices.

The self-inflating bulb (SIB) device and the end-tidal carbon dioxide detector (EtCO2) are both accepted secondary methods for insuring proper placement of the endotracheal tube. Grmec and Mally[23] found that auscultation of endotracheal tube placement alone was not sensitive enough. He found a 10% error rate among placements where auscultation was the only method of confirmation while a 0% error rate among placements confirmed with $EtCO_2$.

In a prospective study of emergency physicians, Kasper and Deem[24] found that the SIB successfully identified 100% of all misplaced esophageal intubations. Of 300 consecutive cases, the SIB detected the 19 misplaced endotracheal tubes. Tanigawa et al.[25] also found similar results. SIB correctly identified 100% of patients with a misplaced esophageal intubation, but did not correctly identify 72% of the misplaced tracheal intubations. Therefore, use of the $EtCO_2$ detector in conjunction with the SIB is advisable.

Proper ventilation is also crucial to the management of the TBI patient. In a 2003 study, Helm et al.[26] evaluated the incidence of hypo- and hyperventilation after instituting capnography during prehospital transport. Of 97 patients included in the study, 71 had head trauma. The incidence of adequate ventilation ($PaCO_2$ = 35–45 mm Hg) was 63.2% in the monitored group versus 20% in the monitor-blind group; the incidence of hypoventilation ($PaCO_2$ > 45 mm Hg) was 5.3% versus 37.5% respectively; and the incidence of hyperventilation ($PaCO_2$ < 35 mm Hg) was 18% versus 17% respectively. Proper ventilation could be guided by the use of the $EtCO_2$ monitors by prehospital personnel.

V. SUMMARY

The assessment and treatment of airway, ventilation, and oxygenation problems must be interwoven step by step to successfully manage the TBI patient. Treatment of an obstructed airway must precede the assessment of ventilation. Similarly, the treatment of a patient who is not breathing must precede the assessment of circulation. This concept in the combat scenario is the same as in the civilian arena. Tactical and logistical considerations dominate the tools available to address these issues for the combat injured, with different provider skill levels and treatment capabilities existing at each level of care. Regardless of the level of care, every effort must be

made to maintain the SaO_2 above 90% in suspected TBI patients. It is equally important to avoid hyper- and hypoventilation in these patients.

A patent airway should be assured and endotracheal intubation performed for patients with a GCS < 9 or for those who are unable to maintain or protect their airway. Evidence indicates that routine hyperventilation should not be performed. If ventilatory assistance after endotracheal intubation is provided, a respiratory rate of 10 breaths per minute should be maintained. After correction for hypoxemia or hypotension, if the patient shows obvious signs of cerebral herniation, such as extensor posturing and pupillary asymmetry or bilateral dilated pupils, the medical provider should hyperventilate the patient at a rate of 20 breaths per minute. This hyperventilation may be performed as a temporizing measure until the patient arrives at a medical facility when blood gas analysis will guide the ventilation rate. We believe that end tidal CO_2 monitors or the use of the SIB tool will help avoid improper endotracheal tube placements. Further $EtCO_2$ monitors will help avoid hyper- or hypoventilation.

The airway/ventilation/oxygenation treatment training for military personnel (whether they be combat medics, paramedics, nurses, or physicians) should highlight TBI as a special consideration because of its long term impact on patient outcome. Evidence suggests that airway management skills decline early after initial training. Independent practice combined with periodic feedback should be encouraged. New and emerging simulation technologies show promise for practical skills training and education.

VI. KEY ISSUES FOR FUTURE INVESTIGATION

1. Difficult as they may be to execute, prospective trials of airway management, ventilation, and oxygenation technique and assessment tools in the tactical and combat environment are needed. Future development of field practical and reliable monitoring equipment will solve some of these problems.
2. Monitoring equipment that is of lighter weight, rugged, simple to use, and minimizing of power consumption will be helpful in the tactical (and standard EMS) environment.
3. Medications to facilitate intubation that have less untoward effects, are easier to reverse, and have no storage problems will improve airway and ventilatory management in the field.
4. Prospective randomized trials of teaching and learning for practitioners of airway management will also help to define what level of intervention can be mastered and maintained by medical personnel.
5. Studies are currently ongoing and standards are changing regarding the effects of positive pressure ventilation on venous return and cardiac output. The results of these studies may necessitate changes in current practices of airway and ventilatory management. Development of ventilators with the same attributes as the monitoring equipment may also prove useful in combat when continuous manual ventilation is impractical.

VII. EVIDENCE TABLE

Muizelaar,[11] 1991

Description of Study: Prospective randomized clinical trial comparing neurological outcomes in patients hyperventilated to 25 mm Hg pCO_2 vs. patients kept at 35 mm Hg pCO_2.

Classification: II

Conclusions: Patients hyperventilated to a pCO_2 of 25 mm Hg had worse neurological outcomes at 3 and 6 months.

Ben Abraham,[21] 2000

Description of Study: 250 patients were examined for the prevalence of clinical criteria that could predispose them to difficult intubation. Known anatomical features and the Mallampati classification were assessed at a military outpatient clinic of the Israel Defense Forces. Most soldiers had normal airways. Limitations of head and neck movement or in opening the mouth were not observed. Other risk factors were noted in only a small percentage of the study population. Mallampati classes I and II were noted in 40% and 31% of the patients, respectively.

Classification: III

Conclusions: Complicated scenarios and skill deficiency are the greatest contributing factors to failed field intubations among combat physicians.

Biswas,[17] 2005

Description of Study: Prospective study using 82 adult patients. Testing intubation with intubating laryngeal mask airway's (ILMA®) in right lateral and left lateral patient positions. Right lateral, 41 patients (40/41 = 97% success rate) & left lateral, 41 patients (40/41 = 97% success rate).

Classification: III

Conclusions: ILMA® is effective for lateral blind intubations.

Choyce,[19] 2001

Description of Study: 75 patient study with 24 inexperienced technicians for intubation using both the ILMA® and the LMA. Results show ILMA® (58/75 = 77% success rate) vs. LMA (42/75 = 56% success rate). Both adjuncts had similar success rates when used by inexperienced practitioners, but the ILMA® faired better statistically.

Classification: III

Conclusions: Given that training can be performed rather quickly on the ILMA®, it could be considered for use by personnel with little training.

Deibel,[18] 2005

Description of Study: Prospective study analyzing skills of a 70 person group (EMS, house staff, and ED physicians) using mannequins in three different confined space scenarios. Time to successful ventilation using endotracheal intubation, Combitube®, and LMA was 70 seconds, 51.3 seconds, and 43.2 seconds respectively.

Classification: III

Conclusions: ETI is still preferred technique but if space and/or patient is difficult, alternative advanced airway adjuncts can be successfully placed and can be lifesaving.

Dorges,[14] 2003

Description of Study: Prospective simulated emergency situation using different airway devices. 48 apneic patients in a hospital operating room. Paramedics were successful at placing LMA's, Combitubes®, and cuffed oropharyngeal airways.

Classification: III

Conclusions: LMA's, Combitubes®, and cuffed oropharyngeal airway devices can be useful alternatives to endotracheal intubation in field.

Grmec,[23] 2004

Description of Study: Prospective observational study of 81 patients with TBI and GCS score < 9 who had endotracheal intubation performed in field with evaluation of correct placement by auscultation and $EtCO_2$ monitors. Auscultation alone carried a 10% error [4 false negative and 4 false positive]. $EtCO_2$ monitors were 100% correct.

Classification: III

Conclusions: $EtCO_2$ monitors are significantly superior to auscultation for identifying correct ETI tube placement.

Helm,[26] 2003

Description of Study: Prospective study of 97 trauma patients (71 TBI patients). Use or non-use of end tidal CO_2 monitor in pre-hospital setting was randomized. Patients with $EtCO_2$ monitor had hypoventilation 5.3% and hyperventilation 32% of the time. Patients without $EtCO_2$ monitor had hypoventilation 38% and hyperventilation 43% of the time.

Classification: III

Conclusions: There were fewer incidences of hypoventilation and hyperventilation in the group using $EtCO_2$ monitors. $EtCO_2$ monitors are very useful for TBI patients in the prehospital setting.

Hsiao,[13] 1993

Description of Study: Retrospective trauma registry-based study of 120 patients with a GCS score < 14. The group evaluated the need for emergency intubation in the field or ED. Of patients with GCS 3–5, all required intubation; GCS 6–7, 73% were intubated; GCS 8–9, 62% were intubated; and GCS 10–13, 20% were intubated.

Classification: III

Conclusions: The lower the GCS score the more likely endotracheal intubation is necessary.

Kovacs,[22] 2000

Description of Study: Prospective randomized control study of 84 health science students with no prior airway management experience. Participants trained in advance airway management skills. Participants were then evaluated at 16, 25, and 40 weeks post training

Classification: III

Conclusions: Overall time interval scores declined hence re-training in advanced airway skills is necessary.

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TREATMENT: *FLUID RESUSCITATION*

I. RECOMMENDATIONS

A. Standards

Data are insufficient to support a treatment standard for fluid resuscitation in the patient with severe traumatic brain injury (TBI).

B. Guidelines

It is customary to treat hypotension with fluids in patients with TBI. Inadequate data exist to support a specific target blood pressure. Inadequate clinical outcome data exist to prefer one resuscitation fluid choice over another; however, hypertonic saline and colloids offer clear logistical advantages over isotonic crystalloids in a combat environment. Hypertonic saline in the prehospital phase is safe in doses < 500 ml and can be used for hypovolemia.

C. Options

Hypotension (systolic blood pressure < 90 mm Hg) in patients with TBI has an association with poor outcome. Fluid therapy can be used to maintain adequate cerebral perfusion pressure and limit secondary brain injury. Inadequate fluid resuscitation with aggressive diuresis can precipitate hypotension and should be avoided in the field setting. Hypertonic saline resuscitation, with or without dextran, has been used with some encouraging results compared to isotonic fluids. If a casualty requires additional fluids after the administration of 500 ml of hypertonic saline, isotonic fluids or colloids can be used.

II. OVERVIEW

The primary purpose of fluid resuscitation of TBI patients in the field is to treat shock and to prevent hypotension. Since there is an association of worse outcome in TBI patients with hypotension, it is thought that treatment with fluid resuscitation may potentially prevent secondary brain injury.

While the treatment of hypotension to prevent secondary brain injury may be intuitive, the quality of human data to demonstrate the cause and effect is lacking. However, it has been shown that even a single episode of hypotension can double mortality.[1,2] Whether the worse outcome is due to the secondary TBI or is merely an association is unclear. Autoregulation sometimes fails following head injury, placing the brain at increased risk from hypovolemia as the compensatory mechanisms to maintain brain perfusion are disrupted. Although some animal data examine these phenomena, no research in humans exists.

In the civilian setting, a rapid infusion of 2 liters of crystalloid fluid (lactated Ringer's solution [LR] or normal saline) is customarily utilized to treat hypovolemia in adults.[3] In casualties without head injury, there is concern that resuscitation without surgical control of the source of bleeding may increase blood loss by displacement of potentially hemostatic clots due to higher blood pressure. No clinical studies have demonstrated that prehospital fluid resuscitation is associated with improved outcome. Indeed, one randomized prospective study in hypotensive patients with penetrating torso trauma showed that patients treated with fluids had increased mortality.[4] Stud-

ies have also demonstrated that the type of fluid used in the prehospital setting does not affect mortality. This is consistent in that if the use of fluids does not make a difference, then neither would the type of fluid.

It may not be legitimate to extend the findings on civilian prehospital fluid use to the combat setting. Transport times may be significantly longer on the battlefield compared to the urban settings of published civilian studies. The epidemiology and pathophysiology of combat-related trauma differs from civilian trauma with far less blunt trauma and more blast related and high velocity projectile penetrating trauma. In addition, the logistics of combat casualty care differ from civilian trauma care, with weight and volume of all emergency response equipment critically balanced with the weight and volume of gear required for mission accomplishment.

The primary goals of combat casualty care in the field are to control hemorrhage and to rapidly transport casualties to higher levels of care. Due to potential problems with aggressive fluid use, the current recommendation regarding fluid resuscitation for patients without head injury is to allow "permissive hypotension" by monitoring mental status and pulse character.[5] In the noisy and potentially dangerous environment of first response and initial evacuation, sphyngomanometers are not likely to be effectively utilized. It is recommended that all casualties have intravenous access established when not under hostile fire. No fluids should be instituted in the presence of a strong radial pulse and normal mentation. If the mental status and radial pulse are not normal, fluids can be titrated to improve mental status and restore a weakly palpable radial pulse. This scheme of resuscitation is termed "permissive hypotension" and offers the potential benefit of minimizing uncontrolled blood loss and the logistical burden of fluid resuscitation on the battlefield.[6] Since the vast majority of combat casualties do not require fluid administration, this has real logistical advantages.[7] In addition, the use of oral hydration is recommended for the casualty without TBI, penetrating abdominal injury, or severe uncontrolled hemorrhage.

In the setting where the casualty has TBI, permissive hypotension and oral hydration are **not** yet recommended.[8] Fluid resuscitation should be performed to establish normal pulse character or blood pressure in order to prevent possible secondary brain injury. On the battlefield, the optimal initial fluid of choice is (3–7.5%) hypertonic saline. There are ample human data to verify that hypertonic saline is safe as the initial fluid for resuscitation, although an outcome advantage over other types of fluid has not been proven definitively. Due to the logistical advantage of hypertonic saline being able to resuscitate equivalently to isotonic fluids with less weight and cube, it is the ideal fluid of choice. In addition to its ability to restore perfusion, it offers other proven and theoretical advantages such as its ability to reduce intracranial pressure and modulate the immune system to possibly reduce the inflammatory response which is often seen after severe injury.

In 1999, the Institute of Medicine recommended two 250 ml rapid infusions of 7.5% hypertonic saline as the initial fluid treatment of choice in both combat casualties and in civilian trauma.[9] Since 7.5% hypertonic saline is not currently commercially available, alternative initial fluid choices are two 250 ml infusions of 5% hypertonic saline or two 500 ml infusions of 3% hypertonic saline. These latter solutions are commercially available, but they are not currently standard military field supplies.

Another option that has been recommended by the U.S. Special Operations Command and some military trauma experts is to use colloids as initial resuscitation fluid.[10] Hextend is 6% hetastarch in LR and is currently available in the field. Two 500 ml boluses can be used in the forward area with an effect functionally equivalent to six bags of LR. If the casualty remains hypotensive after the infusion of hypertonic saline or colloids, the casualty should be assumed to have ongoing blood loss and continued efforts to maintain blood pressure should be weighed against logistical and tactical considerations. While the weight and volume of resuscitation fluids may not be as important in the setting of civilian trauma, it is of major concern on the battlefield. An option if hypertonic saline or colloids are not available is to use isotonic fluid, though this is less desirable for the reasons discussed above.

III. SEARCH PROCESS

A MEDLINE search was conducted from 1978 to 2005 using the keywords "head injury," "field or prehospital," and "fluid resuscitation." The search turned up 150 references, 40 of which were relevant to fluid therapy for the patient with severe head injury. These were individually reviewed for content. The results were collated, and the analysis is presented here.

IV. SCIENTIFIC FOUNDATION

The traditional method of resuscitation of a hypotensive patient with TBI is with crystalloids. Although the scientific evidence still is not abundant, most textbooks and trauma courses such as the Advanced Trauma Life Support™ course recommend crystalloid use. While LR is the customary fluid in trauma, normal saline is preferred in the setting of TBI as the sodium content is higher, thus minimizing the potential for resuscitation with a hypotonic solution which could increase cerebral edema.

Because sodium is vital in casualties with TBI, the research regarding hypertonic saline is important. Hypertonic saline has multiple theoretical advantages. Resuscitation can be achieved safely with approximately one eighth the volume of normal saline and LR when using 7.5% hypertonic saline. While not very important in the civilian sector, it is critical in the combat scenario as the medics and corpsman have to carry the fluids to be used. Hypertonic saline may have immunomodulatory capabilities as the sodium affects neutrophils which have been implicated in the aberrant inflammatory response after trauma and massive resuscitation. Another potential benefit of hypertonic saline is the reduction of intracranial pressure as the high osmolarity produced from the sodium infusion reduces cerebral edema.

Clinical studies in patients with TBI have been performed examining the effect of hypertonic saline. In a multicenter trial, Mattox et al.[11] demonstrated a higher systolic blood pressure in patients treated with hypertonic saline versus crystalloid resuscitation. Survival was significantly better in patients who required surgery, and the hypertonic saline group had fewer complications compared with the group receiving the standard isotonic crystalloid treatment. That trial did not mention head injuries specifically. Wade et al.[12] performed a meta-analysis on published controlled studies of hypertonic saline/dextran, then abstracted the data on patients who had TBI (defined by an abbreviated injury score [AIS] for the head of 4 or greater). Survival to discharge was 37.9% for patients treated with hypertonic saline and 26.9% for standard therapy. These findings failed to reach statistical significance ($p = 0.08$). When logistic regression analysis was performed, the odds ratio was 1.92 for 24-hour survival and 2.12 for survival to discharge when

hypertonic saline was compared with standard therapy. This was a statistically significant difference (p = 0.048). Wade concluded that patients who had TBI and received hypertonic saline/dextran were about twice as likely to survive as those who receive standard therapy.

Vassar and her colleagues[13–16] published four prospective randomized double-blind trials between 1990 and 1993 concerning the use of hypertonic saline. In 1990, they compared two groups of head injury patients, one group receiving 7.5% hypertonic saline, the other receiving normal saline.[13] Twenty-six percent of the head injury patients were found to have intracranial pathology with bleeding. No difference in outcome was found between the two groups. In addition, intracranial bleeding did not increase with either therapy. In 1991, Vassar et al.[14] compared 7.5% hypertonic saline with LR in 166 patients, 32% of whom had severe TBI (defined as an AIS of 4 or higher). Crude mortality measurement was the same. When logistic regression analysis was used, hypertonic saline/dextran was associated with a statistically significant higher survival rate than isotonic crystalloid.

In 1993, Vassar et al.[15] published a trial of 7.5% hypertonic saline versus 7.5% hypertonic saline dextran in 258 patients. Only 10% had severe TBI. However, in patients with a Glasgow Coma Scale (GCS) score < 8 and in patients with severe anatomic cerebral damage, survival with either agent was statistically significantly greater than what would be predicted with the Trauma Related Injury Severity Score (TRISS). The addition of dextran to the hypertonic saline did little to improve survival. In 1993, Vassar et al.[16] also published a multicenter trial of 194 patients of whom 74% had severe TBI. There was no statistically significant increase in the survival in the overall patient population with the use of hypertonic saline. However, the survival rate in the hypertonic saline group was higher than in the LR group for patients with an initial GCS score of 8.

A recent study by Cooper et al.[17] examined the use of 7.5% hypertonic saline in the prehospital setting in 229 hypotensive blunt trauma patients with TBI. This study was a well-performed prospective randomized trial to determine the affect of one 250 ml dose of 7.5% hypertonic saline or LR in the prehospital setting. The primary outcome variable was neurologic function as measured by the Extended Glasgow Outcome Score (GOSE, 1–8) at 6 months. Entry criteria in this study were hypotensive (systolic BP < 90 mm Hg) trauma patients with severe blunt traumatic head injury (GCS < 8). The control group (n = 115) received LR compared to 250 ml of 7.5% hypertonic saline (n = 115). The patients were otherwise treated identically in the field and in the hospital and were given as much LR or colloids as providers deemed necessary. This is an important fact as the effect of hypertonic saline may have been diluted by the liberal use of other fluids which were not controlled in this study. Cooper found that there was no difference in GOSE between those that received HTS compared to those that received LR at 6 months even though the patients were very similar in injury severity, pattern, and their demographics.

There is some criticism regarding this study that should be considered. The design of the study may have doomed it to fail. Hypotensive trauma patients with head injuries are one of the most serious of trauma patients as confirmed by this study. Approximately half the patients in this study died. In general, there are minimal proven treatment options to change the outcome after such a severe head injury other than providing an airway, controlling blood loss, decompression of the skull for mass effect, and aggressive supportive critical care to minimize secondary brain injury. Even in the optimal setting, these treatment options only affect a small minority of pa-

tients. Although intracranial hypertension is associated with poor outcome, the scientific clinical data to demonstrate that benefit of reducing intracranial hypertension or increasing cerebral perfusion pressure in humans are scarce.

Although the Cooper study can be interpreted as a failure of hypertonic saline to improve outcome, the converse interpretation is also valid. This study did demonstrate that the use of hypertonic saline is as safe as conventional fluid therapy in hypotensive trauma patients with severe TBI. Although the group that was treated with 7.5% hypertonic saline had a higher survival rate (55% vs. 50%, $p = 0.23$), it was not statistically significant. This study was not powered for survival as the primary outcome. This study also demonstrated that the mean ICP tended to be lower (10 vs. 15, $p = 0.08$) upon arrival to the intensive care unit and the duration of the cerebral perfusion pressure less than 70 mm Hg also tended to be shorter (9.5 hours vs. 17 hours, $p = 0.06$).

Pentastarch, another hyperosmolar solution, was tested in 1992 by Younes et al.[18] in a Phase 2 clinical trial of 23 hemorrhage patients. Although that study did not state the number of patients with severe TBI, some of them almost certainly had head injuries because the average GCS score was 11 ± 5. Both Pentastarch and saline increased blood pressure equally, although the volume requirements with Pentastarch were less. No differences were found in complication rates in the two patient groups.

Mannitol is another therapy that has been proven to reduce ICP in hospital patients with intracranial hypertension. One concern is that mannitol may produce hypotension from volume deficits secondary to its osmotic diuresis. This could potentially produce secondary brain injury. One prospective randomized double-blind controlled trial investigated the prehospital administration of mannitol in head-injured patients, comparing mannitol with standard crystalloid resuscitation.[19] The demographics in that study did not differ, nor did the overall head injury severity between the two groups. Mortality was the same in both groups. Importantly, systolic blood pressure did not change significantly in the mannitol group at the time of ED presentation. However, two hours after hospital arrival, systolic blood pressure was statistically significantly lower in the mannitol group when compared with the placebo group. Very few of these patients were hypotensive. In addition, since hypotension is treated with fluids, the avoidance of mannitol may potentially reduce the total volume of fluids required.

While mannitol can reduce ICP, it has not yet been conclusively been shown to effect outcome. The exception to this is three prospective randomized trials from one center in Brazil.[20–22] These studies, however, used "high dose mannitol (~1.4 grams/kg)" compared to standard dose mannitol. The mannitol was given in the ED approximately 80–90 minutes after injury and the results are extremely impressive. They found improved survival and disability scores in the group that received the high dose mannitol. However, these studies should be examined with caution as the high dose mannitol required preemptive aggressive fluid resuscitation and aggressive invasive monitoring which included jugular bulb oxyhemoglobin saturation monitoring. Patients in these studies all had blunt TBI, not penetrating, and they had access to craniotomy within 4 hours of admission.

Hypertonic saline has also been shown to reliably reduce ICP. Human studies have also shown this effect as Hartl et al.[23] demonstrated that hypertonic saline reliably reduces ICP in patients

with TBI and intracranial hypertension. In a prospective randomized study in two centers, Shackford et al.[24] demonstrated that the use of hypertonic saline in 34 patients lowered ICP. Two studies showed in children with severe head injury that hypertonic saline reduced ICP and increased cerebral perfusion pressure.[25,26] Bentsen et al.[27] also demonstrated that in seven critically ill patients with subarachnoid hemorrhage that needed urgent treatment for elevated ICP, the infusion of 7.2% hypertonic saline with 6% hydroxyethyl starch lowered ICP and elevated cerebral perfusion pressure.

There are also some studies comparing 7.5% hypertonic saline versus 20% mannitol. A randomized prospective crossover trial demonstrated that 100 ml of 7.5% HTS with 6% dextran (RescueFlow®—not approved yet by FDA in the U.S.) caused a significantly decreased ICP, and had a longer duration of effect than mannitol. However, this study was small and only had nine patients.[28] A study by Vialet et al.[29] on 20 consecutive patients demonstrated that 7.5% hypertonic saline was more effective than 20% mannitol in treating intracranial hypertension. Horn et al.[30] showed that in patients with elevated ICP that was resistant to mannitol and barbiturates, 7.5% HTS was effective in decreasing ICP. De Vivo et al.[31] evaluated the effectiveness of 3% hypertonic saline and mannitol in neurosurgery (supratentorial cerebral tumors) and found that hypertonic saline could be used safely to reduce ICP without reducing central venous pressures. Since hypertonic saline can reduce ICP while also increasing intravascular volume, it would make sense to avoid the use of mannitol in the field setting.

V. SUMMARY

The deleterious association of hypotension in patients with TBI has been documented in the literature. While permissive hypotension is practiced in the field for penetrating torso trauma, it is not advisable to recommend this for patients with TBI at this point. Because the underlying cause of hypotension in TBI patients is almost always secondary to bleeding or other fluid losses, intravascular volume resuscitation seems to be the most efficacious way of restoring blood pressure. Isotonic crystalloid solution is the fluid most often used in the prehospital resuscitation of head injury patients.

There is Class I evidence that demonstrates that the use of hypertonic saline is a safe alternative method of treating hypotensive TBI without worsening outcome and there is lesser quality data to show it may have survival advantages in patients with TBI. Because hypertonic saline offers logistic advantage in terms of weight and cube in the field, it can be used in patients with TBI as it can reduce ICP while restoring intravascular volume. Two 250 ml bolus of 5% hypertonic saline or two 500 ml boluses of 3% hypertonic saline can be used as the initial resuscitation fluid. Colloids such as Hextend also offer weight and volume advantage compared to other fluids so it is also an alternative that can be used in the field setting. In patients with TBI that have no evidence of significant blood loss and have normal pulse character or blood pressure, there is no evidence to show that any fluid resuscitation is necessary. Mannitol in the prehospital/field setting has not yet been shown to improve outcome.

VI. KEY AREAS FOR FUTURE INVESTIGATION

Research on fluid resuscitation in hypotensive patients with TBI has been very limited. There are little data to guide endpoints of therapy. One target blood pressure may be better than another, and MAP may be a better guide to therapy than systolic pressure, but these questions require in-

vestigation. In addition, the current concern that raising blood pressure may increase secondary blood loss, thus worsening cerebral hemodynamics, needs to be better validated in humans. Finally, more work must be done to elucidate the most effective fluid for resuscitation. The following specific questions should be studied in the future:

1. What is the optimal target blood pressure for resuscitation in both isolated TBI and the patient with multiple injuries?
2. Is mean arterial blood pressure a better endpoint than systolic blood pressure?
3. Is there a subgroup of patients in whom a lower volume of resuscitation fluid should be used?
4. What is the ideal resuscitation fluid for TBI patients in the prehospital setting?
5. Is there a role for large particle colloids in the prehospital setting?

VII. EVIDENCE TABLE

Chesnut,[1] 1993

Description of Study:	A prospective study of 717 consecutive severe head injury patients admitted to four centers investigated the effect on outcome of hypotension (SBP < 90 mm Hg) occurring from injury through resuscitation.
Classification:	III
Conclusions:	Hypotension was a statistically independent predictor of outcome. A single episode of hypotension during this period doubled mortality and also increased morbidity. Patients whose hypotension was not corrected in the field had a worse outcome than those whose hypotension was corrected by time of ED arrival.

Cruz,[20] 2004

Description of Study:	Prospective randomized clinical trial of 44 patients with non-missile, acute TBI. The patients were comatose (GCS 3) with bilateral, abnormal papillary widening and had severe diffuse brain swelling and recent clinical signs of impending brain death at a single university-based trauma center in Brazil. Patients randomized to receive high dose mannitol (~1.4 g/kg) or standard dose mannitol (~0.7 g/kg). Patients were well matched.
Classification:	II
Conclusions:	High dose mannitol treated patients in the ED tended to have higher survival (p = 0.68), had better improvement in papillary response and 6-month clinical outcome (p < 0.02). 43.5% and 47.6% for the high dose and standard dose mannitol group required decompressive surgery.

Vassar,[15] 1993

Description of Study: A prospective randomized double-blind multicenter trial comparing the efficacy of administering 250 ml of hypertonic saline vs. normal saline as the initial resuscitation fluid in 194 hypotensive trauma patients over a 15-month period. 144 of these patients (74%) had a severe brain injury (defined as an abbreviated injury score AIS for the head of 4, 5, or 6). Here, hypertonic saline significantly increased blood pressure and decreased overall fluid requirements. Post-hoc analysis of the severe head injury group (Class II analysis) revealed that the hypertonic saline group had a statistically significant improvement in survival to discharge. However, the improvement in overall survival was not statistically significant.

Classification: II

Conclusions: Raising the blood pressure in the hypotensive, severe head injury patient improves outcome in proportion to the efficacy of the resuscitation. Pre-hospital administration of 7.5% sodium chloride to hypotensive trauma patients was associated with a significant increase in blood pressure compared with infusion of LR solution. The survivors in the LR and hypertonic saline (HS) groups had significantly higher blood pressures than the non-survivors. There was no significant increase in the overall survival of patients with severe brain injuries; however, the survival rate in the HS group was higher than that in the LR group for the cohort with baseline GCS scores ≤ 8.

Vassar,[16] 1993

Description of Study: Prospective randomized double-blind controlled clinical trial of 258 hypotensive patients over 31 months at a university-based trauma center. Twenty-seven of these patients (10%) had a severe head injury (defined as an abbreviated injury score for the head of 4, 5, or 6 only for anatomic lesions).

Classification: II

Conclusions: The administration of 7.5% NaCl (HS) and 7.5% NaCl/6% dextran 70 (HSD) caused no neurologic abnormalities. On the contrary, their use was associated with improvement in survival (as compared with predicted survival) in the patients with low initial GCS score (< 8) and in patients with anatomic confirmation of severe cerebral damage. It appeared that the dextran added little to improvement in survival when compared with hypertonic saline alone. Hypertonic saline solution did increase the blood pressure response in all patients.

Vassar,[14] 1991

Description of Study: Prospective randomized double-blind multicenter clinical trial of 166 hypotensive patients over a 44-month period. Fifty-three of these patients (32%) had a severe head injury (defined as an AIS for the head of 4, 5, or 6).

Classification: II

Conclusions: Survival was not significantly different in the total patient group. The rate of survival to hospital discharge in patients with severe head injuries was significantly higher in those patients who received hypertonic saline/dextran (HSD) (32% of patients with HSD vs. 16% in patients with LR) when using logistic regression analysis. Patients with severe head injury could benefit from HSD administration both because the solution can reduce brain swelling, and because by increasing cardiac output, it can increase O_2 supply to injured cerebral parenchyma.

Vassar,[13] 1990

Description of Study: A prospective randomized double-blind clinical trial of 106 patients over an 8-month period. Intracranial hemorrhage was present in 28 patients (26%).

Classification: II

Conclusions: No adverse effects of rapid infusion of 7.5% NaCl or 7.5% NaCl/6% dextran 70 were noted. Nor were any beneficial effects noted. There was no evidence of potentiating intracranial bleeding. There were no cases of central pontine myelinolysis; however, patients with severe preexisting disease were excluded from the study.

Vialet,[29] 2003

Description of Study: A prospective randomized study in 20 consecutive patients with head trauma and persistent coma who required infusions of an osmotic agent to treat episodes of intracranial hypertension resistant to well-conducted standard modes of therapy. Patients received 2ml/kg of either 7.5% hypertonic saline or 20% mannitol.

Classification: II

Conclusions: 7.5% Hypertonic saline was more effective than mannitol for treating intracranial hypertension. The mean number (6.9 ± 5.6 vs. 13.3 ± 14.6 episodes) of intracranial hypertension episodes per day and the daily duration (67 ± 85 vs. 131 ± 123 min) of intracranial hypertension episodes were significantly lower in the hypertonic saline solution group ($p < .01$). The rate of clinical failure was also significantly lower in the hypertonic saline solution group: 1 of 10 patients vs. 7 of 10 patients ($p < .01$).

Wade,[12] 1997

Description of Study: Cohort analysis of individual patient data from previously published prospective randomized double-blind trials of hypertonic saline/dextran in patients with TBI and hypotension. TBI was defined as AIS for the head of 4 or greater. Hypotension was defined as a systolic blood pressure ≤ 90 mm Hg. 1,395 data records were analyzed from six separate studies. 233 patients were then included in this review. Eighty patients were treated in the ED and 143 were treated in the prehospital phase.

Classification: III

Conclusions: There was no statistically significant difference in overall survival when hypertonic saline was compared with normal saline. Logistic regression analysis was performed on patients with TBI showing an odds ratio of 1.92 for 24-hour survival and 2.12 for survival until discharge. Thus, patients with TBI in the presence of hypotension who received hypertonic saline/dextran were approximately twice as likely to survive as those who received saline. This was statistically significant with $p = 0.048$.

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TREATMENT: *PAIN MANAGEMENT AND THE USE OF ANALGESICS FOR SEDATION*

I. RECOMMENDATIONS

A. Standards:
Class I data regarding management of pain in the prehospital setting is insufficient to support a standard of treatment.

B. Guidelines:
Evidence regarding management of pain in the prehospital setting does not exist to support guidelines on this topic.

C. Options:

1. There are valid reasons to sedate TBI patients (i.e. to reduce the risk of further harm to self or others and to facilitate evaluation or evacuation) and analgesic medications are a standard part of most sedative regimens. In this case, analgesic medications should be administered in small incremental doses and with appropriate physiologic monitoring of blood pressure, oxygenation (PaO_2 or SaO_2), and ventilation (pCO_2 or $EtCO_2$).
2. There is no scientific data or physiologic evidence to support a hypothesis that pain relief improves outcomes in TBI patients, but there is some evidence to support the possibility that the most commonly available analgesic medications (including opiates and Ketamine) increase ICP and may thereby be harmful. Therefore, withholding analgesics from TBI patients who cannot self-score pain (Glasgow Coma Scale score [GCS] < 13; see Guidelines on Assessment: Glasgow Coma Scale Score) for short periods in the prehospital phase, where monitoring is unavailable, is a reasonable option.

II. OVERVIEW

Promoting patient comfort and reducing or eliminating pain, while at the same time ensuring patient safety, are responsibilities of all clinicians, including prehospital providers. Prospective randomized controlled studies on the prehospital use of analgesics in TBI patients have not been published. In addition, there is no scientific physiologic evidence to defend or refute the hypothesis that pain management is necessary in the prehospital setting—that relieving pain improves outcomes in TBI patients or that withholding analgesics causes harm. There is, however, evidence to show that all the commonly used analgesics (including opiates and Ketamine) can increase intracranial pressure (ICP) and should therefore be administered in small incremental doses in a monitored setting. Vital signs, such as blood pressure and respiratory rate, which indirectly correlate with ICP and brain tissue oxygenation, are inadequate for monitoring the effects of interventions on brain tissue. Until technology capable of measuring the effects of analgesics on brain tissue is available, the benefit to risk ratio of pain control will remain speculative. However, the use of analgesia and sedation can ease immediate suffering of all TBI patients.

Much of the literature on TBI and pain management is related to the negative effects of *chronic* pain on all aspects life, but most specifically on the significant hindrance it poses to physical and psychosocial rehabilitation. The pain-fear cycle is a learned behavior that can and should be con-

trolled in order to optimize return to full potential function. In this regard, if a TBI patient is capable of learning to fear pain in the prehospital setting, then early intervention may be desirable.

III. SEARCH PROCESS

An MEDLINE search of the literature from 1996 to April 2005 was conducted using the terms "pain" or "analgesics" or "opioid" (yield 35872 articles), "prehospital" or "EMS" (yield 3698 articles), and "brain injuries" or " head (craniocerebral) trauma" (yield 12089 articles). Combined searches including "pain and prehospital" yielded 57 articles and "pain and brain injury" yielded 150 articles. The combination of "brain injury" and "pain" and "prehospital" yielded no articles.

IV. SCIENTIFIC FOUNDATION

Pain receptors are stimulated by chemicals including bradykinins, serotonin, histamine, potassium ions, acids, some prostaglandins, acetylcholine, and the proteolytic enzymes that are released with tissue damage,[1] signaling that some remedial action should be done at once to stop the on-going damage.[2] The treatment of pain by itself does not address on-going tissue damage, but is meant to mask the effects of tissue damage. There is no physiologic evidence to support a necessity for pain control.

Objective pain measurements in widely scattered populations of people demonstrate that there is little difference in their recognition of pain thresholds; however, different people do react very differently to perceptions of pain. The perception of pain causes motor reactions such as withdrawal reflexes and psychic disturbances such as agitation and delirium and it is these effects that may be important to treat.[2]

Ventilated and sedated TBI patients in the ICU showed large transient increases in VO_2, energy expenditure, and mean arterial blood pressure in the first 12 hours following cessation of sedation. Although these changes are described as undesirable in head-injured patients, they were not predictive of early neurologic outcome.[3]

Opiates have analgesic and sedative effects and decrease sympathetic discharge and thus exert a mild negative inotropic and chronotropic effect. They also tend to decrease right ventricular filling due to splanchnic vasodilatation, ultimately resulting in decreased left ventricular end-diastolic pressure. Opiates also exert a direct depressive effect on the medullary respiration center with respiratory rate affected in the early stages before depression of tidal volume as well.[1,4] Opioid-induced hypotension is therefore a combination of direct vasodilatation, vagally mediated bradycardia, and histamine release.[5]

Morphine and fentanyl are the two most commonly used opioids for the analgesia of critically ill patients, including TBI patients, yet the cerebrovascular effects of such drugs remain controversial. In patients with intact autoregulation, reduced MAP would be expected to result in vasodilatation, increased cerebral blood volume, and thus increased ICP; however, studies show that autoregulation may be preserved, impaired, or abolished in TBI patients. Arteriojugular venous oxygen content difference as an estimate of cerebral blood flow can be used to clarify the role of autoregulation and opioid effect on ICP.

Studies consistently show that fentanyl, alfentanil, and sufentanil cause vasodilatation due to a chemical sympathectomy that decreases MAP, which in turn, leads to increases in ICP in neurosurgical patients due to autoregulated vasodilatation to maintain cerebral blood flow in the face of decreased systemic pressure. The findings were consistent in elevated ICP due to head trauma, neoplasia, or hemorrhage.[6–10]

Data regarding physiologic effects of analgesics on injured brain tissue are yet to be published, and as such, these data have not been analyzed for applicability to this discussion.

While the effects of narcotics in critically ill patients on blood pressure and ICP are well known and predictable, morphine and fentanyl have become drugs of choice in the ICU and in the OR for agitated brain-injured patients with a protected airway because they not only treat pain but have antitussive effects, suppress respiratory drive, and can therefore facilitate compliance with mechanical ventilation, and are reversible with naloxone.

Although there are no randomized trials of individualized therapeutic parameters (MAP and CPP) to allow absolute recommendations on minimally safe standards, most practitioners agree that narcotics are safe in head-injured patients if MAP and CPP can be maintained.[11] When changes in MAP are minimized, the effects on ICP can be ameliorated.[12–14]

Although the need for adequate sedation and analgesia in trauma patients is generally accepted,[2,5] there is no consensus regarding which drugs or what specific protocol should be used.[15]

From the patient point of view, pharmacologic control of pain and anxiety are critical to improving outcome, but many of the opioids may cause nausea, vomiting, vagal or anaphylactic reactions, and have significant detrimental hemodynamic and respiratory side-effects in situations where standard monitoring equipment is limited or not available.[16]

A number of studies have shown that emergency physicians may not be giving adequate analgesia to patients admitted to the ED or to patients managed by prehospital providers based on fear of adverse opioid side-effects, a belief that pain is needed for making a diagnosis, or priority given to life-threatening disease. A quality control program is necessary in order to measure and positively impact pain management in these settings.[17]

In a review of the medical, including EMS, literature, Borland et al.[18] found a short list of options for safe and effective analgesia for prehospital providers that included nitrous oxide/oxygen mixtures, intravenous/intramuscular nalbuphine, intravenous tramadol, and intravenous pure opiate angonists. There were no prospective or randomized studies.

Tramadol has only weak opioid angonist properties and enhances monaminergic spinal inhibition of pain. When given IV, it is one-tenth as potent as morphine on a weight basis, with onset of action within minutes and duration of effect of 3–6 hours. In comparison with equianalgesic doses of opioids, Tramadol rarely causes respiratory depression and cardiovascular side effects are minor as are episodes of dizziness, nausea, sedation, dry mouth, and sweating. Tramadol is an acceptable alternative to morphine in the prehospital trauma setting.[19]

V. SUMMARY

There may be valid reasons for wanting to control pain in the prehospital setting if it contributes to anxiety or to harmful activity but there is simply no evidence to indicate whether this is helpful or harmful in this setting. The Hippocratic Rule to "First Do No Harm" should therefore guide commonplace practice. Cautious discriminate use with as much physiologic monitoring as possible is advised.

Pain management for TBI patients in the prehospital setting should be guided by the following principles.

a) In the case of a minor closed head injury (GCS 13–15), a subjective assessment scale should be used before administering any analgesic and again before each additional dose. The goal should be to reduce pain to a level so that the patient remains comfortable but is not obtunded by the medication.

b) In addition to effective pain relief, the ideal analgesic must not alter vital signs, hide complications, or cause delay in therapeutic decision-making.

c) Analgesics should always be administered in small incremental doses.

d) Monitoring should not be limited to intermittent manual observation; the paramedic must be able to use, interpret, and act upon the data derived from patient assessment and monitoring technology to help ensure a positive outcome for the patient.

e) Hypotension (SBP < 90 mm Hg) must be avoided or corrected immediately by administering IV fluids. SBP should be monitored as frequently as possible or continuously. (See Guidelines on Treatment: Fluid Resuscitation.)

f) Oxygen saturation should be monitored as frequently as possible or continuously. Hypoxemia (apnea, cyanosis, or arterial hemoglobin oxygenation saturation [SaO_2] < 90%) must be avoided, if possible, or corrected immediately by administering supplemental oxygen. (See Guidelines on Treatment: Airway, Ventilation, and Oxygenation.)

g) $EtCO_2$ should be monitored as frequently as possible or continuously. Hypocapnea with hypercarbia (respiratory depression with rise in $EtCO_2$) causes cerebral vasodilatation and subsequent increased intracranial pressure that must be avoided, if possible, or corrected immediately by administering small incremental doses of Narcan or by assisting ventilation with a bag-valve-mask device or by intubating and placing the patient on a ventilator. (See Guidelines on Treatment: Airway, Ventilation, and Oxygenation).

VI. KEY ISSUES FOR FUTURE INVESTIGATION

1. How can the direct or even indirect effects of interventions, including pain control, be monitored in brain-injured tissue, particularly in the prehospital setting?
2. Do TBI patients remember prehospital pain and does this memory hinder ultimate rehabilitation?

3. Are analgesics that do not increase ICP, reduce blood pressure, or depress respiratory drive effective in the prehospital setting?

VII. EVIDENCE TABLE

Albanese,[20] 1999

Description of Study: A randomized unmasked crossover study of six patients with head trauma and ICP monitoring who received IV bolus infusions of fentanyl, alfentanil, and sulfentanyl.

Classification: III (due to insufficient sample size)

Conclusions: Patients showed dramatic decreases in MAP leading to a small increase in ICP but a significant reduction in CPP to 40 mm Hg, well below the range suggested by the Brain Trauma Foundation for preventing secondary brain injury. Regional injury from hypoperfusion could not be excluded.

Bruder,[3] 1994

Description of Study: In 15 TBI-injured patients who were sedated and on ventilators in the ICU, energy expenditure as measured by indirect calorimetry rose to 150% above BEE and VO_2, pulse, and MAP increased when sedation was discontinued. These increases persisted for 24–48 hours, gradually decreasing to 30% above BEE.

Classification: III

Conclusions: These increases were attributed to increase in muscle activity, work of breathing, and catecholamines levels but were not predictive of early neurologic outcomes.

Lauer,[21] 1997

Description of Study: Fifteen severely head-injured patients (GCS < 8) were randomly assigned to receive fentanyl, sufentanil, or morphine, titrating the drug to maximal 10% decrease in MAP.

Classification: III (due to insufficient sample size)

Conclusions: No increase in ICP when careful titration of narcotics was used in head-injured patients if MAP was maintained with 10% of baseline.

Mayberg,[22] 1993

Description of Study: Middle cerebral artery blood flow was measured in 16 patients undergoing neurosurgical procedures and in 16 patients undergoing orthopedic procedures after random assignment to receive 25 or 50 mcg/kg of IV alfentanil.

Classification: III (due to insufficient sample size)

Conclusions: No significant increase in ICP after administration of alfentanil in neurosurgical patients with tumors or aneurysms when phenylephrine was used to maintain MAP at baseline.

Nadal,[4] 2000

Description of Study: In 29 of 29 patients with severe head injury and elevated ICP, morphine and fentanyl caused significant increases in ICP and decreases in MAP both in patients with preserved and impaired cerebrovascular autoregulation but induced no significant changes in cerebral blood flow.

Classification: III

Conclusions: Other mechanisms besides autoregulation, possibly direct cerebral vasodilatory effects, could be implicated in the ICP process after opioid administration.

Sanchez,[23] 1998

Description of Study: Studied the physiologic effects of sedation using Midazolam and Propofol in 106 ventilated patients.

Classification: II

Conclusions: While decreases in blood pressure and heart rate were found and these effects can be deleterious in head-injured patients, Midazolam and Propofol can be used safely once the patient is stabilized.

Werner,[8] 1995

Description of Study: Transient increases in ICP were seen with concomitant decreases in MAP in head-injured patients given sufentanil but ICP values did not change when MAP was controlled.

Classification: III

Conclusions: Sufentanil does not cause an increase in cerebral blood flow as measured by cerebral blood flow velocity.

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TREATMENT: *BRAIN-TARGETED THERAPY*

I. RECOMMENDATIONS

A. Standards

Insufficient data to support a treatment standard for any brain-targeted therapy for patients with severe head injury.

B. Guidelines

Data supports the use of mannitol in response to herniation at doses of 1.4–2.1 g/kg if supported by the capacity to provide high fluid volume compensation for any ensuing urine loss.

C. Options

Hypertonic Saline

Hypertonic saline appears to reduce ICP when given as a bolus and may be given for this purpose although an improvement in neurological outcome with resuscitation with hypertonic saline over standard fluid resuscitation has not been demonstrated.

Hyperventilation

Hyperventilation is to be avoided both as an intended therapy and inadvertently as part of other airway management, except in the context of visible signs of cerebral herniation, when its use may delay herniation.

Antibiotic Prophylaxis for Penetrating Brain Injury

Use of prophylactic broad-spectrum antibiotics is recommended for patients with penetrating brain injury.

Treatments to optimize patient transport

While sedation and analgesia will be given for many reasons to the brain-injured patient, no literature supports a specific brain-targeted or protective effect from these medications.

Treating other causes of altered mental status

Hypoglycemia can result in altered mental status and coma. Exact correlation between symptoms and serum glucose levels does not exist. Finger-stick serum glucose should be obtained as soon as possible in the patients care and any hypoglycemia corrected.

II. OVERVIEW

In remote environments it is easy to assume a nihilistic approach to traumatic brain injury (TBI), based on the assumption that brain-targeted therapies are not available in such remote circumstances. In fact, several very effective brain-targeted therapies can be made available to remote environments, providing the potential for some brain resuscitation. This chapter reviews the scientific basis for these therapies: hyperventilation, hyperosmolar therapy, analgesics, sedatives, lidocaine, paralysis, and control of hyperglycemia.

III SEARCH PROCESS

A MEDLINE search was conducted from 1966 to 2005 using the keywords "hyperglycemia," "hyperventilation," "glucose," "mannitol," "urea," "lidocaine," "conscious sedation," "analgesics," "hypnotics," and "sedatives," "neuromuscular blocking agents," "neuromuscular blockade," and "neuromuscular junction," in combination with "emergency medical services," "air ambulance," "emergency medical technician," "intracranial trauma," "military medicine," "recreation," "critical care," "prehospital," and "wilderness medicine." From this group, articles relevant to the field management of TBI with human data and generally more than 25 subjects with outcome related to mortality were selected. Fourteen articles met these criteria. Additional articles and animal studies are referenced only as a part of background discussion.

IV. SCIENTIFIC FOUNDATION

Treatments of Cerebral Herniation

Hyperventilation

Hyperventilation can reduce ICP by inducing cerebral vasoconstriction and thereby reducing cerebral blood volume. Because of extensive data suggesting that hyperventilation also decreases cerebral blood flow and one Class II study demonstrating poorer outcomes at 3 and 6 months in patients who were hyperventilated versus those who were not,[1] prophylactic hyperventilation is discouraged and hyperventilation is reserved for patients with objective signs of cerebral herniation. In a field or prehospital environment without an ICP monitor in place, the indications that herniation is occurring are unilateral or bilateral fixed and dilated pupils, asymmetric motor posturing, or declining mental status.[2]

Hyperosmotic Agents

Hyperosmotic therapy was first proposed in 1919 by Weed and McKibben[3] who noted that infusion of intravenous distilled water increased brain tissue mass and infusion of 30% saline dehydrated the brain. Fremont-Smith and Forbes[4] began the clinical use of hyperosmolar urea the late 1920s. Javid et al.[5–7] became aware of urea's dehydrating properties in 1956 and published an extensive clinical experience with it in controlling cerebral edema, popularizing its use. In 1962, mannitol was proposed as a hyperosmotic agent.[8] Although urea could be given in much smaller volumes than mannitol, mannitol replaced urea as the hyperosmolar agent of choice because of concerns about rebound intracranial hypertension associated with urea's use.[9,10] Recently, hypertonic saline has been proposed as an alternative hyperosmotic agent, with volume expansion qualities as well as brain dehydrating qualities.[10–17]

Hyperosmolar therapies reduce ICP by two distinct mechanisms. The commonly- appreciated mechanism is via the establishment of an osmolar gradient across the blood brain barrier, with the gradient favoring the flow of water out of the brain and into the circulation. This mechanism is estimated to require 15–30 minutes to act and can last 90 minutes–6 hours.

Osmolar agents, however, can act in a much shorter time frame via a second mechanism. These agents also improve the rheology of the blood via plasma expansion, reduced hematocrit, and reduced blood viscosity resulting in more efficient cerebral blood flow. This increased efficiency means that at any given CPP, the cerebrovascular resistance will be higher, the cerebral blood

volume will be lower, and ICP will therefore be lower while cerebral blood flow remains unaltered.[18] Mannitol and hypertonic saline are believed to utilize both of these mechanisms.[19]

Mannitol

Mechanism of Action

Mannitol has long been accepted as an effective tool for reducing intracranial pressure.[20–24] Numerous mechanistic laboratory studies support this conclusion. Its impact on outcome has never, however, been directly demonstrated via a Class I trial testing mannitol against placebo. Schwartz et al.[23] conducted a Class III study comparing mannitol to pentobarbital which failed to demonstrate the superiority of pentobarbital and which did demonstrate better outcomes and maintenance of CPP in the mannitol group.

Cruz et al.[25–27] has published three Class II studies demonstrating benefit of high dose mannitol versus conventional dose mannitol in the very early stages (emergency department) of a patient's treatment. Patient populations with acute subdural hematomas, temporal lobe hemorrhages, and diffuse brain swelling were studied. Patients who received early high dose mannitol had better preoperative improvement of pupillary widening and better Glasgow Outcome Scores at 6 months. Fortune et al.[28] compared mannitol, hyperventilation, and ventricular drainage in 22 patients. Mannitol was most effective in reducing ICP.

Rate of Infusion

There is a commonly held belief that mannitol administration can cause or exacerbate hypotension in the early resuscitation of trauma victims. There is Class III data that infusion of mannitol at rates of 0.2–0.8 g/kg/min can lead to transient drops in blood pressure.[29–31] From these observations, a recommended rate of no higher than 0.1 g/kg/min or 1 g/kg delivered over 10 minutes or more is recommended.[18] Careful monitoring of urine output with aggressive replacement of this fluid loss is also recommended to prevent hypotension associated with the use of mannitol.

Sayre et al.[32] tested the hypothesis that mannitol would exacerbate hypotension in a prehospital environment in a Class II study. Patients were randomized to a mannitol or normal saline group. Mannitol was allowed to be given rapidly over as little as 5 minutes. No difference in heart rate or blood pressure was observed over the 2-hour subsequent observation period between the two groups.

Dose

Mannitol can be given in response to an elevated ICP or as a continuous drip in a more prophylactic fashion. Class II data have found bolus administration to be effective and some Class III data have found no difference between the two routes.[20,22,24,33–35]

Mannitol and other hyperosmotics are known to be able to briefly open the blood brain barrier. Furthermore, at rates of administration which exceed the rate of excretion of mannitol, mannitol can accumulate in the extracellular space. These factors lead to the accumulation of mannitol in the extracellular space and a reverse osmotic gradient which can lead to a "rebound effect" or movement of water into the brain. Class III data suggests that this effect is more likely with continuous infusion of mannitol as opposed to bolus administration.[36,37] In a field or prehospital environment the time need to see a rebound effect would normally not be present.

Class II and Class III data have shown that doses of 0.25–1.0 g/kg of mannitol may be needed to achieve a reduction in ICP. This required dose varies from patient to patient and even may vary from time to time in the same patient.[22,37,33]

In a field or prehospital environment, mannitol cannot usually be given based on a measured ICP. Data from Cruz et al.[25–27] (Class II) show that doses from 1.4–2.1 g/kg can be effective in response to the clinical findings of pupillary widening, declining mental status or asymmetric motor examination, as opposed to ICP.

Hypertonic Saline

Hypertonic saline offers an attractive alternative to mannitol as a brain-targeted hyperosmotic therapy. Its ability to reduce elevated ICP has been demonstrated with Class II and III data in the ICU and in the operating room.[15–17,38] Several issues require clarification in discussing hypertonic saline as a brain-targeted therapy.

The first is that hypertonic saline is also a potential low volume resuscitation fluid. Its actions in this role are discussed elsewhere in these Guidelines. While the qualities that make it useful as a low volume resuscitation fluid and as a brain-targeted therapy are related, this discussion will be limited to its role as a brain-targeted therapy.

Secondly, there is no consensus on what is meant by "hypertonic saline." Concentrations of 3%, 7.2%, 7.5%, 10%, and 23.4% have all been used. There is no consensus on the optimum concentration for reduction of ICP.[11,15–17]

Lastly, hypertonic saline is dosed in different ways. In some studies, it is given as an infusion, the goal of which is to elevate serum sodium to 155–160 mEq/L, although some investigators have gone as high as 180 mEq/L. This elevated serum sodium is thought to help stabilize ICP and reduce the therapeutic intensity required to prevent elevated ICP.[39,40] This modality would not be used in the prehospital or field environment. A field environment would utilize hypertonic saline as a bolus, taking advantage of the rapid rheologic improvement and improved cerebral blood flow, which like mannitol, hypertonic saline can create. Multiple animal studies and several human studies have demonstrated that hypertonic saline, as a bolus, can reduce ICP in a monitored environment such as the operating room or ICU where ICP monitoring is present.[40–42] Comparison of these studies is difficult since they do not use the same concentrations or protocols.

No study has demonstrated an effect on clinical indicators of herniation such as pupillary widening or posturing such as Cruz demonstrated for mannitol. One study looked at the impact of prehospital hypertonic saline on neurological outcome. Hypertonic saline did not demonstrate any advantage over normal saline on neurological outcome when given as a prehospital resuscitation fluid.[43]

Lidocaine

Expert opinion supports the use of lidocaine to prophylax against ICP elevations during interventions, in particular intubation. No data exists to support this recommendation.

Antibiotic Prophylaxis for Penetrating Brain Injury

The evidence-based *Guidelines for the Management of Penetrating Brain Injury* recommends the use of prophylactic broad-spectrum antibiotics in patients who are the victims of penetrating brain injury (PBI). Although there is no evidence directly supporting the use of antibiotics for PBI in a field environment, there is evidence that prophylactic antibiotics do reduce postoperative cranial infections.[44,45] From this data, the Guidelines authors reasoned that the early administration of broad spectrum antibiotics would also reduce cerebral infections in the field environment. They recommend prophylactic antibiotics at the level of an option.[46] Patients with CSF leaks and air sinus wounds have been identified as being at especially high risk for cerebral abscess after PBI.[46,47]

Treatments to optimize patient transport

Sedation and Analgesia

While sedation and analgesia will be given for many reasons to the brain-injured patient, no literature supports a specific brain-targeted or protective effect from these medications.

Managing Hypoglycemia

There is literature to suggest that poor control of hyperglycemic patients in the ICU results in poorer outcomes for brain-injured patients.[48] In addition, patients with higher serum glucose on admission to the hospital appear to have worse clinical outcomes.[48–52] Early hyperglycemia appears to be part of the early stress response to head injury.[51,52] Whether early elevated serum glucose contributes to poor outcome or is simply associated with poor neurological outcome is not clear.[48–52] Patients with serum glucose greater than 200 mg/dl, and probably 150 mg/dl, early in their hospital course appear to have poorer outcomes.[48–52]

Hypoglycemia can result in altered mental status and coma. Exact correlation between symptoms and serum glucose levels does not exist, but levels < 80 mg/dl can be symptomatic, and < 30 mg/dl can be seriously symptomatic.[53,54] While there are technical flaws that can occur with finger stick glucose monitoring, this technique remains the best available method early in a patient's care to detect and correct hypoglycemia. As soon as this technology becomes available to the patient, a finger stick serum glucose should be obtained and any hypoglycemia corrected.[55–57]

II. SUMMARY

The brain-targeted therapies possible away from a treatment facility in a prehospital or remote environment are hyperventilation, hyperosmolar therapy, sedation, and control of glucose. Hyperventilation will delay herniation but can also impact outcomes by creating ischemia, limiting its use to patients who show clinical evidence of herniation. Hyperosmolar therapy has been shown to improve outcome. Unfortunately, the hyperosmolar agent demonstrated to provide benefit, mannitol, is a high volume agent. The lower volume agent, hypertonic saline, has shown neither benefit nor detriment over isotonic solutions. While analgesics, sedatives and lidocaine will continue to be part of the early care of brain-injured patients, no evidence exists for a specific beneficial brain effect. Prevention of hypoglycemia should continue to be a priority. The impact on neurological outcome of limiting hyperglycemia is still to be determined. Although obtaining tight control of serum glucose in the prehospital environment may not be practical in

all cases, checking and managing serum glucose as soon as practical in the patient's course is advisable.

III. KEY AREAS FOR FUTURE INVESTIGATION

1. Much of what is known about bolus hypertonic saline as a brain-targeted therapy is from animal models. More human data are needed.
2. The early management of glucose in the field needs to be better defined in terms of ultimate outcome.
3. A better way to manage ventilation without the benefit of blood gas analysis is needed.
4. Exploration of alternative, low volume hyperosmolar agents, such as urea, could prove productive.

IV. EVIDENCE TABLE

Cooper,[43] 2004

Description of Study:	Randomized prospective clinical trial of hypertonic vs. normal saline as a prehospital resuscitation fluid. Neurological outcome was used as an end point.
Classification:	II
Conclusions:	Hypertonic saline offered no advantage in long term neurological outcome.

Cruz,[25] 2001

Description of Study:	Randomized prospective clinical trial of 178 adult patients with nonmissile, traumatic, acute, subdural hematomas. The experimental group received emergency, preoperative, intravenous HDM treatment compared with a control group treated with a lower preoperative mannitol dose.
Classification:	II
Conclusions:	Administration of high dose mannitol in the emergency room resulted in more frequent reduction in papillary widening and better outcomes at 6 months for the experimental group.

Cruz,[26] 2002

Description of Study:	Randomized prospective clinical trial of 141 adult patients with traumatic, nonmissile, acute, intraparenchymal temporal lobe hemorrhages associated with early abnormal pupillary widening. Patients received either emergency preoperative intravenous HDM treatment (approximately 1.4 g/kg; 72 patients) and were compared with a control group that was treated with a lower preoperative mannitol dose (approximately 0.7 g/kg; 69 patients).
Classification:	II
Conclusions:	Early high dose mannitol resulted in more frequent reduction in papillary widening and better outcomes at 6 months.

Cruz,[27] 2004

Description of Study: Randomized prospective clinical trial of 44 adult patients with traumatic, nonmissile-inflicted, acute, severe diffuse brain swelling with clinical signs of impending brain death on the first emergency room evaluation. These signs included bilateral abnormal pupillary widening and lack of motor responses to painful stimulation (GCS 3). The study group received ultra-early and fast intravenous high-dose mannitol treatment (approximately 1.4 g/kg), whereas the control group received half that dose (approximately 0.7 g/kg).

Classification: II

Conclusions: Early high dose mannitol resulted in more frequent reduction in papillary widening and better outcomes at six months.

Davis,[58] 2004

Description of Study: A retrospective linear regression analysis of the impact of hypocapnia and decreased oxygen saturation during prehospital rapid sequence intubation on patient mortality. Patients undergoing RSI were matched with historical controls.

Classification: III

Conclusions: Hyperventilation and severe hypoxia during paramedic RSI are associated with an increase in mortality.

James,[22] 1980

Description of Study: Retrospective analysis of 60 patients treated with mannitol for increased ICP.

Classification: III

Conclusions: Mannitol reduced ICP 97% of the time when given as a bolus.

Lam,[48] 1991

Description of Study: A retrospective analysis of the relationship between elevated serum glucose and mortality in 169 patients with head injury.

Classification: III

Conclusions: Patients whose final outcome was a vegetative state or who went on to die had significantly higher admission and post-operative glucose levels.

Margulies,[49] 1994

Description of Study: A retrospective study correlating the peak serum glucose and GCS with neurological outcome using logistic regression analysis. GCS predicted outcome with the power of the prediction not being improved by the addition of peak serum glucose data.

Classification: III

Conclusions: Elevated serum glucose early in the course of head injury is associated with but not necessarily a cause of poor neurological outcome.

Muizelaar,[1] 1991

Description of Study: Prospective randomized clinical trial comparing neurological outcomes in patients hyperventilated to 25 mm Hg pCO_2 vs. patients kept at 35 mm Hg pCO_2.

Classification: II

Conclusions: Patients hyperventilated to a pCO_2 of 25 mm Hg had worse neurological outcomes at 6 and 6 months.

Schwartz,[23] 1984

Description of Study: Prospective randomized clinical trial comparing mannitol and barbiturates for ICP control.

Classification: III

Conclusions: Mannitol group had a lower mortality rate. Mannitol and barbiturate felt to be equivalent therapies.

Smith,[24] 1986

Description of Study: A randomized prospective clinical trial comparing ICP-directed mannitol administration vs. empiric mannitol administration.

Classification: III

Conclusions: There was no difference in mortality or neurological outcome between the two groups.

Walia,[50] 2002

Description of Study: A regression analysis on 338 patients investigating the relationship between hypoglycemia, hypotension, and outcome.

Classification: III

Conclusions: Both hypoglycemia and hypotension were found to be independent predictors of outcome.

Yang,[51] 1995

Description of Study: A study comparing serum glucose and catecholamine levels in the first seven days after injury in 48 head injured patients with 38 normal controls. Both serum catecholamine and glucose levels were elevated in the brain injured group.

Classification: III

Conclusions: Hyperglycemia was associated with elevated serum catecholamine levels. Both were interpreted to be part of the post injury stress response. Elevated serum glucose was associated with increased mortality.

Young,[52] 1989

Description of Study: An observational study of the relationship of admission serum glucose levels and outcome.

Classification: III

Conclusions: Patients with higher admission serum glucose levels had worse outcomes.

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TREATMENT: *TRIAGE AND TRANSPORT DECISIONS*

I. RECOMMENDATIONS

A. Standards:
Class I data are insufficient to support a treatment standard for this topic.

B. Guidelines:
Class II data are insufficient to support a treatment standard for this topic.

C. Options:

1. Class III data support the assertion that civilian regions having organized trauma care systems have better outcomes. This, combined with Class III data from military studies, would suggest that continuing to improve on the military's existing organized trauma care system is appropriate.
2. Class III civilian data supports the recommendation that patients with GCS score 9–13 should be transported to a trauma center for evaluation.
3. Patients with Glasgow Coma Scale (GCS) score 14 should not return to duty until disorientation resolves. GCS data obtained in the hyperacute setting, particularly concerning decisions for expectant management, should be used cautiously as it may overestimate the severity of intracranial injury. Pupillary examination may have limited usefulness due to the frequency of blast injury and the potential for traumatic iridoplegia resulting in fixed, dilated pupils which are not indicative of severe brain injury. Both GCS score and pupillary examination should be obtained, documented and repeated throughout the transport as frequently as is practical in order to follow and report the patient's clinical course.

II. OVERVIEW

Triage and transport decisions in combat scenarios may be complicated by tactical conditions. The essence of the decision making process involves making an assessment and categorizing patient status as return to duty, requires evacuation, or not likely to survive. In addition, those being evacuation must be further categorized as to the level of care required.

It is important to make a neurologic assessment and determine whether the patient has a nonsurvivable injury. It must be kept in mind that horrific appearing injuries involving the face and head may be survivable. If damage is limited to a single hemisphere of the brain, a tremendous amount of brain loss—coupled with massive facial tissue loss and scalp bleeding—may have the inaccurate initial appearance of being nonsurvivable. Patient responsiveness should be carefully assessed in a serial fashion. Any purposeful or repetitive movement, any ability to follow commands, and the presence of smooth, spontaneous respirations can be indicators of a survivable injury. Alternatively, absence of spontaneous respirations and/or heartbeat is a uniformly poor prognostic indicator. Massive bilateral skull and brain tissue loss are not survivable. Here again it should be emphasized that bilateral fixed, dilated pupils may be the result of direct trauma to the globe from blast injury or blunt trauma and no assessment should rely solely on pupillary exami-

nation. Overall neurologic status should be determined from the best reproducible segment of the neurologic examination: motor, verbal, eye-opening, or pupillary examination.

Return to duty decisions must be made based on a combination of medical and tactical factors. A head injury which is potentially life-threatening for the patient or which affects the patient's ability to make appropriate life-and-death decisions will demand that the medic, in most cases, recommend removal from active engagement. In instances that are not clear-cut, the chain of command can be used to assist in the decision. Patients with GCS ≤ 14 should not return to duty until they are oriented to person, place, time, and situation.

From a neurologic standpoint, the decision to evacuate must be made based upon the immediate condition of the patient and the likelihood for short-term improvement, the threat that the injury poses to the patient, the threat that the patient may pose to the unit or mission, and the availability of evacuation assets. Patients with GCS 3–8 should be evacuated to a facility with neurosurgical capability, potentially bypassing a closer facility in order to insure the level of care necessary is made available in the most expeditious fashion. Finally, the urgency of evacuation must be considered. The possible danger to evacuation personnel, vehicles, and/or aircraft must be weighed against the immediate needs of the patient. It is incumbent upon the medical provider to base recommendations on the medical needs of the patient first, and the chains of command of both the tactical unit and evacuation unit will determine whether the evacuation asset is dispatched. However, the requesting medic must be aware of the implications of making a recommendation for a priority evacuation from a hot landing zone and carefully consider whether the patient can be stabilized on-site without increased morbidity or mortality.

In tactical environments where explosions are common, it should be kept in mind that the GCS score may be artificially low for a period of time due to the patient being rendered unconscious from a blast. Additionally, pupillary examination may demonstrate fixed, dilated pupils which are due to globe trauma and not brain injury. Dehydration, combat stress, and traumatic brain injury (TBI) all may result in global neurologic dysfunction. In mild cases of disorientation the decision to evacuate should be made based upon serial examinations over whatever time is available. If the neurologic status is deteriorating, the decision to evacuate becomes clear. If the patient rapidly improves to normal, there may be an opportunity to return to duty. Appropriate frequency of reexamination has not been established.

III. SEARCH PROCESS

A MEDLINE search without date limits was performed using combinations of the keywords "combat," "triage," "evacuation," "tactical," "casualty," and "head injury." The 286 articles listed were reviewed in abstract form and 25 were selected for full review. None contained pertinent data specifically related to the evacuation and triage of neurologically injured patients. A MEDLINE search from 1970 to 1999 using the keywords "trauma systems," "trauma centers," "emergency medical services," "prehospital care," and "ambulance transports" identified 147 articles. Careful review and analysis of all 147 articles permitted an assessment of trauma systems and the role of EMS in managing patients with severe TBI.

IV. SCIENTIFIC FOUNDATION

Since the late 1970s, several investigators have tried to demonstrate the efficacy of EMS systems and trauma systems. Studies performed in the late 1970s and early 1980s attempted to show that excessive "preventable" trauma deaths occurred in regions without organized EMS or trauma care.[1] The investigators' methodology relied on physician panels who reviewed patient care case by case and then used various consensus methods to determine the appropriateness of the treatment. This technique has been criticized as being too subjective because blinding of the panel participants to the treatment setting is often extremely difficult and the various means used to reach consensus produce different results.[2] Later studies relied on series of patients treated at one or more trauma centers and compared them with those patients treated in a non-trauma center within a region[3] or across the United States,[4] using prospectively collected, standardized data on severity and outcome. In all comparisons between organized and nonorganized EMS and trauma systems, patient outcome was worse without organization.[3,5] A number of studies and their methodologies have been summarized in publications.[4,6] To deliver the best possible trauma care, it is crucial that trauma victims first receive competent on-scene prehospital EMS care before being removed directly to a hospital. In addition, because victims of severe trauma usually have a life-threatening condition, the receiving hospital must be sufficiently equipped and qualified to take care of their injuries.

Recent literature suggests that the outcome of trauma patients clearly improve when prehospital care, triage, and admission to designated trauma centers are coordinated within regional trauma systems. It should be noted, however, that nearly all of these studies refer to the general trauma patient, and only a few primarily address the patient with TBI. There are no published data suggesting that the lack of a trauma care system is superior to organized systems. There is a retrospective study that compared head trauma outcome before and after the implementation of a trauma system in Oregon, which reported that an odds ratio of 0.80 for mortality after system implementation.[7]

A report of preventable deaths in San Diego County compared non-TBI and TBI deaths before and after instituting a regional trauma care system.[8] Reviewers were blinded to the facility where care was rendered. Preventable deaths for non-TBI cases decreased from 16/83 (20%) to 2/211 (1%) ($p < 0.005$), and for TBI cases, preventable deaths decreased from 4/94 (5%) to 1/149 (0.7%) ($p < 0.10$), respectively, before and after the trauma system was put in place.

Another before and after study compared outcome of injured patients in a rural hospital before it chose to meet American College of Surgeons Committee on Trauma guidelines for a level II trauma center with outcome after it became a level II trauma center.[9] Survival for all patients who had a calculated probability of survival of 25% was 13% before and 30% after meeting trauma center criteria. For patients with closed head trauma, the survival was 15.4% before and 32% after meeting the criteria.

Several articles studied the EMS system's impact within the overall trauma system. One study in New Delhi, India and in Charlottesville, Virginia, compared mortality rates after head injury using the motor score portion of the GCS to stratify patients.[10] While outcome was not statistically different in those patients with the lowest motor scores, mortality in patients with a motor score of 5 was notably different. Patients in Charlottesville had a mortality of 4.8%, whereas those in New

Delhi had a mortality of 12.5% (p = 0.001). The authors postulated that one reason for this difference may be that only 0.5% of patients in New Delhi arrived to the hospital by ambulance, versus 84% in Charlottesville. In addition, only 7% of patients in New Delhi arrived at the hospital within 1 hour and an additional 33% in 2–3 hours, compared with 50% within 1 hour and an additional 39% within 3 hours in Virginia. Thus, the lack of an EMS system and delay in presentation were thought to be important factors that account for the difference in outcome between the two cities.

The second study compared trauma patients with an injury severity score (ISS) of 9 or more in Seattle and Monterrey, Mexico.[11] Patients were taken to an urban hospital in Monterrey and to a level I trauma center in Seattle. Overall mortality was 55% in Monterrey and 34% in Seattle (p = 0.001). Deaths in Monterrey occurred in the field (40%) and in the ED (11%) compared with Seattle where 21% died in the field and 6% in the ED (p = 0.001 and 0.003, respectively). In addition, at hospital arrival, 39% of patients in Monterrey had a systolic blood pressure less than or equal to 80 mm Hg compared with 18% (p = 0.001) in Seattle. Of those patients who were hypotensive, 5% in Monterrey and 79% in Seattle underwent endotracheal intubation in the field (p = 0.001) and 70% in Monterrey and 99% in Seattle had fluid resuscitation en route (p = 0.001).

The need for the in-house presence of the trauma surgeon 24 hours a day versus the ability of the trauma surgeon to respond quickly to the hospital has generated significant controversy. A report from one level II trauma center in Oklahoma concluded that level II trauma centers with attending trauma surgeons who are available but not "in-house" have outcomes as good as those with surgeons present in the hospital at all times.[12] This study was performed internally comparing daytime hours when the attending trauma surgeon was in-hospital versus evening and night hours when call was taken from outside. Using survival as predicted by the Major Trauma Outcome Study, this study evaluated 3,689 patients with major trauma. Overall survival was 97% with a predicted survival of 96%. Subgroup analysis revealed that, for patients with a trauma score < 12, predicted survival and actual survival was 84%. In comparing whether the trauma surgeon was present, patients with severe thoracoabdominal trauma had a predicted survival of 79% and actual survival of 77% when the surgeon was in-house and a predicted and actual survival of 74% and 81% when the surgeon was called in from outside. In addition, patients with head trauma had predicted survival of 61% and actual of 63% when the surgeon was immediately available, and 57% predicted and 63% actual when the surgeon came in from home. All p-values were described as nonsignificant. Whether or not the trauma surgeon takes call from home, the important point in delivering trauma care to the patient is the physical presence of an appropriate team at the time of patient arrival in the ED.

Another issue that has also resulted in significant controversy relates to experience and patient volume criteria. Using data collected by trauma nurse coordinators, a retrospective study evaluating volume measurements on patient outcome compared trauma centers in Chicago. The trauma centers treating larger volumes of trauma patients were found to have better patient outcomes than those with fewer admissions. Patients transported to low volume centers had a 30% greater chance of death when compared with high-volume centers.[13] However, a recent report questions the impact of case volume on patient outcome. Richardson et al.[14] evaluated mortality and morbidity outcomes, such as length of stay of trauma patients by case volume per attending surgeon. They found no difference based upon annual case volume or years of experience. While

the optimal number of cases per trauma center and per trauma surgeon may be debated, the individual physicians on the treating team must have adequate experience to make the complex decisions often required when caring for a patient with severe multisystem or brain injury.

Another study that evaluated 1,332 patients with femoral fractures who underwent operative repair compared outcome in terms of morbidity and mortality between trauma centers and non-trauma centers.[2] Morbidity was 21% in the trauma centers and 33% in the nontrauma centers ($p = 0.001$), and mortality was 1.0% versus 2.2% respectively.

Several studies from Quebec demonstrated similar results. Mortality for all trauma patients before implementation of a trauma system was 20%, but only 10% after the system was put in place.[15] A subsequent review of trauma care in Quebec compared the outcome of 2,756 trauma patients transported directly to a trauma center with 1,608 patients who first were treated at a local hospital and subsequently transferred to the trauma center.[16] Mortality was 4.8% for patients taken directly to the trauma center and 8.9% if transfer occurred later ($p = 0.001$).

These findings apply to both adults and children transported by EMS systems directly from the scene to trauma centers. For example, in a study of 1,320 children of whom 98 sustained severe head injuries, mortality for the children brought directly from the accident scene to a pediatric trauma center was 27%. However, children transported first to the nearest available hospital and subsequently transferred to the trauma center had a mortality of 50%.[17]

A number of studies attempted to evaluate the differences and difficulties associated with providing trauma care in rural settings compared with urban settings that have integrated trauma systems. Rogers et al.[18] reviewed trauma deaths in an organized urban trauma system compared with a rural state without a formal trauma system. The authors suggest that the higher incidence of prehospital deaths may be related to delays in discovering the patient and the longer response and transport times required in the rural setting, particularly for interhospital transfers.

Young et al.[19] compared the outcome of patients with an ISS > 15 who were transported directly to their level I trauma center with those who were first taken to another rural hospital and subsequently transferred. Outcome measures included mortality, total hospital days, and ICU days. When all patients were included the two groups did not differ. However, when patients who died within the first 24 hours were excluded, length of stay, both in the hospital and in the ICU, was significantly longer ($p < 0.05$) in the group transferred from another hospital, although there was no difference in mortality. The GCS of the patients who died within the first 24 hours should, however, be noted. The GCS for the patients taken directly to the trauma center was 5, compared with 10 for those patients transferred from an outside hospital ($p < 0.05$). In addition, of patients who died in the first 24 hours (probability of survival > 0.50), the observed mortality for the direct transport group was 28% (7/25) compared with 75% (12/16) in the transferred group ($p < 0.05$). The authors stated that although these differences were noted between the groups, the study did not identify specific subgroups that would clearly benefit from direct transport to the trauma center. However, they did recommend that whenever possible patients with major trauma should be transported from the scene directly to a trauma center.

As noted in the section on Glasgow Coma Scale, a significant percentage of patients with hospital GCS scores 9–13 have serious intracranial injury requiring neurosurgical intervention and poor outcome, but no studies were found that compared outcomes based upon choice of destination.

Severe TBI patients transported to trauma centers without prompt neurosurgical care or intracranial pressure monitoring are at risk for a poor outcome. Acute subdural hematomas in severe TBI patients are associated with 90% mortality if evaluated more than 4 hours after injury and only 30% mortality if evaluated earlier.[20] If subdural evaluation is done in less than 2 hours after injury, one study reported a 70% decrease in mortality.[21] To achieve this surgical timing, 24-hour availability of CT scanning is necessary. Intracranial pressure monitoring guides specific treatment to maintain cerebral perfusion and is recommended based on supporting scientific evidence for improved patient outcome given in the *Guidelines for the Management of Severe Head Injury*.[22]

A recent study of 4014 patients involved in motor vehicle collisions reported that a GCS ≤ 14 predicted the need for hospital admission after arrival at a trauma center.[23] Hospital admission rates were 96% for GCS ≤ 12, 73% for GCS 13–14 and 32% for GCS 15. The authors concluded that activation of the trauma system should be strongly considered for GCS ≤ 14. However, since the resources available in combat differ, these Guidelines recommend holding patients with GCS 14 in the field for observation.

V. SUMMARY

The combat management of the acutely head injured patient is complicated by tactical, logistical, and medical considerations. Ideally, this "fog of war" would clear, allowing the combat medic the luxury of being able to provide the best available care based on civilian standards practiced in the U.S. on a sunny day with no distractors. Unfortunately, this is likely to be the exception in combat, and the medics must be given the tools, training, and confidence to be able to provide optimal care under these most demanding of circumstances to the most deserving patients in the world.

VI. KEY ISSUES FOR FUTURE INVESTIGATION

Future investigations should focus on rapid evaluation of the neurologically injured patient. Examination algorithms which are rapidly administered, reliable, and feasible *in a combat environment* are essential. Diagnostic tools or devices that are accurate, lightweight, rugged enough for combat use, and simple to use under tactical conditions should be developed.

VII. EVIDENCE TABLE

Arreola-Risa,[11] 1995

Description of Study:	This study compared patients with ISS > 8 in Seattle and Monterrey, Mexico.
Classification:	III
Conclusions:	There was significantly greater mortality in Monterrey compared to Seattle. EMS differences included fewer patients undergoing endotracheal intubation or fluid resuscitation in Mexico.

Colohan,[10] 1989

Description of Study: Comparison of outcome after head injury between New Delhi, India and Charlottesville, Virginia using GCSM to group patients

Classification: III

Conclusions: Outcome in New Delhi was significantly worse in patients with GCSM = 5 compared to Charlottesville, suggested that differences in EMS were significant factors

Guss,[8] 1989

Description of Study: The authors compared non-CNS and CNS preventable deaths before and after a trauma system was implemented

Classification: III

Conclusions: Preventable deaths for both non-CNS and CNS patients decreased after placement of a trauma system

Johnson,[17] 1995

Description of Study: This study compared the mortality of 98 children who sustained severe head injury and were transported directly to a pediatric trauma center with those that were first taken to the closest hospital and later transferred.

Classification: III

Conclusions: Mortality for children taken directly to the pediatric trauma center was 27% and for those taken to the closest hospital first it was 50%.

Mullins,[7] 1996

Description of Study: Evaluate the influence of implementing the Oregon statewide trauma system on admission distribution and risk of death using a before and after comparison.

Classification: III

Conclusions: The Oregon trauma system resulted in reduction in risk of trauma related death.

Norwood,[23] 2002

Description of Study: Retrospective review of 4014 consecutive patients involved in motor vehicle collisions. Multiple physiologic parameters were gathered on 2880 of these patients and studied using logistic regression analysis to determine which parameters were associated with hospital admission.

Classification: III

Conclusions: The prehospital GCS score is a reliable physiologic parameter for predicting hospital admission after motor vehicle collisions. When other obvious indicators (hypoxemia, multiple long bone fractures, focal neurologic deficits) for trauma activation are lacking, the prehospital GCS score may be used to reduce overtriage and undertriage rates.

Rogers,[18] 1997

Description of Study: Trauma deaths in an urban trauma system were compared with those in a rural state without a trauma system.

Classification: III

Conclusions: Rural patients were more likely to die at the scene and were found to have lower ISS scores. The authors suggest long discovery and transfer times as possible causes of the increased mortality and suggest focusing on improving the EMS system in rural areas.

Sampalis,[15] 1995

Description of Study: The study evaluated the impact of trauma center development and designation on mortality in Quebec, Canada comparing mortality before and after the trauma system was implemented.

Classification: III

Conclusions: There was a significant reduction in trauma related mortality after implementing a trauma system.

Sampalis,[16] 1997

Description of Study: The study compared outcome of severely injured patients (including head trauma) who were transported directly to trauma centers with those who were transferred after first being transported to less specialized, local facility (n = 1608)

Classification: III

Conclusions: This study showed that transport of severely injured patients from the scene to level 1 trauma centers is associated with a significant reduction in mortality.

Shackford,[4] 1987

Description of Study: Analysis of patients admitted after traumatic injury, of whom 283 were severely injured (trauma score < 8). Of those who had sufficient data (n = 189) to compare with a national cohort study that provided a model for predicting survival in patients, actual survival was 29% whereas predicted survival (PS) was 18%. In patients with penetrating injury, PS was 8% and actual survival was 20% (n = 3393).

Classification: III

Conclusions: The improved survival was attributed to the integration of prehospital and hospital care and expeditious surgery.

Smith,[3] 1990

Description of Study: Analysis of data abstracted from computerized discharge information about patients with femoral shaft fractures requiring operation over a one-year period (n = 1332) comparing morbidity and mortality between patients treated at trauma centers and those treated at nontrauma centers.

Classification: III

Conclusions: Patients treated in trauma care centers had significantly fewer deaths and complications than in nontrauma centers

Smith,[13] 1990

Description of Study: A cohort analysis was performed on data from severely injured patients using three statistical methods to determine the relationship between trauma center volume and mortality (n = 1643)

Classification: III

Conclusions: Low-volume trauma centers (fewer than 140 patients annually) had significantly higher mortality when adjusted for head injury, than did high-volume trauma centers (more than 200 patients annually) ($p < 0.04$).

Thompson,[12] 1992

Description of Study: Cohort analysis of trauma admissions at a level II trauma center showed no difference between survival in that center and survival among patients in the Major Trauma Outcome Study (n > 15,000). Whether the trauma surgeon was on call out of the hospital or in did not adversely affect survival in patients with severe thoracoabdominal injury, compared with the trauma surgeon available in house (n = 3689).

Classification: III

Conclusions: Level II trauma centers can achieve mortality rates equal to that shown in a large multicenter trauma study, and trauma surgeons promptly available from outside a hospital can produce mortality rates equal to in-house trauma surgeons.

Young,[19] 1998

Description of Study: Trauma patients with ISS > 15 who were taken directly to a trauma center were compared with those who were first taken to a rural hospital and later transferred.

Classification: III

Conclusions: Patients taken directly to the trauma center had shorter ICU and total hospital stays although mortality was not different.

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THE TREATMENT ALGORITHM FOR THE FIELD MANAGEMENT OF COMBAT-RELATED HEAD TRAUMA

Based on the evidence contained in the *Guidelines for the Field Management of Combat-Related Head Trauma*, the authors produced an assessment and treatment algorithm to be used as a framework to assess, treat, and transport combat casualties with traumatic brain injury (TBI). Individual service branch and tactical situations may require medical providers to modify the algorithm, because it may not be appropriate for all casualties, locations, or tactical situations. The following points provide more detail on the steps in the graphic algorithm. The decision to evacuate must be made based upon the immediate condition of the patient and the likelihood for short-term improvement, the threat that the injury poses to the patient, the threat that the patient may pose to the unit or mission, and the availability of evacuation assets. The authors recognize that some treatment recommendations may be outside of the levels of care prescribed by military doctrine. It is the hope of the authors that military medical direction will consider these recommendations in reviewing the current military doctrine affecting battlefield combat casualty care.

As previous chapters have noted, there are many factors influencing combat casualty care. The first and most important aspect to providing care in the forward environment is safety. Field medical personnel mitigate injuries sustained during combat operations and are often under fire when doing so. This unique austere environment challenges the provider to weigh personal safety against the needs of their injured team members. Frequently, these difficult choices are made under the most extreme circumstances of life and limb. The military ethos of not leaving a man behind often dictates acts of extreme heroism on the part of these medical providers. It is, however, still important for field medical providers to be vigilant of safety threats and other operational hazards they may encounter while performing these life saving skills.

The medical provider's first priority in assessing, stabilizing, and treating a TBI casualty is to follow basic resuscitation protocols that prioritize airway, breathing, and circulation assessment and treatment.

- Following stabilization of airway, breathing, and circulation, the medical provider assesses the casualty by first asking him or her, "What happened to you?"
- If the casualty opens his eyes, the provider then asks him the questions in the verbal and motor sections of the Glasgow Coma Scale (GCS) to determine the total score. Casualties with a GCS score of 9–13 (moderate TBI) and casualties with a GCS score 3–8 (severe TBI) should be evacuated from the forward environment.
- If the casualty does not open his eyes, the medical provider applies blunt pressure to the nail bed or pinches the anterior axillary skin to elicit eye opening.
- If the casualty opens his eyes with nail bed pressure or axillary pinch, the medical provider assesses the verbal and motor sections of the GCS to determine the total score.

- Casualties who are unresponsive with a GCS score 3–8 should be evacuated from the forward area to a medical facility with the following surgical capabilities:
  1. 24-hour CT scanning capability
  2. 24-hour available operating room and prompt neurosurgical care
  3. The ability to monitor intracranial pressure and treat intracranial hypertension as delineated in the *Guidelines for the Management of Severe Head Injury*
- Casualties with a GCS of 9–13 should be evacuated from the forward area. This field evacuation is not, however, as emergent as it is with the GCS 3–8 casualty. If prioritization of evacuations is necessary, special attention should be given to the field observation of this casualty as neurological deterioration is possible.
- If the casualty does not open his eyes with nail bed pressure or axillary pinch, he should be evacuated from the forward area to a medical facility.
- For unresponsive casualties who respond to nail bed pressure with extensor posturing or who are flaccid, the medical provider should secure the airway (intubate, if available) and hyperventilate (20 bpm).
- For unresponsive casualties who respond to nail bed pressure or axillary pinch with abnormal flexion or a higher GCS motor response, but have asymmetric and/or dilated and fixed pupil(s), the medical provider should hyperventilate at the rate described above.
- All TBI casualties should have their oxygenation assessed at least every 5 minutes and their O_2 saturation maintained at 90%. Systolic blood pressure should also be measured and maintained greater than 90 mm Hg.
- Because the casualty's neurological status may change, the medical provider should fully assess the casualty every 5 minutes and treat or modify treatment as appropriate.
- Hypertonic saline at concentrations of 3.0–7.5% is both a safe and an effective means to resuscitate the TBI casualty in the field. Weight considerations and limitations make this a practical treatment option for field providers.
- Empirical administration of dextrose is not recommended. Providers should only administer dextrose when they have the means to measure serum glucose levels and have evidence of hypoglycemia (serum glucose levels $\leq$ 80 mg/dl).
- Casualties found to have GCS scores of 14–15 can remain in the forward area. They do need to be observed for any changes in neurological status. Since ICP changes can occur several hours post injury, all casualties with changes in neurological status need to be re-evaluated for fitness of duty if remaining in the forward area.
- Any casualty with a GCS < 15 should not return to full duty until GCS resolves to 15 and the casualty is back to his/her baseline.
- Symptomatic casualties (headaches, dizziness, not oriented to time and situation, or asking repetitive questions) may be kept in theater but should not return to full combat status.

There are several other important points for field medical providers to remember when treating the TBI casualty.

- As soon as it becomes available, oxygen should be administered to all TBI casualties.
- Not all TBI casualties will require ALS airway managements (ET intubation, Combitube®, etc.). Some casualties requiring airway support may be successfully managed using BLS adjuncts (oral or nasal airways) and either a pocket mask or bag valve mask.

- As soon as it becomes available, all casualties undergoing any ALS airway management should have their $EtCO_2$ monitored. These levels should be maintained between 25–35 mm Hg.
- Only casualties showing signs of cerebral herniation should be hyperventilated.
- Isolated TBI does not cause shock. If signs of shock are present in the casualty, the medical provider needs to assess the patient for other causes of shock.