

The EPIC Blue Book

Provider Training Manual



This program and manual was adopted from EPIC-TBI Program.



EMS, Trauma Systems and Injury Prevention Section
Department of Public Health & Human Services



EPIC-MT PROGRAM COORDINATORS:

Janet Trethewey
jtrethewey@mt.gov
TSII Program Manager

Shari Graham
sgraham2@mt.gov
EMS System Manager

EMS & Trauma Systems Contact Information
PO Box 202951 // 1400 Broadway, RM C-303
Helena, MT 59620-2951
PH:(406) 444-3895

TABLE OF CONTENTS

Excellence in Prehospital Injury Care in Montana (EPIC-MT)	4
Mission	4
Background	4
Strategies	4
Student Pre-Test	5
TBI Background & History	6
EPIC Guidelines & Algorithm for Adults	12
EPIC Algorithm for Adults	16
EPIC4Kids Guidelines & Algorithm Definitions	17
EPIC4Kids Algorithm	22
Documentation & Quality Improvement Guide.....	23
Student Post-Test & Course Evaluation	25
EPIC-MT Agency Certification	26
References	27
EPIC Blue Book References.....	27
EPIC Guidelines & Algorithm for Adults References	31
EPIC4Kids Guidelines & Algorithm References	33

Excellence in Prehospital Injury Care in Montana (EPIC-MT)

MISSION

“To reduce death and disability of Montanans who experience traumatic brain injury (TBI) through evidence-based best practices, education, and continuous quality improvement.”

BACKGROUND

Each year, over 300 Montanans die from TBI and another 800 are hospitalized. Nationally, TBI leads to 2.2 million emergency department visits, 280,000 hospitalizations and 52,000 deaths. Montana has an elevated injury and death rate from TBI compared to the nation. The Emergency Medical Services and Trauma Systems Section (EMSTS), in partnership with Montana’s EMS providers and trauma receiving centers is moving forward with participating in the EPIC protocol in attempt to improve the quality of care, and outcomes, that people suffering from TBI receive.

Excellence in Prehospital Injury Care (EPIC) for TBI is a treatment protocol and quality improvement initiative. In Arizona, where the program began, the protocol demonstrated a doubling of survival to discharge for patients with severe TBI and a tripling of survival for intubated patients with severe TBI. In children with severe TBI, the adjusted odds of survival are seven-fold. Similar results have been achieved by partner agencies across the nation.

STRATEGIES

- Educate a cadre of EPIC-MT Trainers who will provide training to EMS agencies and providers within their region/county.
- Recognize and incentivize agencies that participate in the EPIC-MT program.
- Support participating agencies by providing initial equipment inventory and ongoing training opportunities.

Student Pre-Test

1. The main goal of prehospital management of a TBI is:
 - Keep blood sugar \geq to 90
 - Maintain SBP $>$ 150
 - Prevent secondary brain injury
 - Provide positive pressure ventilation
2. At what rate should you ventilate an intubated adult with TBI?
 - 8 BPM
 - 10 BPM
 - 12 BPM
 - 14 BPM
3. In treating an adult TBI patient, the SaO₂ should be maintained at or above:
 - 80%
 - 85%
 - 90%
 - 95%
4. What is the target EtCO₂ for an intubated TBI patient?
 - 20-30 mmHg
 - 25-35 mmHg
 - 30-40 mmHg
 - 35-45 mmHg
5. When managing an adult TBI patient, the SBP should be maintained at or above:
 - 60 mmHg
 - 70 mmHg
 - 80 mmHg
 - 90 mmHg
6. When managing a 5 year-old TBI patient, the SBP should be maintained at or above:
 - 60 mmHg
 - 70 mmHg
 - 80 mmHg
 - 90 mmHg
7. Decreasing CO₂ will cause which of the following (check all that apply):
 - Cerebral artery vasoconstriction
 - Increased secondary injury
 - Decreased cerebral perfusion
 - Increased cerebral perfusion
8. The effect of a SINGLE episode of hypoxia results in:
 - Increased morbidity and mortality
 - Bradycardia
 - Hypotension
 - No impact on neurological outcome
9. At what rate should an intubated 5 year-old with a TBI be ventilated? (check all that apply)
 - 10 BPM
 - 15 BPM
 - 20 BPM
 - T_p keep EtCO₂ 40 mmHg
10. If the EtCO₂ in an intubated patient falls below 35, what is the most likely cause? required
 - Hypoventilation
 - Hypoxia
 - Acidosis
 - Hyperventilation

TBI Background & History

SIGNIFICANCE

Every year, over 1.4 million patients are evaluated in U.S. Emergency Departments (EDs) after TBI. Of these patients, 235,000 require hospitalization and 50,000 die.¹ The total cost for the care of this patient population in 2000 was estimated to be 60 billion dollars, with more than 2% of the US population requiring long-term assistance with activities of daily living secondary to TBI.² Major trauma is a leading cause of death in children and 80% of these injuries include TBI. It is difficult to overstate the massive impact of this major public health problem on our society.

WHAT IS EPIC?

The Excellence in Prehospital Injury Care (EPIC) Project started as a unique, statewide effort to improve survival and neurologic outcome for victims of major TBI who are cared for by the EMS agencies in Arizona, which has since been adopted by EMS agencies across the nation. Over 5 years, the EPIC Project Team worked with EMS agencies to implement and evaluate TBI care and outcomes. This happened through the linkage of prehospital and trauma registry data, to fully document the impact of implementing the nationally vetted TBI Guidelines in moderate and severe TBI patients. EPIC implemented the TBI Guidelines in EMS systems that respond to 911 calls across the urban, suburban, rural, and wilderness areas. Interventions in the “EPIC Protocol” include optimizing the management of hemodynamics, oxygenation, and ventilation in the field for major TBI victims, with special emphasis on patients who received positive pressure ventilation. The primary goal was to help EMS systems save as many lives as possible from TBI and improve the quality of those lives saved.



TOM BRIDGE photo, Independent Record



MICHAEL GALLACHER photo, Missoulian

IMPORTANCE OF EMS IN TBI CARE

As with other intensely time-sensitive medical emergencies, survival after TBI is profoundly impacted by early care of patients immediately after the event. The time-sensitive nature of these injuries is shown by the fact that half of the patients who ultimately die from TBI, do so within the first 2 hours after injury. One of the reasons patient outcomes are so dramatically impacted by the early care is because survival is not determined solely by the severity of the initial insult, termed “primary brain injury.” Secondary, potentially preventable damage to the central nervous system (CNS) often occurs after the primary injury. If the consequences of the injury are not properly identified and rapidly treated, this additional insult can quickly become irreversible. Thus, even if the patient receives optimal management later in the hospital, the outcome will be much worse due to the permanent damage that occurred in the prehospital environment. There is growing evidence that the care provided in the first few minutes after major TBI may be more important than what happens later. In fact, the prehospital and in-hospital care are probably powerfully synergistic. The success of the subsequent critical care and surgical interventions is probably dramatically enhanced by optimal prehospital care, which gives the patients a chance to benefit from “definitive care” at the trauma center. This means that the EMS care of TBI victims (like other time-sensitive illnesses such as cardiac arrest, STEMI, and acute stroke) hinges on the care provided by the prehospital providers. **In other words, your care is what makes the difference in the outcomes for TBI victims...likely even more than the neurosurgeon.** This has created both an enormous responsibility and an incredible opportunity for EMS systems to impact care and save lives.

HISTORICAL UNDERSTANDING

Pathophysiology and Prehospital Management of Severe TBI: Initial observations in the early 1970s revealed that patients with an intracranial pressure (ICP) of <20 mmHg had a neurologically intact survival rate of 56% compared to only 8% for those with an ICP of >40 mmHg.³ At that time, the treatment of severe TBI focused on the treatment/manipulation of the blood pressure and/or ICP. Given the well-known relationship between cerebral perfusion pressure (CPP), mean arterial pressure (MAP) and ICP in the equation $CPP = MAP - ICP$, it was believed that doing whatever was necessary to decrease ICP was the best way to treat TBI. Initial attempts to increase MAP were found to be ineffective in maintaining CPP in the setting of increased ICP. However, several methods were known to decrease ICP by reducing cerebrospinal fluid (CSF) volume. These included infusions of hypertonic solutions such as Mannitol and the use of “therapeutic hyperventilation.” Hyperventilation became the preferred non-surgical method to reduce ICP and, for years, it was commonly used in both the prehospital and in-hospital settings to treat, and sometimes even to prevent, increased ICP.

In the 1990s, major questions began to emerge related to this ventilatory intervention. It was found that prolonged periods of hyperventilation decreased the rate of favorable outcome in severe TBI.⁴⁻⁴⁵ It was also found that even short periods of hyperventilation, causing hypocarbia [reduced carbon dioxide (CO₂) in the blood], decreased cerebral perfusion and cerebral blood flow and increased morbidity and mortality.^{12, 33, 35, 39, 46-53}

In 1995, armed with this knowledge, the first evidence-based guidelines for the management of severe TBI were established, which recommended against prophylactic hyperventilation.⁵⁴ The TBI Guidelines emphasized that there are areas of the brain that, after acute injury, are susceptible to secondary injury. Furthermore, these areas are at risk of conversion from “borderline cerebral ischemia into frank ischemia with ensuing neuronal death.”⁵⁵ In other words, brain cells that are injured can die if even moderate hyperventilation occurs. Because of this new evidence, the therapeutic goals of management shifted from focusing on the classic CPP/MAP/ICP relationship to maintaining tissue oxygenation at the cellular level in the portions of the brain that were damaged or susceptible to damage.



photo, MSU Billings

These findings have been supported by numerous studies demonstrating that even brief episodes of hypotension and hypoxia are very harmful to victims of TBI.^{4-11, 46, 47, 56-71} For example, a single episode of hypotension (SBP<90 mmHg) has been shown to be associated with a doubling of mortality in TBI and a single non-spurious reading of O₂ saturation <90% is independently associated with a doubling of mortality.⁴

There is now powerful evidence that the optimal field treatment of TBI is to focus on maintaining blood flow to the brain.

We know that hyperventilation, hypotension, and hypoxia are well-established causes of secondary brain injury and each of these occurs commonly in the prehospital management of TBI.⁴ Aggressive measures to prevent and treat these complications have been widely accepted and practiced in the ICU setting with improved patient outcomes.^{72, 73} Although a full discussion of the CNS physiology and changes associated with hyperventilation is outside the scope of this training guide, a brief description of the most important and well-accepted physiologic changes that occur with hyperventilation can be found below and is summarized in Table 1 and Figure 1.

Table 1. Pathophysiology of Secondary CNS Injury during Hyperventilation

Parameter/ Treatment	Physiologic Change	Secondary Injury	Reference
↓ PaCO ₂	Global CNS vasoconstriction	↓ CBF	1, 2, 37, 50, 74-77
	↑pH → left shift of oxygen-hemoglobin association curve	↓ O ₂ delivery to tissue	50, 75
	Cell Membrane Permeability alteration of membrane permeability → Apoptosis (programmed cell death)	Neuronal cell death	50, 75, 80, 81
↑Intrathoracic Pressure	↓ Cardiac Output (effects increase with hemorrhage)	↓MAP	50, 66, 78, 79
	↑ JVP (if JVP > ICP); ↓CPP according to CPP = MAP – JVP	↓ CBF	50, 75
Alterations in MAP and ICP	MAP response is variable during hyperventilation and may decrease significantly	Thus, CPP still <i>decreases</i> despite ↓ ICP	50, 66, 78, 79
Variations in ventilatory rate, depth, mechanics	Hyperventilation → global ↓CBF → periods of normal ventilation → ↑ blood flow to healthy brain “steals” blood from injured brain	↓ blood flow to area of injury (“Post-hyperventilatory Steal”)	82-86

Abbreviations:

CBF - Cerebral Blood Flow

ICP - Intracranial Pressure

PaCO₂ - Arterial Partial Pressure of Carbon Dioxide

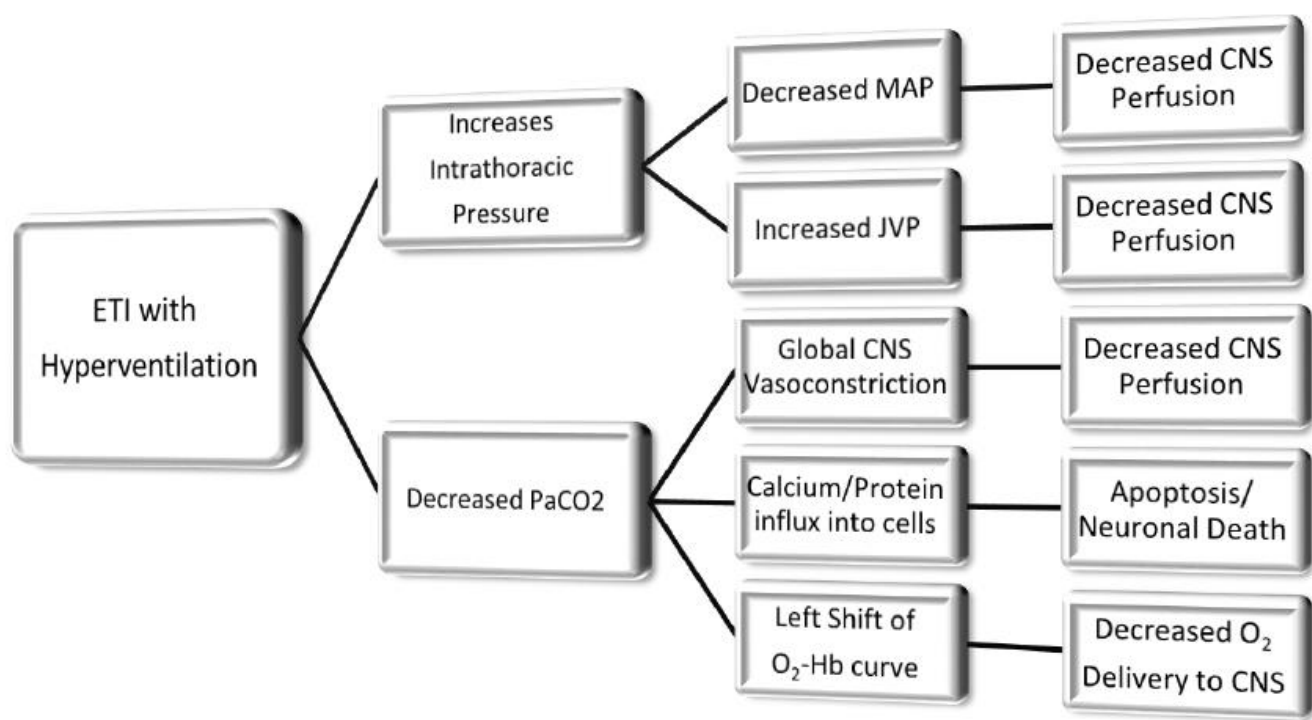
CNS - Central Nervous System

JVP - Jugular Venous Pressure

CPP—Cerebral Perfusion Pressure

MAP - Mean Arterial Pressure

Figure 1. Mechanisms of Secondary Injury Induced During Hyperventilation

Abbreviations:

CNS - Central Nervous, System

ETI - Endotracheal Intubation

Hb - Hemoglobin

ICP - Intracranial Pressure

JVP - Jugular Venous Pressure

MAP - Mean Arterial Pressure

O₂ - OxygenPaCO₂ - Arterial Partial Pressure of Carbon Dioxide

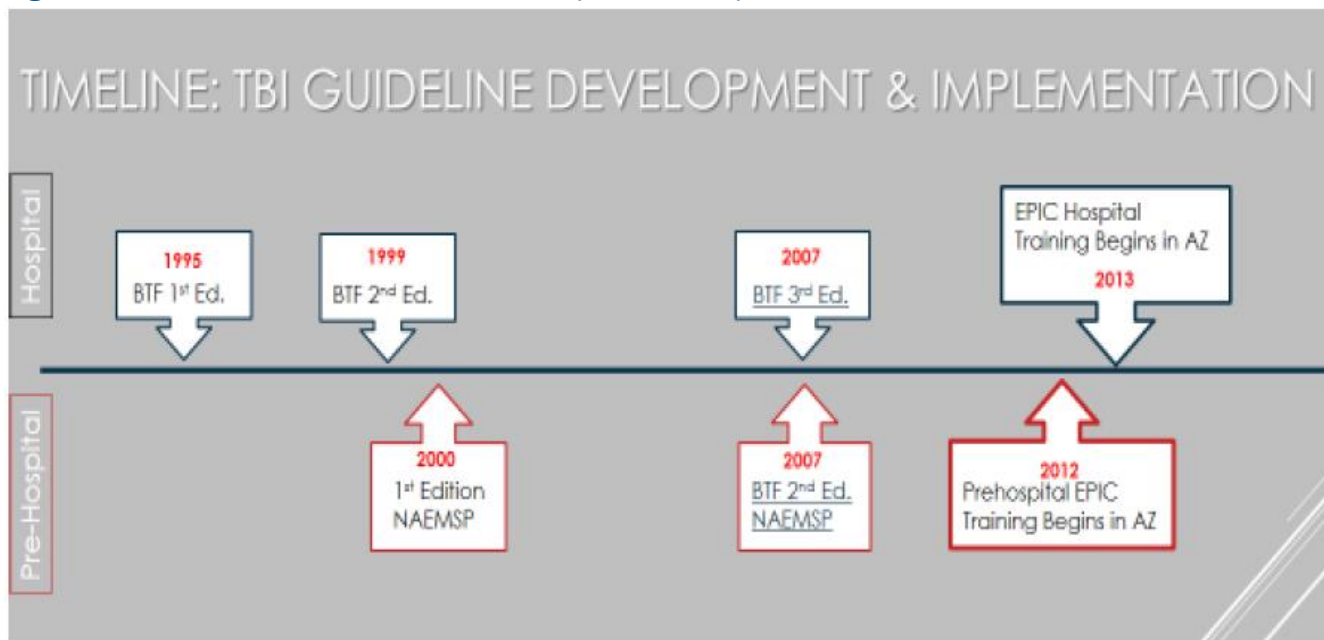
Hyperventilation (and the resulting decrease in the PaCO₂) causes the blood vessels supplying the brain to constrict. This results in a decrease in cerebral blood flow and is a powerful factor leading to secondary brain injury. At the cellular/neuronal level, low CO₂ can initiate a chain of reactions leading to cellular death through a mechanism called “apoptosis.” In addition, pH changes associated with low CO₂ result in increased cell membrane permeability and protein shifts. This cascade of events creates free radicals and irreversible cellular damage. All these effects from hyperventilation ultimately result in failure to supply adequate oxygen to the neurons and the greatest compromise of O₂ delivery is in the injured regions of the CNS. The cumulative effect of hyperventilation results in significant secondary brain injury and dramatically increases morbidity and mortality from TBI.

*****The optimal treatment of TBI patients in the prehospital setting centers on strictly preventing and aggressively treating alterations in cerebral blood flow and oxygenation. These changes include hypotension, hyperventilation (both intentional and inadvertent) and hypoxemia.*****

WHAT HAS HAPPENED IN THE PAST?

Historically, the prehospital management of patients with severe TBI focused on reducing ICP by performing endotracheal intubation (ETI) and then intentionally hyperventilating patients. However, because of the overwhelming recent evidence revealing very detrimental effects, TBI management guidelines vetted by authoritative national organizations have radically reversed the previous approach. The guidelines have changed the focus of early management to emphasize *strict avoidance* of hyperventilation (see timeline below). This shift began in the 1990s when data indicated that prophylactic hyperventilation was associated with worse outcomes. Over the last ten years, there have been many animal and human studies demonstrating that *even short periods of moderate* hyperventilation during the early treatment of TBI result in increased morbidity and mortality. In fact, some studies have shown as much as a six-fold increase in mortality from hyperventilating patients with severe TBI.⁶⁷

Figure 2. Timeline for TBI Guideline Development & Implementation



The timeline demonstrates the shift in TBI Guideline care to encourage strict avoidance of hyperventilation as well as recognition and management of the other 3 H-Bombs: hypoxia, hypotension, and hypoglycemia. Note that the guidelines are 18 years old! **Prehospital Providers must avoid the four “H-Bombs” in caring for TBI patients.**

The “H-Bombs” of the EPIC Protocol are:

1. 2. Hypoxia: Prevention, immediate recognition, and urgent treatment of Hypoxia
3. Hypotension: Prevention, rapid identification, and aggressive treatment of Hypotension
4. Hyperventilation: Strict avoidance and immediate correction of Hyperventilation/low ETCO₂
5. Hypoglycemia: Assess early and correct

EPIC Guidelines & Algorithm for Adults

DEFINITIONS

- Adults: Age \geq 18 years
- The prehospital identification of moderate or severe TBI: Anyone with physical trauma and a mechanism consistent with the *potential* to induce a brain injury and:
 - Any injured patient with loss of consciousness, especially those with GCS $<$ 15 or confusion, **OR**
 - Multisystem trauma requiring intubation whether the primary need for intubation was from TBI or from other potential injuries, **OR**
 - Post-traumatic seizures, whether they are continuing or not, **OR**

OVERALL APPROACH TO MONITORING AND CONTINUOUS EVALUATION

1. Continuous O₂ saturation (sat) via pulse oximetry,
2. Continuous quantitative end-tidal CO₂ (ETCO₂) monitoring in intubated patients, and
3. Systolic blood pressure (SBP) every 3-5 minutes.

SPECIFIC, GUIDELINE-BASED THERAPY

- I. Management of airway/oxygenation:

CLINICAL AXIOM: A single non-spurious O₂ sat of $<$ 90% is independently associated with a doubling of mortality. Hypoxia kills neurons!

- A. Management is initiated by continuous high-flow O₂ for all *potential* TBI cases. Emphasis is placed on prevention, identification, and treatment of hypoxia (O₂ sat $<$ 90% and/or cyanosis).¹⁻⁶ If high-flow O₂ fails to correct hypoxia, basic maneuvers for airway repositioning will be attempted, followed by reevaluation. If this does not restore O₂ saturation to 90% or greater, or if there is inadequate ventilatory effort, bag-valve-mask (BVM) ventilation will be performed using appropriate airway adjuncts (e.g., oropharyngeal airway).
- B. If airway compromise or hypoxia persists after these interventions, ETI will be performed when an experienced ALS provider is available.^{1,2,5,7-10} Following ETI, tube placement will be confirmed via multiple means including ETCO₂ detection and/or capnography.

- II. Management of ventilation: Special emphasis is placed on identifying and treating hypoventilation as well as preventing hyperventilation when assisting ventilation.

CLINICAL AXIOM: In intubated patients, hyperventilation is *independently* associated with *at least* a doubling of mortality and some studies have shown that *even moderate* hyperventilation can increase the risk of death by *six* times. Hyperventilation kills neurons!

COROLLARY: It has been shown repeatedly that inadvertent hyperventilation happens *reliably* if not meticulously prevented by proper external means. No one, no matter how experienced, can properly ventilate without ventilatory adjuncts (Flow-Controlled Bags (FCB), Ventilation Rate Timers (VRT), ETCO₂, ventilators). FCBs/VRTs should be used immediately after intubation and until the patient can be placed on a mechanical ventilator even if this will only take 3-5 minutes (note: that's all the hyperventilation it takes to begin killing neurons).

- A. Hypoventilation [ineffective respiratory rate for age, shallow or irregular respirations, periods of apnea, or measured hypercarbia (elevated ETCO₂)]: If there is evidence of hypoventilation despite high-flow O₂ therapy, assisted ventilation will be performed via BVM and, if ineffective, ETI will be performed if an experienced ALS provider is present.^{1, 2, 11,12}
- B. Intubated patients: After ETI, use FCB/VRT immediately for ventilation and ETCO₂ levels will be strictly maintained between 35 and 45 mmHg when monitoring is available (target = 40).^{1, 2,12-15}
- All agencies are strongly encouraged to use FCBs/VRTs. Agencies without ETCO₂ monitors, maintain age-appropriate ventilatory rates and decrease the risk of inadvertent hyperventilation.^{1, 2, 10-12, 16-24} Agencies with ETCO₂ monitors should use FCBs/VRTs for the initial rate of manual ventilation and then gently modify the ventilation to obtain the target ETCO₂ of 40 mmHg. Beware of the tendency to only use the ETCO₂ monitor to verify tube placement and then to fail to carefully maintain ETCO₂ in target range.
 - Ventilators should be used post-intubation whenever available to optimize ventilatory mechanics and O₂ therapy.^{11,12, 25-27} This is the *best* way to care for an intubated TBI patient. FCBs/VRTs should be used immediately after intubation and until the patient is placed on the ventilator even if this will only take several minutes.
 - i. Target tidal volume (TV) will be 7cc/kg with rates adjusted to keep the ETCO₂ within target range (35-45 mmHg).
 - ii. **Note:** This is consistent with the TBI guidelines and recent literature showing that intrathoracic pressure, lung mechanics, hemodynamics, and ICP are optimized by this TV compared to the “classic” 10-12 cc/kg that remains common in many settings.^{14,18,30-37}

- C. Impending cerebral herniation:
- The EPIC guidelines do not encourage even mild hyperventilation for “impending cerebral herniation” for the following reasons:
 - i. There is no evidence that it improves outcome in any setting.
 - ii. There is much evidence that even mild hyperventilation harms moderate and severe TBI patients.
 - iii. The “practical application” of this “treatment” is that many patients who do not have actual impending herniation end up being hyperventilated since the real-world interpretation often ends up thinking... “The worse a TBI is, the faster you should ventilate.” Thus, many patients who will be harmed by hyperventilation may end up with the misapplication of this “treatment.”
- D. Non-intubated patients: All relevant monitoring/treatment will be applied, including ETCO₂ monitoring where available.
- III. Management of blood pressure: In patients with a *potential* for TBI, strong emphasis is placed on preventing and *aggressively* treating even a *single* episode of SBP <90mmHg.^{1-5, 35-48}

CLINICAL AXIOM: A *single* episode of SBP <90 mmHg is *independently* associated with *at least* a doubling of mortality. Amazingly, repeated episodes of hypotension can increase the risk of death by as much as *eight* times. Hypotension kills neurons!

- A. Treatment of hypotension: Even a *single* SBP measurement <90 mmHg will initiate intravenous (IV) fluid resuscitation with an initial bolus of 1 liter of normal saline or Ringer’s Lactate. This will be followed by IV administration of isotonic fluids at sufficient rate and volume to keep SBP ≥90 mmHg.^{1, 2} If the rapid infusion of the first liter of crystalloid does not correct the hypotension, do not hesitate to continue aggressive fluid resuscitation.
- **Note:** If rapid infusion of initial crystalloid bolus does not correct the hypotension, continue aggressive fluid resuscitation.
 - **Note:** Do not wait for the patient to become hypotensive. If the SBP is dropping, or if there are any other signs of compensated shock such as increasing heart rate with decreasing SBP, begin aggressive treatment *before* the patient becomes hypotensive.

- Intraosseous access should be attempted if all three of the following criteria are met:
 1. There is hypotension or other signs of shock
 2. Peripheral venous access cannot be quickly established, and
 3. The patient's mental status is such that they can tolerate the procedure without undue pain.

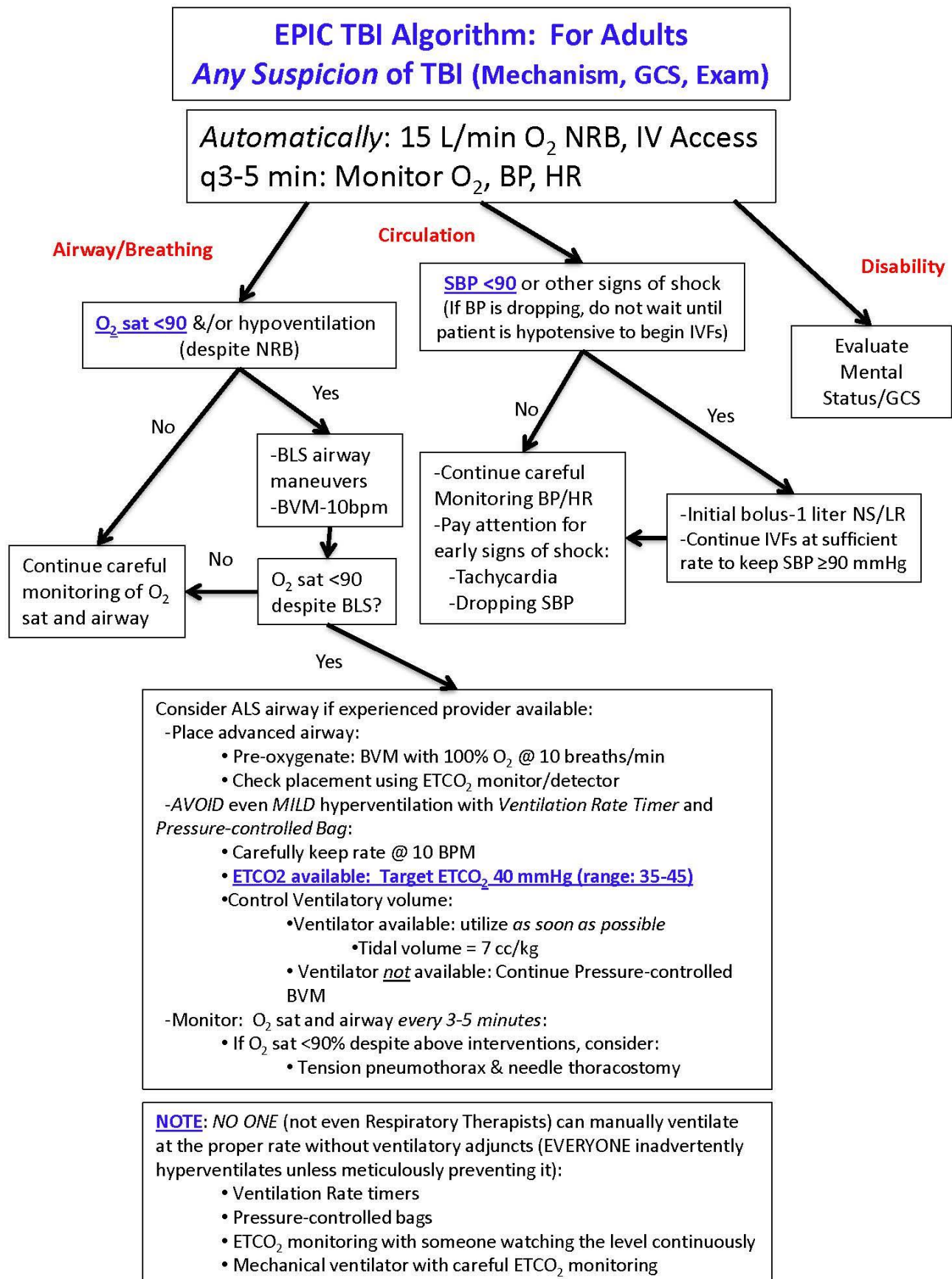
- B. Treatment of hypertension: In TBI, treatment of acute hypertension is not recommended.^{1, 2, 49} However, IV fluids will be restricted to a minimal "keep open" rate in patients with SBP \geq 140 mmHg.

- IV. Assessment and management of hypoglycemia: In patients with any alteration in mental status, *always* check for hypoglycemia early in the clinical course. Hypoglycemia can *mimic* TBI as a cause of altered mental status. It can also *cause* TBI (e.g., diabetic on insulin who misses a meal \rightarrow leads to low blood sugar \rightarrow leads to decreased LOC \rightarrow leads to motor vehicle crash in a hypoglycemic driver).
 - A. Assess blood glucose: Obtain fingerstick or serum glucose level. If glucose level is $<$ 70mg/dl, then administer dextrose according to local protocol or medical direction.

 - B. Reassess blood glucose: Repeat fingerstick in 10 minutes and, if still $<$ 70mg/dl, repeat dose x 1.
 - If no response, contact medical control for further direction.
 - If IV access unsuccessful, dextrose may be given IO.
 - If IV and IO unsuccessful, give Glucagon 0.03mg/kg IM, max dose 1mg.

-- EPIC Guidelines & Algorithm for Adults References start on page 31 --

EPIC ALGORITHM FOR ADULTS



EPIC4Kids Guidelines & Algorithm Definitions



- Age Definitions for Monitoring and Management:¹
 - “Infant”: Age 0-24 months
 - “Child”: Age 2-14 years
 - “Late adolescence”: 15-17 years

- The prehospital identification of moderate or severe TBI: Anyone with physical trauma and a mechanism consistent with the *potential* to induce a brain injury and:
 - GCS of 12 or less, **OR**
 - GCS <15 with decreasing GCS or increasing confusion, **OR**
 - Multisystem trauma requiring intubation whether the primary need for intubation was from TBI or from other potential injuries, **OR**
 - Post-traumatic seizures, whether they are continuing or not, **OR**
 - In infants (where GCS may be difficult to obtain/interpret), decreased level of consciousness, decreased responsiveness, or any deterioration of mental status.

OVERALL APPROACH TO MONITORING AND CONTINUOUS EVALUATION

1. Continuous O₂ saturation (sat) via pulse oximetry,
2. Continuous quantitative end-tidal CO₂ (ETCO₂) monitoring in intubated patients, and
3. Systolic blood pressure (SBP) every 3-5 minutes.

SPECIFIC, GUIDELINE-BASED THERAPY

- I. Management of airway/oxygenation:

CLINICAL AXIOM: A single non-spurious O₂ sat of <90% is independently associated with a doubling of mortality. Hypoxia kills neurons!

- A. Management is initiated by continuous high-flow O₂ for all *potential* TBI cases. Emphasis is placed on prevention, identification, and treatment of hypoxia (O₂ sat <90% and/or cyanosis).¹⁻⁷ If high-flow O₂ fails to correct hypoxia, basic maneuvers for airway repositioning will be attempted, followed by reevaluation. If this does not restore O₂ saturation to 90% or greater, or if there is inadequate ventilatory effort, bag-valve-mask (BVM) ventilation will be performed using appropriate airway adjuncts (e.g., oropharyngeal airway). It should be noted that most infants and children can have their airway managed well using basic maneuvers and BVM.

- B. If airway compromise or hypoxia persists after these interventions, ETI will be performed when an experienced ALS provider is available.^{1-3,6,8-13} Following ETI, tube placement will be confirmed via multiple means including ETCO₂ detection and/or capnography.

- II. Management of ventilation: Special emphasis is placed on identifying and treating hypoventilation as well as preventing hyperventilation when assisting ventilation.

CLINICAL AXIOM: In intubated patients, hyperventilation is *independently* associated with *at least* a doubling of mortality and some studies have shown that *even moderate* hyperventilation can increase the risk of death by *six* times. Hyperventilation kills neurons!

COROLLARY: It has been shown repeatedly that inadvertent hyperventilation happens *reliably* if not meticulously prevented by proper external means. No one, no matter how experienced, can properly ventilate without ventilatory adjuncts (Flow-Controlled Bags (FCB), Ventilation Rate Timers (VRT), ETCO₂, ventilators). FCBs/VRTs should be used immediately after intubation and until the patient can be placed on a mechanical ventilator even if this will only take 3-5 minutes (note: that's all the hyperventilation it takes to begin killing neurons).

- A. Hypoventilation [ineffective respiratory rate for age, shallow or irregular respirations, periods of apnea, or measured hypercarbia (elevated ETCO₂)]: If there is evidence of hypoventilation despite high-flow O₂ therapy, assisted ventilation will be performed via BVM and, if ineffective, ETI will be performed if an experienced ALS provider is present.^{1-3,12-15}
- B. Intubated patients: After ETI, use FCB/VRT immediately for ventilation and ETCO₂ levels will be strictly maintained between 35 and 45 mmHg when monitoring is available (target = 40).^{1-3,15-17}
- All agencies are strongly encouraged to use FCBs/VRTs. Agencies without ETCO₂ monitors, maintain age-appropriate ventilatory rates and decrease the risk of inadvertent hyperventilation.^{1-3,11,14,15,18-26} Agencies with ETCO₂ monitors should use FCBs/VRTs for the initial rate of manual ventilation and then gently modify the ventilation to obtain the target ETCO₂ of 40 mmHg. Beware of the tendency to only use the ETCO₂ monitor to verify tube placement and then to fail to carefully maintain ETCO₂ in target range.

Target ventilatory rates from the National TBI Guidelines: ^{1,27}
Infants: (age 0-24 months): 25 breaths per minute (bpm)
Children: (age 2-14): 20 bpm
Older adolescents: (age 15-17): 10 bpm (same as adults)

- Whenever possible, ventilators should be used post-intubation to optimize ventilatory parameters and O₂ therapy.^{1,14,15,28-30} This is the *best* way to care for an intubated TBI patient. FCBs/VRTs should be used immediately after intubation and until the patient is placed on the ventilator even if this will only take several minutes.

- i. Target tidal volume (TV) will be 7cc/kg with rates adjusted to keep the ETCO₂ within target range (35-45 mmHg).
 - ii. **Note:** This is consistent with the TBI guidelines and recent literature showing that intrathoracic pressure, lung mechanics, hemodynamics, and ICP are optimized by this TV compared to the “classic” 10-12 cc/kg that remains common in many settings.^{14,18,30-37}
- C. Impending cerebral herniation: The EPIC guidelines do not encourage even mild hyperventilation for “impending cerebral herniation” for the following reasons:
- There is no evidence that it improves outcome in any setting.
 - There is much evidence that even mild hyperventilation harms moderate and severe TBI patients.
 - The “practical application” of this “treatment” is that many patients who do not have actual impending herniation end up being hyperventilated since the real-world interpretation often ends up thinking... “The worse a TBI is, the faster you should ventilate.” Thus, many patients who will be harmed by hyperventilation may end up with the misapplication of this “treatment.”
- D. Non-intubated patients: All relevant monitoring/treatment will be applied, including ETCO₂ monitoring where available.
- III. Management of blood pressure: In patients with a *potential* for TBI, strong emphasis is placed on preventing and *aggressively* treating even a *single* episode of hypotension.

CLINICAL AXIOM: A *single* episode of hypotension is *independently* associated with *at least* a doubling of mortality. Amazingly, repeated episodes of hypotension can increase the risk of death by as much as *eight* times. Hypotension kills neurons!

Hypotension will be defined as systolic blood pressure (SBP) below the 5th percentile for age. This will be estimated using the following formula:

SBP Target Thresholds: ^{1,38}
Infants/children age <10: 70 mmHg + (age X 2)
Children age ≥10: 90 mmHg (same as adults)

Good “rules of thumb” to remember:

- ✓ Infant = 70 mmHg
- ✓ 5 year old = 80 mmHg
- ✓ 10 and older = 90 mmHg

- A. Treatment of hypotension: Even a *single* hypotensive measurement (by age) will initiate intravenous (IV) fluid resuscitation. For hypotension or other signs of shock, give IV normal saline. Sufficient volume (via 20cc/kg boluses every 5 minutes) will be given to return SBP to at least the 5th percentile estimate.
- Once hypotension has been corrected, IV administration of NS should occur at a sufficient rate to keep the patient non-hypotensive.
 - i. **Note:** If rapid infusion of initial crystalloid bolus does not correct the hypotension, continue aggressive fluid resuscitation.
 - ii. **Note:** Do not wait for the patient to become hypotensive. If the SBP is dropping, or if there are any other signs of compensated shock such as increasing heart rate with decreasing SBP, begin aggressive treatment *before* the patient becomes hypotensive.
 - iii. Intraosseous access should be attempted if all three of the following criteria are met:
 1. There is hypotension or other signs of shock
 2. Peripheral venous access cannot be quickly established, and
 3. The patient’s mental status is such that they can tolerate the procedure without undue pain.
- B. Treatment of hypertension: In TBI, treatment of acute hypertension is not recommended.^{1-3,39} However, IV fluids will be restricted to a minimal “keep open” rate in infants/young children with SBP ≥ 100 mmHg and in older children/adolescents with SBP ≥ 130 mmHg.
- IV. Assessment and management of hypoglycemia: In patients with any alteration in mental status, *always* check for hypoglycemia early in the clinical course. Hypoglycemia can *mimic* TBI as a cause of altered mental status.
- A. Assess blood glucose: Obtain fingerstick or serum glucose level. If glucose level is <70 mg/dl, then provide dextrose according to local protocol or medical direction.

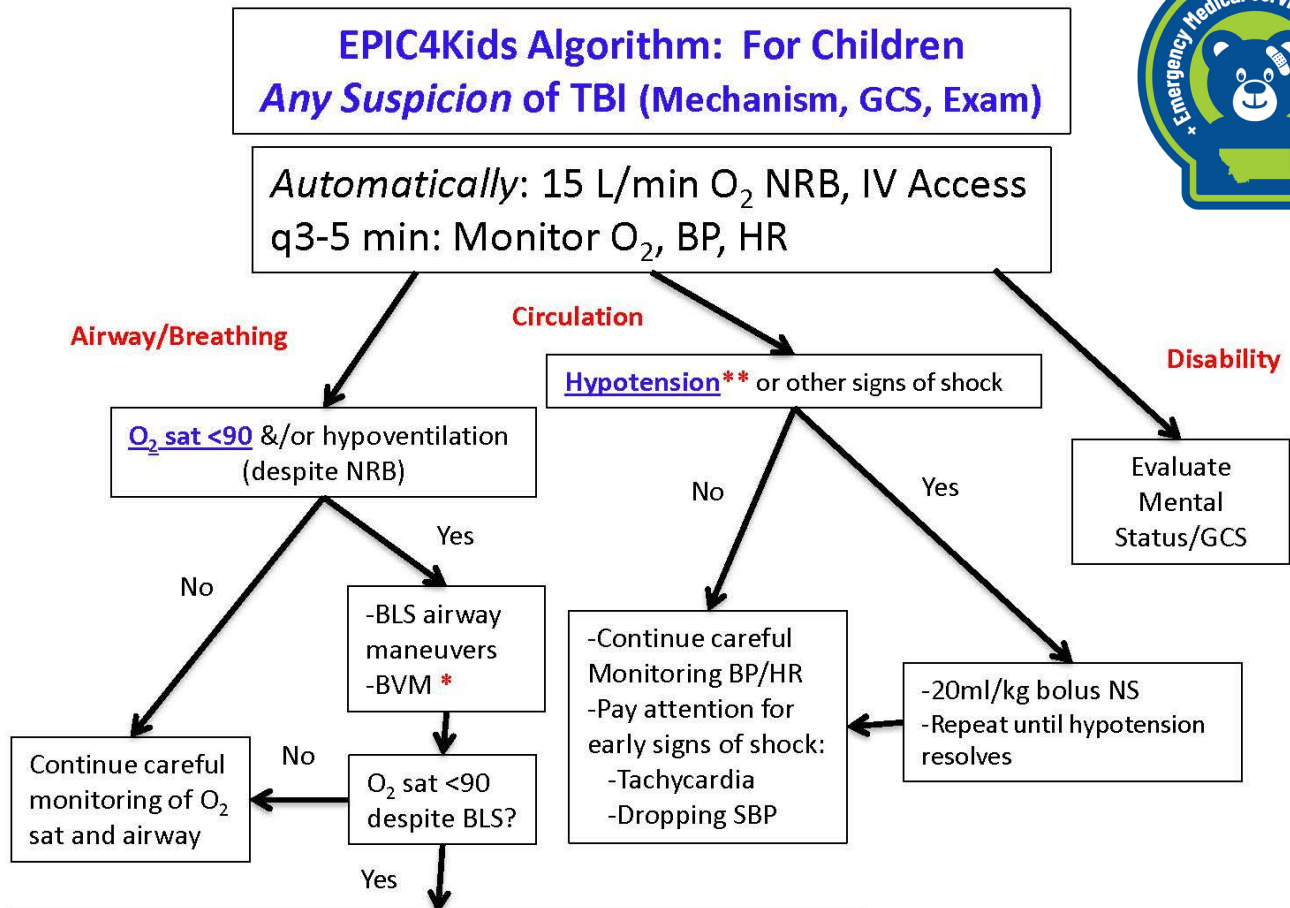
B. Reassess blood glucose: Repeat fingerstick in 10 minutes and, if still <70mg/dl, repeat dose x 1.

- If no response, contact medical control for further direction.
- If IV access unsuccessful, dextrose may be given IO.
- If IV and IO unsuccessful, give Glucagon 0.03mg/kg IM, max dose 1mg.

Note: Consult with your medical director if there are differences between the guidelines outlined above and your regional/agency protocols/standing orders for treating hypoglycemia in the setting of TBI.

-- EPIC4Kids Guidelines & Algorithm References start on page 33 --

EPIC4KIDS ALGORITHM



Consider ALS airway if experienced provider available:

- Place advanced airway:
 - Pre-oxygenate: BVM with 100% O₂ @ age-appropriate rate *
 - Check placement using ETCO₂ monitor/detector
- AVOID** even *MILD* hyperventilation with *Ventilation Rate Timer* and *Pressure-controlled Bag*:
 - Carefully keep rate @ age-appropriate rate *
 - **ETCO₂ available: Target ETCO₂ 40 mmHg (range: 35-45)**
 - Control Ventilatory volume:
 - Ventilator available: utilize *as soon as possible*
 - Tidal volume = 7 cc/kg
 - Ventilator *not* available: Continue Pressure-controlled BVM
- Monitor: O₂ sat and airway *every 3-5 minutes*:
 - If O₂ sat <90% despite above interventions, consider:
 - Tension pneumothorax & needle thoracostomy

*** Ventilation Rates:**

- Infants:** (0-24 mo.):
-25 breaths/min (bpm)
- Children:** (2-14 yrs):
-20 bpm
- Adolescents:** (15-17 yrs):
-10 bpm (same as adults)

**** Identifying Hypotension in children**

- 0-9 yrs: 70 + (age x 2)
- ≥10 yrs: <90mmHg
- Rules of thumb:**
- Newborn: <70mmHg
- 5 year old: <80mmHg
- 10 and older: <90mmHg →
(Same as adults)

NOTE: NO ONE (not even Respiratory Therapists) can manually ventilate at the proper rate without ventilatory adjuncts (EVERYONE inadvertently hyperventilates unless meticulously preventing it):

- Ventilation Rate timers
- Pressure-controlled bags
- ETCO₂ monitoring with someone watching the level continuously
- Mechanical ventilator with careful ETCO₂ monitoring

Documentation & Quality Improvement Guide

EMS DOCUMENTATION

In addition to all standard requirements, documentation necessary for optimal recognition of your care in TBI includes the following:

- ✓ **Glasgow Coma Score (GCS)** - at least 2 (initial and transfer) with eyes/verbal/motor components
- ✓ **Blood pressure** - readings every 5 minutes*
- ✓ **SPO2** - readings every 5 minutes (as available)*
- ✓ **Capillary blood glucose** - initial (as available)
- ✓ **ETCO2** - readings every 5 minutes (as available)*

*Whenever possible, providers are encouraged to upload and attach/import their cardiac monitor case file in order to record ongoing blood pressure, SPO2, and ETCO2 readings.



Note: In order to be EPIC-MT Certified, an EMS agency must submit electronic prehospital care to EMSTS through utilization of Montana's ImageTrend Elite EMS ePCR or export of ePCR data to the EMSTS Online Prehospital Information System (OPHI-ePCR). EPIC-MT Certified Hospitals must participate in data submission to Montana's Trauma Registry.

SYSTEM-WIDE QUALITY IMPROVEMENT

EPIC-MT Certified Agencies must participate in system-wide continuous quality improvement throughout the duration of the EPIC-MT project. Providers utilizing Montana's ImageTrend Elite ePCR will be asked if the EPIC protocols were utilized for patients where a head injury is noted; when answered "Yes" the provider will be prompted to complete an *EPIC-MT for TBI Worksheet*. The worksheet is a data collection tool for the performance and process quality improvement indicators noted below. Participating agencies may access these worksheets and the aggregate performance data through ImageTrend Report Writer.

Note: System-wide quality improvement data is in aggregate form and does not include individual provider identifiers. This data is used to measure state-wide success with implementation and the impact on patient outcomes when using these guidelines.

PERFORMANCE/PROCESS INDICATORS

In order to assess prehospital utilization of the EPIC guidelines the following performance and process indicators have been selected for review:

1. Communication & Delegation: The potential for TBI is identified early in scene care and communicated to the team.
 - a. A team member is assigned to the oxygen administration role within 1 minute of arrival at patient.
2. Oxygen Administration: High-flow oxygen is administered within 1 minute of arrival at patient.
 - a. Oxygen saturation is maintained at or above 90%.
3. Positive Pressure Ventilation: In patients receiving positive pressure ventilation, hyperventilation (ETCO₂ <35mmHg) is avoided.
 - a. If SGA/ETI airway is placed, hypoxia (SPO₂ <90%) does not occur during the intubation period.
4. Fluid Resuscitation: SBP is maintained at or above 90mmHg.
 - a. In patients where SBP falls below 90mmHg, IV/IO was placed within 3 minutes of arrival at patient and aggressive fluid resuscitation given.
5. Blood Glucose: Blood glucose value is documented.
 - a. Dextrose is administered for findings less than 70mg/dl.

For EPIC-MT Certified agencies, the performance/process indicators' performance threshold is 80% (minimum). These indicators shall be monitored for the duration of the EPIC-MT project, or until the thresholds have been met for a minimum of 3 consecutive months.

EPIC-MT Agency Certification

To be an EPIC-MT Certified agency, an EMS/hospital provider agency is making a commitment to meet minimum training standards, maintain necessary equipment, ensure adherence to the treatment protocol, and participate in submission of traumatic brain injury (TBI) patient care and outcome related data to the EMSTS Section. These factors are imperative in the success of the EPIC-MT program and improved outcomes of TBI patients across the state.

REQUIREMENTS

1. Agency's Medical Director authorizes us of the EPIC-MT treatment protocol for use in patients with suspected traumatic brain injury.
2. Agency agrees to train at least 80% of their EMS/hospital providers to the EPIC-MT Guidelines and provide annual (at minimum) refresher trainings/drills.
3. Front line vehicles will be equipped with one adult pressure-controlled bag-valve mask with ventilation rate timing light (i.e., SmartBag).
4. A front line EMS vehicle is a vehicle that is fully ready to respond to an EMS call without moving equipment from another vehicle. This generally excludes command vehicles, utility trucks, and other support vehicles.
5. Agency actively uses the State ePCR system (ImageTrend) or submits EMS/trauma data to the EMSTS or Trauma Registry.

BENEFITS

- ★ Recognition as an EPIC-MT Certified Agency.
- ★ Assistance with initial supply of pressure-controlled bag-valve masks with ventilation rate timers for front line vehicles.
- ★ Inclusion in EPIC-MT related patient outcome and continuous quality improvement reporting.
- ★ Knowing you are using current, evidence-based best practice to reduce morbidity and mortality for patients with TBI.

EPIC-MT AGENCY CERTIFICATION

To complete the application, please visit
<https://www.cognitofrms.com/DPHHS1/EPICMTAgencyCertification>

The two-part application includes the following:

- ✓ Chief or EMS Director commitment to meeting the program requirements
- ✓ Medical Director Authorization to use the EPIC protocol

Both parts may be completed together, or the Chief/EMS Director may complete their portion and forward their completed form to the Medical Director for authorization.

AGENCY LINK



References

EPIC BLUE BOOK REFERENCES

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil.* Sep-Oct 2006;21(5):375-378.
2. Finkelstein E CP, Miller TR. The incidence and economic burden of injuries in the United States. New York: Oxford University Press; 2006.
3. Johnston IH, Johnston JA, Jennett B. Intracranial-pressure changes following head injury. *Lancet.* Aug 29 1970;2(7670):433-436.
4. Chesnut RM, Marshall LF, Klauber MR, et al. The role of secondary brain injury in determining outcome from severe head injury. *J Trauma.* Feb 1993;34(2):216-222.
5. Robertson CS, Valadka AB, Hannay HJ, et al. Prevention of secondary ischemic insults after severe head injury. *Crit Care Med.* Oct 1999;27(10):2086-2095.
6. Zornow MH, Prough DS. Does acute hyperventilation cause cerebral ischemia in severely head-injured patients? *Crit Care Med.* Dec 2002;30(12):2774-2775.
7. Davis DP, Heister R, Poste JC, Hoyt DB, Ochs M, Dunford JV. Ventilation patterns in patients with severe traumatic brain injury following paramedic rapid sequence intubation. *Neurocrit Care.* 2005;2(2):165-171.
8. Bao Y, Jiang J, Zhu C, Lu Y, Cai R, Ma C. Effect of hyperventilation on brain tissue oxygen pressure, carbon dioxide pressure, pH value and intracranial pressure during intracranial hypertension in pigs. *Chin J Traumatol.* Nov 15 2000;3(4):210-213.
9. Forbes ML, Clark RS, Dixon CE, et al. Augmented neuronal death in CA3 hippocampus following hyperventilation early after controlled cortical impact. *J Neurosurg.* Mar 1998;88(3):549-556.
10. Ausina A, Bagueña M, Nadal M, et al. Cerebral hemodynamic changes during sustained hypocapnia in severe head injury: can hyperventilation cause cerebral ischemia? *Acta Neurochir Suppl.* 1998;71:1-4.
11. van Santbrink H, vd Brink WA, Steyerberg EW, Carmona Suazo JA, Avezaat CJ, Maas AI. Brain tissue oxygen response in severe traumatic brain injury. *Acta Neurochir (Wien).* Jun 2003;145(6):429-438; discussion 438.
12. Davis DP. Early ventilation in traumatic brain injury. *Resuscitation.* Mar 2008;76(3):333-340.
13. Adelson PD, Clyde B, Kochanek PM, Wisniewski SR, Marion DW, Yonas H. Cerebrovascular response in infants and young children following severe traumatic brain injury: a preliminary report. *Pediatr Neurosurg.* Apr 1997;26(4):200-207.
14. Kiening KL, Hartl R, Unterberg AW, Schneider GH, Bardt T, Lanksch WR. Brain tissue pO₂-monitoring in comatose patients: implications for therapy. *Neurol Res.* Jun 1997;19(3):233-240.
15. Steiner LA, Balestreri M, Johnston AJ, et al. Sustained moderate reductions in arterial CO₂ after brain trauma time-course of cerebral blood flow velocity and intracranial pressure. *Intensive Care Med.* Dec 2004;30(12):2180-2187.
16. Coles JP, Fryer TD, Coleman MR, et al. Hyperventilation following head injury: effect on ischemic burden and cerebral oxidative metabolism. *Crit Care Med.* Feb 2007;35(2):568-578.
17. Dahl BL, Bergholt B, Cold GE, et al. [CO₂ and indomethacin vasoreactivity in patients with cranial trauma]. *Ugeskr Laeger.* Jan 19 1998;160(4):416-420.
18. Sharples PM, Stuart AG, Matthews DS, Aynsley-Green A, Eyre JA. Cerebral blood flow and metabolism in children with severe head injury. Part 1: Relation to age, Glasgow coma score, outcome, intracranial pressure, and time after injury. *J Neurol Neurosurg Psychiatry.* Feb 1995;58(2):145-152.
19. Sharples PM, Matthews DS, Eyre JA. Cerebral blood flow and metabolism in children with severe head injuries. Part 2: Cerebrovascular resistance and its determinants. *J Neurol Neurosurg Psychiatry.* Feb 1995;58(2):153-159.
20. Muizelaar JP, Ward JD, Marmarou A, Newlon PG, Wachi A. Cerebral blood flow and metabolism in severely head-injured children. Part 2: Autoregulation. *J Neurosurg.* Jul 1989;71(1):72-76.

21. Bouma GJ, Muizelaar JP, Stringer WA, Choi SC, Fatouros P, Young HF. Ultra-early evaluation of regional cerebral blood flow in severely head-injured patients using xenon-enhanced computerized tomography. *J Neurosurg.* Sep 1992;77(3):360-368.
22. Jaggi JL, Obrist WD, Gennarelli TA, Langfitt TW. Relationship of early cerebral blood flow and metabolism to outcome in acute head injury. *J Neurosurg.* Feb 1990;72(2):176-182.
23. Marion DW, Darby J, Yonas H. Acute regional cerebral blood flow changes caused by severe head injuries. *J Neurosurg.* Mar 1991;74(3):407-414.
24. Schroder ML, Muizelaar JP, Kuta AJ. Documented reversal of global ischemia immediately after removal of an acute subdural hematoma. Report of two cases. *J Neurosurg.* Feb 1994;80(2):324-327.
25. Fortune JB, Feustel PJ, Graca L, Hasselbarth J, Kuehler DH. Effect of hyperventilation, mannitol, and ventriculostomy drainage on cerebral blood flow after head injury. *J Trauma.* Dec 1995;39(6):1091-1097; discussion 1097-1099.
26. Sioutos PJ, Orozco JA, Carter LP, Weinand ME, Hamilton AJ, Williams FC. Continuous regional cerebral cortical blood flow monitoring in head-injured patients. *Neurosurgery.* May 1995;36(5):943-949; discussion 949-950.
27. Crockard HA, Coppel DL, Morrow WF. Evaluation of hyperventilation in treatment of head injuries. *Br Med J.* Dec 15 1973;4(5893):634-640.
28. Cold GE, Christensen MS, Schmidt K. Effect of two levels of induced hypocapnia on cerebral autoregulation in the acute phase of head injury coma. *Acta Anaesthesiol Scand.* Oct 1981;25(5):397-401.
29. Imberti R, Bellinzona G, Langer M. Cerebral tissue PO₂ and S_{ij}VO₂ changes during moderate hyperventilation in patients with severe traumatic brain injury. *J Neurosurg.* Jan 2002;96(1):97-102.
30. Schneider GH, Sarrafzadeh AS, Kiening KL, Bardt TF, Unterberg AW, Lanksch WR. Influence of hyperventilation on brain tissue-PO₂, PCO₂, and pH in patients with intracranial hypertension. *Acta Neurochir Suppl.* 1998;71:62-65.
31. Sheinberg M, Kanter MJ, Robertson CS, Contant CF, Narayan RK, Grossman RG. Continuous monitoring of jugular venous oxygen saturation in head-injured patients. *J Neurosurg.* Feb 1992;76(2):212-217.
32. Davis DP, Dunford JV, Ochs M, Park K, Hoyt DB. The use of quantitative end-tidal capnometry to avoid inadvertent severe hyperventilation in patients with head injury after paramedic rapid sequence intubation. *J Trauma.* Apr 2004;56(4):808-814.
33. Poste JC DD, Hoyt DB, Ochs M. Aeromedical transport of severely head-injured patients undergoing paramedic rapid sequence intubation. *Air Med J.* 2004;23(4):36-40.
34. Muizelaar JP, Marmarou A, Ward JD, et al. Adverse effects of prolonged hyperventilation in patients with severe head injury: a randomized clinical trial. *J Neurosurg.* Nov 1991;75(5):731-739.
35. Diringner MN, Videen TO, Yundt K, et al. Regional cerebrovascular and metabolic effects of hyperventilation after severe traumatic brain injury. *J Neurosurg.* Jan 2002;96(1):103-108.
36. Guidelines for the management of severe traumatic brain injury. *J Neurotrauma.* 2007;24 Suppl 1:S1-106.
37. Pigula FA, Wald SL, Shackford SR, Vane DW. The effect of hypotension and hypoxia on children with severe head injuries. *J Pediatr Surg.* Mar 1993;28(3):310-314; discussion 315-316.
38. Pepe PE, Roppolo LP, Fowler RL. The detrimental effects of ventilation during low-blood-flow states. *Curr Opin Crit Care.* Jun 2005;11(3):212-218.
39. Manley GT, Hemphill JC, Morabito D, et al. Cerebral oxygenation during hemorrhagic shock: perils of hyperventilation and the therapeutic potential of hypoventilation. *J Trauma.* Jun 2000;48(6):1025-1032; discussion 1032-1023.
40. Prause G, Hetz H, Lauda P, Pojer H, Smolle-Juettner F, Smolle J. A comparison of the end-tidal-CO₂ documented by capnometry and the arterial pCO₂ in emergency patients. *Resuscitation.* Oct 1997;35(2):145-148.
41. Skippen P, Seear M, Poskitt K, et al. Effect of hyperventilation on regional cerebral blood flow in head-injured children. *Crit Care Med.* Aug 1997;25(8):1402-1409.

42. Coles JP, Minhas PS, Fryer TD, et al. Effect of hyperventilation on cerebral blood flow in traumatic head injury: clinical relevance and monitoring correlates. *Crit Care Med*. Sep 2002;30(9):1950-1959.
43. Marion DW, Puccio A, Wisniewski SR, et al. Effect of hyperventilation on extracellular concentrations of glutamate, lactate, pyruvate, and local cerebral blood flow in patients with severe traumatic brain injury. *Crit Care Med*. Dec 2002;30(12):2619-2625.
44. McLaughlin MR, Marion DW. Cerebral blood flow and vasoresponsivity within and around cerebral contusions. *J Neurosurg*. Nov 1996;85(5):871-876.
45. Sarrafzadeh AS, Sakowitz OW, Callsen TA, Lanksch WR, Unterberg AW. Detection of secondary insults by brain tissue pO₂ and bedside microdialysis in severe head injury. *Acta Neurochir Suppl*. 2002;81:319-321.
46. Bernard SA, Nguyen V, Cameron P, et al. Prehospital rapid sequence intubation improves functional outcome for patients with severe traumatic brain injury: a randomized controlled trial. *Ann Surg*. Dec 2010;252(6):959-965.
47. Davis DP, Hoyt DB, Ochs M, et al. The effect of paramedic rapid sequence intubation on outcome in patients with severe traumatic brain injury. *J Trauma*. Mar 2003;54(3):444-453.
48. Davis DP, Stern J, Sise MJ, Hoyt DB. A follow-up analysis of factors associated with head-injury mortality after paramedic rapid sequence intubation. *J Trauma*. Aug 2005;59(2):486-490.
49. Laffey JG, Kavanagh BP. Hypocapnia. *N Engl J Med*. Jul 4 2002;347(1):43-53.
50. Hemphill JC, 3rd, Knudson MM, Derugin N, Morabito D, Manley GT. Carbon dioxide reactivity and pressure autoregulation of brain tissue oxygen. *Neurosurgery*. Feb 2001;48(2):377-383; discussion 383-374.
51. Pollock JM, Deibler AR, Whitlow CT, et al. Hypercapnia-induced cerebral hyperperfusion: an underrecognized clinical entity. *AJNR Am J Neuroradiol*. Feb 2009;30(2):378-385.
52. Noth U, Kotajima F, Deichmann R, Turner R, Corfield DR. Mapping of the cerebral vascular response to hypoxia and hypercapnia using quantitative perfusion MRI at 3 T. *NMR Biomed*. Jun 2008;21(5):464-472.
53. Warner KJ, Cuschieri J, Copass MK, Jurkovich GJ, Bulger EM. The impact of prehospital ventilation on outcome after severe traumatic brain injury. *J Trauma*. Jun 2007;62(6):1330-1336; discussion 1336-1338.
54. Bullock R, Chesnut RM, Clifton G, et al. Guidelines for the management of severe head injury. Brain Trauma Foundation. *Eur J Emerg Med*. Jun 1996;3(2):109-127.
55. Bouma GJ, Muizelaar JP, Choi SC, Newlon PG, Young HF. Cerebral circulation and metabolism after severe traumatic brain injury: the elusive role of ischemia. *J Neurosurg*. Nov 1991;75(5):685-693.
56. Badjatia N, Carney N, Crocco TJ, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. *Prehosp Emerg Care*. 2008;12 Suppl 1:S1-52.
57. Jankowitz BT, Adelson PD. Pediatric traumatic brain injury: past, present and future. *Dev Neurosci*. 2006;28(4-5):264-275.
58. Bulger EM, Copass MK, Sabath DR, Maier RV, Jurkovich GJ. The use of neuromuscular blocking agents to facilitate prehospital intubation does not impair outcome after traumatic brain injury. *J Trauma*. Apr 2005;58(4):718-723; discussion 723-714.
59. Davis DP, Idris AH, Sise MJ, et al. Early ventilation and outcome in patients with moderate to severe traumatic brain injury. *Crit Care Med*. Apr 2006;34(4):1202-1208.
60. Gervais HW, Eberle B, Konietzke D, Hennes HJ, Dick W. Comparison of blood gases of ventilated patients during transport. *Crit Care Med*. Aug 1987;15(8):761-763.
61. Helm M, Hauke J, Lampl L. A prospective study of the quality of pre-hospital emergency ventilation in patients with severe head injury. *Br J Anaesth*. Mar 2002;88(3):345-349.
62. Mori K, Maeda M, Miyazaki M, Iwase H. Effects of mild (33 degrees C) and moderate (29 degrees C) hypothermia on cerebral blood flow and metabolism, lactate, and extracellular glutamate in experimental head injury. *Neurol Res*. Dec 1998;20(8):719-726.
63. Adelson PD, Bratton SL, Carney NA, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents. Chapter 12. Use of hyperventilation in the acute management of severe pediatric traumatic brain injury. *Pediatr Crit Care Med*. Jul 2003;4(3 Suppl):S45-48.

64. Davis DP, Peay J, Serrano JA, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. *Ann Emerg Med.* Aug 2005;46(2):115-122.
65. Davis DP, Fakhry SM, Wang HE, et al. Paramedic rapid sequence intubation for severe traumatic brain injury: perspectives from an expert panel. *Prehosp Emerg Care.* Jan-Mar 2007;11(1):1-8.
66. Davis DP, Peay J, Sise MJ, et al. The impact of prehospital endotracheal intubation on outcome in moderate to severe traumatic brain injury. *J Trauma.* May 2005;58(5):933-939.
67. Denninghoff KR, Griffin MJ, Bartolucci AA, Lobello SG, Fine PR. Emergent endotracheal intubation and mortality in traumatic brain injury. *West J Emerg Med.* Nov 2008;9(4):184-189.
68. Murray JA, Demetriades D, Berne TV, et al. Prehospital intubation in patients with severe head injury. *J Trauma.* Dec 2000;49(6):1065-1070.
69. Bochicchio GV, Ilahi O, Joshi M, Bochicchio K, Scalea TM. Endotracheal intubation in the field does not improve outcome in trauma patients who present without an acutely lethal traumatic brain injury. *J Trauma.* Feb 2003;54(2):307-311.
70. Arbabi S, Jurkovich GJ, Wahl WL, et al. A comparison of prehospital and hospital data in trauma patients. *J Trauma.* May 2004;56(5):1029-1032.
71. Faul M, Wald MM, Rutland-Brown W, Sullivent EE, Sattin RW. Using a cost-benefit analysis to estimate outcomes of a clinical treatment guideline: testing the Brain Trauma Foundation guidelines for the treatment of severe traumatic brain injury. *J Trauma.* Dec 2007;63(6):1271-1278.
72. Bulger EM, Nathens AB, Rivara FP, Moore M, MacKenzie EJ, Jurkovich GJ. Management of severe head injury: institutional variations in care and effect on outcome. *Crit Care Med.* Aug 2002;30(8):1870-1876.
73. Arabi YM, Haddad S, Tamim HM, et al. Mortality reduction after implementing a clinical practice guidelines-based management protocol for severe traumatic brain injury. *J Crit Care.* Jun 2010;25(2):190-195.
74. Dopenberg EM, Zauner A, Bullock R, Ward JD, Fatouros PP, Young HF. Correlations between brain tissue oxygen tension, carbon dioxide tension, pH, and cerebral blood flow--a better way of monitoring the severely injured brain? *Surg Neurol.* Jun 1998;49(6):650-654.
75. Ishige N, Pitts LH, Berry I, Nishimura MC, James TL. The effects of hypovolemic hypotension on high-energy phosphate metabolism of traumatized brain in rats. *J Neurosurg.* Jan 1988;68(1):129-136.
76. Shutter LA, Narayan RK. Blood pressure management in traumatic brain injury. *Ann Emerg Med.* Mar 2008;51(3 Suppl):S37-38.
77. Kokoska ER, Smith GS, Pittman T, Weber TR. Early hypotension worsens neurological outcome in pediatric patients with moderately severe head trauma. *J Pediatr Surg.* Feb 1998;33(2):333-338.
78. Grande PO, Asgeirsson B, Nordstrom C. Aspects on the cerebral perfusion pressure during therapy of a traumatic head injury. *Acta Anaesthesiol Scand Suppl.* 1997;110:36-40.
79. Price DJ, Murray A. The influence of hypoxia and hypotension on recovery from head injury. *Injury.* Apr 1972;3(4):218-224.
80. Stocchetti N, Furlan A, Volta F. Hypoxemia and arterial hypotension at the accident scene in head injury. *J Trauma.* May 1996;40(5):764-767.
81. Michaud LJ, Rivara FP, Grady MS, Reay DT. Predictors of survival and severity of disability after severe brain injury in children. *Neurosurgery.* Aug 1992;31(2):254-264.
82. van Hulst RA, Lameris TW, Haitsma JJ, Klein J, Lachmann B. Brain glucose and lactate levels during ventilator-induced hypo- and hypercapnia. *Clin Physiol Funct Imaging.* Jul 2004;24(4):243-248.
83. Levin HS, Aldrich EF, Saydjari C, et al. Severe head injury in children: experience of the Traumatic Coma Data Bank. *Neurosurgery.* Sep 1992;31(3):435-443; discussion 443-434.
84. Carrel M, Moeschler O, Ravussin P, Favre JB, Boulard G. [Prehospital air ambulance and systemic secondary cerebral damage in severe craniocerebral injuries]. *Ann Fr Anesth Reanim.* 1994;13(3):326-335.
85. Jeffreys RV, Jones JJ. Avoidable factors contributing to the death of head injury patients in general hospitals in Mersey Region. *Lancet.* Aug 29 1981;2(8244):459-461.
86. Kohi YM, Mendelow AD, Teasdale GM, Allardice GM. Extracranial insults and outcome in patients with acute head injury--relationship to the Glasgow Coma Scale. *Injury.* Jul 1984;16(1):25-29.

EPIC GUIDELINES & ALGORITHM FOR ADULTS REFERENCES

1. Guidelines for the management of severe traumatic brain injury. *J Neurotrauma* 2007;24 Suppl 1:S1-106.
2. Badjatia N, Carney NA, Crocco TJ, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. *Prehosp Emerg Care* 2008;12:S1-52.
3. Fearnside MR, Cook RJ, McDougall P, McNeil RJ. The Westmead Head Injury Project outcome in severe head injury. A comparative analysis of pre-hospital, clinical and CT variables. *Br J Neurosurg* 1993;7:267-79.
4. Gentleman D. Causes and effects of systemic complications among severely head injured patients transferred to a neurosurgical unit. *Int Surg* 1992;77:297-302.
5. Chesnut RM, Marshall LF, Klauber MR, et al. The role of secondary brain injury in determining outcome from severe head injury. *J Trauma* 1993;34:216-22.
6. Silverston P. Pulse oximetry at the roadside: a study of pulse oximetry in immediate care. *Bmj* 1989;298:711-3.
7. Bernard S. A randomized trial of endotracheal intubation in patients with head injury. In: *Resuscitation Science Symposium*; 2008 Nov. 9; New Orleans, LA: American Heart Association; 2008.
8. Moppett IK. Traumatic brain injury: assessment, resuscitation and early management. *Br J Anaesth* 2007;99:18-31.
9. Davis DP, Dunford JV, Poste JC, et al. Impact of hypoxia and hyperventilation on outcome after paramedic rapid sequence intubation of severely head-injured patients. *J Trauma* 2004;57:1-8; discussion -10.
10. Stiver SI, Manley GT. Prehospital management of traumatic brain injury. *Neurosurg Focus* 2008;25:E5.
11. Davis DP. Early ventilation in traumatic brain injury. *Resuscitation* 2008;76:333-40.
12. Davis DP, Heister R, Poste JC, Hoyt DB, Ochs M, Dunford JV. Ventilation patterns in patients with severe traumatic brain injury following paramedic rapid sequence intubation. *Neurocrit Care* 2005;2:165-71.
13. Adelson PD, Bratton SL, Carney NA, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents. *Pediatr Crit Care Med* 2003;3:S2-S81.
14. Davis DP, Dunford JV, Ochs M, Park K, Hoyt DB. The use of quantitative end-tidal capnometry to avoid inadvertent severe hyperventilation in patients with head injury after paramedic rapid sequence intubation. *Journal of Trauma-Injury Infection and Critical Care* 2004;56:808-14.
15. Lewis F. Supply-dependent Oxygen Consumption: Reversing cause and effect. In: *Resuscitation Science Symposium*; 2008 Nov. 8; New Orleans, LA: American Heart Association; 2008.
16. Davis DP, Douglas DJ, Koenig W, Carrison D, Buono C, Dunford JV. Hyperventilation following aero-medical rapid sequence intubation may be a deliberate response to hypoxemia. *Resuscitation* 2007;73:354-61.
17. Thomas SH, Orf J, Wedel SK, Conn AK. Hyperventilation in traumatic brain injury patients: inconsistency between consensus guidelines and clinical practice. *J Trauma* 2002;52:47-52; discussion -3.
18. Di Bartolomeo S, Sanson G, Nardi G, Michelutto V, Scian F. Inadequate ventilation of patients with severe brain injury: a possible drawback to prehospital advanced trauma care? *Eur J Emerg Med* 2003;10:268-71.
19. Austin PN, Campbell RS, Johannigman JA, Branson RD. Transport ventilators. *Respir Care Clin N Am* 2002;8:119-50.
20. Braman SS, Dunn SM, Amico CA, Millman RP. Complications of intrahospital transport in critically ill patients. *Ann Intern Med* 1987;107:469-73.
21. Gervais HW, Eberle B, Konietzke D, Hennes HJ, Dick W. Comparison of blood gases of ventilated patients during transport. *Crit Care Med* 1987;15:761-3.
22. Helm M, Hauke J, Lampl L. A prospective study of the quality of pre-hospital emergency ventilation in patients with severe head injury. *Br J Anaesth* 2002;88:345-9.
23. Hurst JM, Davis K, Jr., Branson RD, Johannigman JA. Comparison of blood gases during transport using two methods of ventilatory support. *J Trauma* 1989;29:1637-40.
24. Tobias JD, Lynch A, Garrett J. Alterations of end-tidal carbon dioxide during the intrahospital transport of children. *Pediatr Emerg Care* 1996;12:249-51.
25. Davis DP, Peay J, Serrano JA, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. *Ann Emerg Med* 2005;46:115-22.

26. Warner KJ, Cuschieri J, Copass MK, Jurkovich GJ, Bulger EM. The impact of prehospital ventilation on outcome after severe traumatic brain injury. *J Trauma* 2007;62:1330-6; discussion 6-8.
27. Warner KJ, Bulger EM. Does pre-hospital ventilation effect outcome after significant brain injury. *Trauma* 2007;9:283-89.
28. Brower RG, Matthay MA, Morris A, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *New England Journal of Medicine* 2000;342:1301-8.
29. Bloomfield GL, Ridings PC, Blocher CR, Marmarou A, Sugerman HJ. A proposed relationship between increased intraabdominal, intrathoracic, and intracranial pressure. *Critical Care Medicine* 1997;25:496-503.
30. Citerio G, Vascotto E, Villa F, Celotti S, Pesenti A. Induced abdominal compartment syndrome increases intracranial pressure in neurotrauma patients: a prospective study. *Crit Care Med* 2001;29:1466-71.
31. Pavone LA, Halter J, Lutz C, Gatto L, Khan S, Nieman G. Injurious mechanical ventilation (IMV) preferentially damages the non-dependent lung. *Journal of the American College of Surgeons* 2003;197:S37-S.
32. Slutsky AS, Ranieri VM. Mechanical ventilation: lessons from the ARDSNet trial. *Respir Res* 2000;1:73-7.
33. Zhang HB, Downey GP, Suter PM, Slutsky AS, Ranieri VM. Conventional mechanical ventilation is associated with bronchoalveolar lavage-induced activation of polymorphonuclear leukocytes - A possible mechanism to explain the systemic consequences of ventilator-induced lung injury in patients with ARDS. *Anesthesiology* 2002;97:1426-33.
34. Uhlig S. Ventilation-induced lung injury and mechanotransduction: stretching it too far? *Am J Physiol Lung Cell Mol Physiol* 2002;282:L892-6.
35. Shutter LA, Narayan RK. Blood Pressure Management in Traumatic Brain Injury. *Annals of Emergency Medicine* 2008;51:S37-S8.
36. Pigula FA, Wald SL, Shackford SR, Vane DW. The effect of hypotension and hypoxia on children with severe head injuries. *J Pediatr Surg* 1993;28:310-4; discussion 5-6.
37. Price DJ, Murray A. Influence of hypoxia and hypotension on recovery from head injury. *Injury* 1972;3:218-24.
38. Stocchetti N, Furlan A, Volta F. Hypoxemia and arterial hypotension at the accident scene in head injury. *J Trauma* 1996;40:764-7.
39. Luerssen TG, Klauber MR, Marshall LF. Outcome from head injury related to patient's age. A longitudinal prospective study of adult and pediatric head injury. *J Neurosurg* 1988;68:409-16.
40. Carrel M, Moeschler O, Ravussin P, Favre JB, Boulard G. Prehospital air ambulance and systemic secondary cerebral damage in severe craniocerebral injuries. *Ann Fr Anesth Reanim* 1994;13:326-35.
41. Jeffreys RV, Jones JJ. Avoidable factors contributing to the death of head injury patients in general hospitals in Mersey Region. *Lancet* 1981;2:459-61.
42. Kohi YM, Mendelow AD, Teasdale GM, Allardice GM. Extracranial insults and outcome in patients with acute head injury--relationship to the Glasgow Coma Scale. *Injury* 1984;16:25-9.
43. Rose J, Valtonen S, Jennett B. Avoidable factors contributing to death after head injury. *Br Med J* 1977;2:615-8.
44. Seelig JM, Klauber MR, Toole BM, Marshall LF, Bowers SA. Increased ICP and systemic hypotension during the first 72 hours following severe head injury. In: Miller JD, Teasdale GM, Rowan JO, eds. *Intracranial Pressure VI*. Berlin: Springer-Verlag; 1986:675-9
45. Chesnut RM, Ghajar J, Maas AIR, et al. Part 2: Early indicators of prognosis in severe traumatic brain injury. *J Neurotrauma* 2000;17:555+.
46. Miller JD, Becker DP. Secondary insults to the injured brain. *J R Coll Surg Edinb* 1982;27:292-8.
47. Barton CW, Hemphill JC, Morabito D, Manley G. A novel method of evaluating the impact of secondary brain insults on functional outcomes in traumatic brain-injured patients. *Acad Emerg Med* 2005;12:1-6.
48. Manley G, Knudson MM, Morabito D, Damron S, Erickson V, Pitts L. Hypotension, hypoxia, and head injury: frequency, duration, and consequences. *Arch Surg* 2001;136:1118-23.
49. Helmy A, Vizcaychipi M, Gupta AK. Traumatic brain injury: intensive care management. *Br J Anaesth* 2007;99:32-42.

EPIC4KIDS GUIDELINES & ALGORITHM REFERENCES

1. Adelson PD, Bratton SL, Carney NA, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents. *Pediatr Crit Care Med* 2003;3:S2-S81.
2. Guidelines for the management of severe traumatic brain injury. *J Neurotrauma* 2007;24 Suppl 1:S1-106.
3. Badjatia N, Carney NA, Crocco TJ, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. *Prehosp Emerg Care* 2008;12:S1-52.
4. Fearnside MR, Cook RJ, McDougall P, McNeil RJ. The Westmead Head Injury Project outcome in severe head injury. A comparative analysis of pre-hospital, clinical and CT variables. *Br J Neurosurg* 1993;7:267-79.
5. Gentleman D. Causes and effects of systemic complications among severely head injured patients transferred to a neurosurgical unit. *Int Surg* 1992;77:297-302.
6. Chesnut RM, Marshall LF, Klauber MR, et al. The role of secondary brain injury in determining outcome from severe head injury. *J Trauma* 1993;34:216-22.
7. Silverston P. Pulse oximetry at the roadside: a study of pulse oximetry in immediate care. *Bmj* 1989;298:711-3.
8. Bernard S. A randomized trial of endotracheal intubation in patients with head injury. In: *Resuscitation Science Symposium*; 2008 Nov. 9; New Orleans, LA: American Heart Association; 2008.
9. Moppett IK. Traumatic brain injury: assessment, resuscitation and early management. *Br J Anaesth* 2007;99:18-31.
10. Davis DP, Dunford JV, Poste JC, et al. The impact of hypoxia and hyperventilation on outcome after paramedic rapid sequence intubation of severely head-injured patients. *J Trauma* 2004;57:1-8; discussion -10.
11. Stiver SI, Manley GT. Prehospital management of traumatic brain injury. *Neurosurg Focus* 2008;25:E5.
12. Gausche M, Lewis RJ, Stratton SJ, et al. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: a controlled clinical trial. *JAMA* 2000;283:783-90.
13. Cooper A, DiScala C, Foltin G, Tunik M, Markenson D, Welborn C. Prehospital endotracheal intubation for severe head injury in children: a reappraisal. *Semin Pediatr Surg* 2001;10:3-6.
14. Davis DP. Early ventilation in traumatic brain injury. *Resuscitation* 2008;76:333-40.
15. Davis DP, Heister R, Poste JC, Hoyt DB, Ochs M, Dunford JV. Ventilation patterns in patients with severe traumatic brain injury following paramedic rapid sequence intubation. *Neurocrit Care* 2005;2:165-71.
16. Davis DP, Dunford JV, Ochs M, Park K, Hoyt DB. The use of quantitative end-tidal capnometry to avoid inadvertent severe hyperventilation in patients with head injury after paramedic rapid sequence intubation. *Journal of Trauma-Injury Infection and Critical Care* 2004;56:808-14.
17. Lewis F. Supply-dependent Oxygen Consumption: Reversing cause and effect. In: *Resuscitation Science Symposium*; 2008 Nov. 8; New Orleans, LA: American Heart Association; 2008.
18. Davis DP, Douglas DJ, Koenig W, Carrison D, Buono C, Dunford JV. Hyperventilation following aeromedical rapid sequence intubation may be a deliberate response to hypoxemia. *Resuscitation* 2007;73:354-61.
19. Thomas SH, Orf J, Wedel SK, Conn AK. Hyperventilation in traumatic brain injury patients: inconsistency between consensus guidelines and clinical practice. *J Trauma* 2002;52:47-52; discussion -3.
20. Di Bartolomeo S, Sanson G, Nardi G, Michelutto V, Scian F. Inadequate ventilation of patients with severe brain injury: a possible drawback to prehospital advanced trauma care? *Eur J Emerg Med* 2003;10:268-71.
21. Austin PN, Campbell RS, Johannigman JA, Branson RD. Transport ventilators. *Respir Care Clin N Am* 2002;8:119-50.
22. Braman SS, Dunn SM, Amico CA, Millman RP. Complications of intrahospital transport in critically ill patients. *Ann Intern Med* 1987;107:469-73.
23. Gervais HW, Eberle B, Konietzke D, Hennes HJ, Dick W. Comparison of blood gases of ventilated patients during transport. *Crit Care Med* 1987;15:761-3.

24. Helm M, Hauke J, Lampl L. A prospective study of the quality of pre-hospital emergency ventilation in patients with severe head injury. *Br J Anaesth* 2002;88:345-9.
25. Hurst JM, Davis K, Jr., Branson RD, Johannigman JA. Comparison of blood gases during transport using two methods of ventilatory support. *J Trauma* 1989;29:1637-40.
26. Tobias JD, Lynch A, Garrett J. Alterations of end-tidal carbon dioxide during the intrahospital transport of children. *Pediatr Emerg Care* 1996;12:249-51.
27. Badjatia N, Carney N, Crocco TJ, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. *Prehosp Emerg Care* 2008;12 Suppl 1:S1-52.
28. Davis DP, Peay J, Serrano JA, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. *Ann Emerg Med* 2005;46:115-22.
29. Warner KJ, Cuschieri J, Copass MK, Jurkovich GJ, Bulger EM. Impact of prehospital ventilation on outcome after severe traumatic brain injury. *J Trauma* 2007;62:1330-6; discussion 6-8.
30. Warner KJ, Bulger EM. Does pre-hospital ventilation effect outcome after significant brain injury. *Trauma* 2007;9:283-89.
31. Brower RG, Matthay MA, Morris A, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *New England Journal of Medicine* 2000;342:1301-8.
32. Bloomfield GL, Ridings PC, Blocher CR, Marmarou A, Sugerman HJ. A proposed relationship between increased intraabdominal, intrathoracic, and intracranial pressure. *Critical Care Medicine* 1997;25:496-503.
33. Citerio G, Vascotto E, Villa F, Celotti S, Pesenti A. Induced abdominal compartment syndrome increases intracranial pressure in neurotrauma patients: a prospective study. *Crit Care Med* 2001;29:1466-71.
34. Pavone LA, Halter J, Lutz C, Gatto L, Khan S, Nieman G. Injurious mechanical ventilation (IMV) preferentially damages the non-dependent lung. *Journal of the American College of Surgeons* 2003;197:S37-S.
35. Slutsky AS, Ranieri VM. Mechanical ventilation: lessons from the ARDSNet trial. *Respir Res* 2000;1:73-7.
36. Zhang HB, Downey GP, Suter PM, Slutsky AS, Ranieri VM. Conventional mechanical ventilation is associated with bronchoalveolar lavage-induced activation of polymorphonuclear
37. leukocytes - A possible mechanism to explain the systemic consequences of ventilator-induced lung injury in patients with ARDS. *Anesthesiology* 2002;97:1426-33.
38. Uhlig S. Ventilation-induced lung injury and mechanotransduction: stretching it too far? *Am J Physiol Lung Cell Mol Physiol* 2002;282:L892-6.
39. Pediatric Advanced Life Support: American Heart Association; 2010.
40. Helmy A, Vizcaychipi M, Gupta AK. Traumatic brain injury: intensive care management. *Br J Anaesth* 2007;99:32-42.

