Prehospital Care of Traumatic Brain Injury in North Carolina

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Traumatic brain injury results in more than 140,000 visits to North Carolina emergency departments annually. North Carolina first implemented a systematically organized approach to brain injury management in 1967, and the state's emergency medical services community continues to optimize patient care by incorporating evolving knowledge into protocols and procedures.

Traumatic brain injury (TBI) comprises a spectrum of disease resulting in mild to severe brain dysfunction caused by blunt or penetrating head trauma [1]. The main causes of TBI are falls (35.2%), motor vehicle crashes (17.3%), blunt impacts (16.5%), and assault (10%). During the period 2010–2011, there were 140,234 visits to North Carolina emergency departments for head injuries; the most frequent visits occurred among males, very young children, and very old individuals [2].

The evolution of TBI management is rich with both advancements and aborting therapies that caused harm; much of this knowledge has slowly influenced prehospital care in various ways. The oldest known surgical document on trauma is the ancient Egyptian scroll referred to as the Edwin Smith Papyrus (circa 1650–1550 BC). This text describes 48 trauma cases, including head injuries, and classifies them based on presentation [3]. Treatment of head injuries existed even before recorded history in the form of a surgical decompression technique called trepanation, in which a hole was drilled into the skull. Archeological evidence demonstrates that many patients survived this early form of surgery [4].

In 1965, 52 million accidental or general injuries were recorded nationwide. Of these, 107,000 people died, more than 10 million people were temporarily disabled, and 400,000 people were permanently impaired [5]. In 1966, the National Academy of Sciences published *Accidental Death and Disability: The Neglected Disease of Modern Society*. This paper noted that trauma is the leading cause of death in the first half of an individual's lifespan, and it highlighted the significant burden traumatic injuries place on American society. This burden of disease resulted in an annual cost to society of over $18 billion. In addition, the National Academy of Sciences paper described a magnitude of deficiencies, including inadequate layperson training, poor communication systems, and a lack of trauma care systems. This document also called attention to the lack of properly trained and equipped ground and aeromedical emergency medical services (EMS) units [5].

Following publication of *Accidental Death and Disability*, Congress enacted the National Traffic and Motor Vehicle Safety Act of 1966, thus creating the National Highway Traffic Safety Administration. This legislation also directed each state to develop regional EMS systems. North Carolina responded in 1967 by legislating the Ambulance Services Act. This placed the regulatory responsibilities of EMS under the North Carolina Department of Health and Human Services (DHHS). It provided DHHS with authority to adopt required equipment standards, inspect ambulances, and establish qualifications for ambulance attendants [6].

In 1973, North Carolina established the Office of Emergency Medical Services and provided funding to improve training, transportation, emergency departments, and communication systems. In 1993, legislation was enacted to develop a statewide trauma system. In 2001, further legislation was passed to align North Carolina with the National Highway Traffic Safety Administration's EMS Agenda for the Future [6].

As described, significant progress has been made since 1967 with respect to improving EMS and trauma systems in North Carolina. How has this impacted TBI care? Standardization of EMS systems, training for prehospital personnel, improved emergency department capabilities, and a statewide trauma care system all provide a framework for improved TBI care. In addition, several key therapies for TBI had been introduced by 1978, including prehospital resuscitation, prehospital aggressive respiratory and circulatory support, hospital intracranial monitoring and control, and computed tomography (CT) scanning [7].

Prehospital strategies for trauma patients with head injuries include cervical and spinal immobilization; fluid resuscitation to prevent hypotension, which may lead to decreased

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cerebral perfusion pressure; and aggressive oxygenation and ventilation. Unfortunately, hyperventilation—which was advocated as a strategy to decrease intracranial pressure following herniation—became used more generally when herniation was not present. Hyperventilation and hyperoxygenation can cause increased secondary brain injury via decreased cerebral perfusion pressure and apoptosis from free radical formation. This well-known phenomenon has been observed in both adult and pediatric patients in cardiopulmonary resuscitation research over the past few decades [8, 9].

In 1995, the Brain Trauma Foundation and the American Association of Neurological Surgeons jointly published a set of guidelines for the treatment of TBI. The guidelines promote aggressive resuscitation, rapid transport to a trauma center, CT scanning, prompt hematoma surgery, and intracranial pressure monitoring and control [7]. Unfortunately, recent work has demonstrated poor compliance with evidence-based guidelines for TBI. In 2014, a study of Level 1 trauma centers found an overall compliance rate with the guidelines of 73%, with wide variation among the 11 trauma centers [10].

Historically, this variation can also be seen in the EMS system in North Carolina. Since the introduction of paramedical personnel for field treatment, numerous authorities with different agendas have provided education to prehospital personnel over different periods. There is also considerable variability in the leadership of local EMS systems. North Carolina general statutes require that a physician medical director provide oversight of the entire EMS system, but many physicians are not trained in emergency medicine or in the care of TBI patients. In the past, each EMS agency was also responsible for the formation of treatment protocols and procedures. The protocols were locally specific, not standardized, and may not have included a protocol on TBI.

Unfortunately, many of the practices carried out in the field in the 1970s and 1980s did not always contribute positively to patient outcomes. With the introduction of pulse oximetry, many prehospital providers erroneously believed that all patients with head injuries required 100% oxygen saturation at all times, possibly increasing the use of hyperventilation. As the use of the Glasgow Coma Scale (GCS) became more prevalent in the field, a standard was developed that directed paramedics to intubate patients with GCS scores less than 8. Many patients do require endotracheal intubation in the field, but evidence continues to demonstrate increased morbidity and mortality of head-injury patients who are intubated in the field [11]. Patients with isolated head injuries who are intubated in the field have a 23% higher mortality rate than patients intubated in the emergency department [12], possibly due in part to lack of experience of prehospital providers.

Concussion is also managed in the prehospital environment; such injuries are defined as a transient brain impairment following blunt trauma with dysfunction ranging from mild dizziness to amnesia, vomiting, and/or severe headache, with or without loss of consciousness. In 2011, the North Carolina General Assembly passed the Gfeller-Waller Concussion Awareness Act in response to the deaths of 2 high school football players in 2008. Matthew Gfeller was a sophomore who suffered a helmet-to-helmet injury that resulted in an intracranial hemorrhage. Four weeks later, Jaquan Waller died from a "second-impact syndrome" [13].

The Gfeller-Waller Act mandates a concussion training program for public schools. The program must include several components: written information detailing signs and symptoms of a concussion; a description of the physiology and potential short- and long-term effects of concussions; and a medical return-to-play protocol for post-concussion participation in athletic activities. The act also requires each school to develop a venue-specific emergency action plan for serious injury or illness [14]. The Gfeller-Waller Act has increased awareness and has likely improved care of concussions in scholastic sports in North Carolina, but no study to date has evaluated its impact on prehospital personnel.

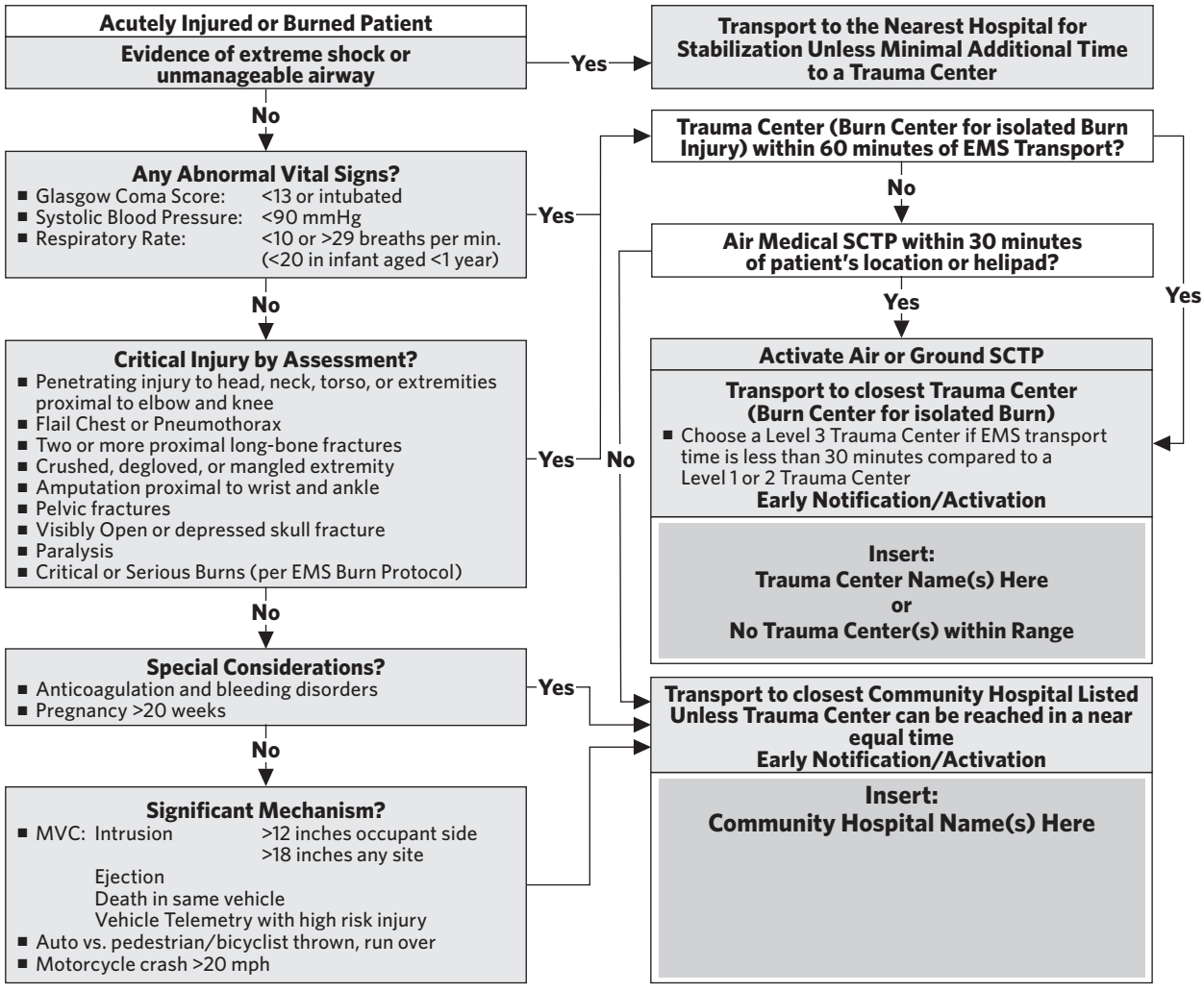
Since the early 2000s, the North Carolina College of Emergency Physicians (NCCEP) has become heavily involved in standards for medical care in EMS systems. An EMS committee within the NCCEP is comprised of board-certified emergency physicians with expertise in EMS. They work to develop protocols, procedures, and policies that are standardized for all EMS agencies across the state; these include protocols for both pediatric and adult patients that are specific to multiple trauma and TBI. Standardized statewide protocols were first introduced in 2005, with subsequent updates in 2009, 2012, and 2014. Once finalized and approved by the NCCEP Board of Directors, the document becomes codified into North Carolina general statute.

Recent Advances

Prehospital TBI care has greatly improved over the past several decades. This care has emphasized rapid, safe extrication of the trauma victim; stabilization of the spine; aggressive resuscitation to prevent hypotension; airway management; and rapid, safe transport to an appropriate receiving facility. Key features of current pediatric and adult head injury protocols aim to decrease secondary brain insult. In 2009, the North Carolina Office of Emergency Medical Services also established triage and destination protocols to aid in the decision-making process of many time-dependent conditions, including trauma.

This is presented as an algorithm with 5 arms (see Figure 1). The first arm of this algorithm directs the patient who presents with an unmanaged airway or profound shock to the nearest hospital for stabilizing measures. The second and third arms assess for abnormal vital signs and critical injuries for hospital triage. The fourth arm accounts for special or associated problems like pregnancy or anticoagulation. The fifth arm takes into account the mechanism of injury. This aids the prehospital provider in deciding upon

FIGURE 1.
Trauma and Burn Triage and Destination Protocol



Note. EMS, emergency medical services; mph, miles per hour; MVC, motor vehicle crash; SCTP, specialty care transport program.
The triage and destination protocol may be viewed at www.ncems.org/pdf/ TraumaTriage 2009.pdf. The adult and pediatric head trauma protocols may be viewed at www.ncems.org/nccepstandards/protocols/41AdultHeadTrauma.pdf and www.ncems.org/nccepstandards/Protocols/65PediatricHeadTrauma.pdf, respectively.

the most appropriate hospital/trauma center and if ground transport is sufficient or if air/helicopter transport should be considered.

Advances in TBI care continue to evolve in North Carolina, with strategies culminating in a standardized approach to care for TBI patients. In 2005, rapid sequence intubation was established in North Carolina. Agencies employing this procedure are required to use end-tidal capnography to monitor the airway, assure endotracheal intubation, and prevent a missed esophageal tube placement. Advanced life support (ALS) personnel are able to monitor oxygen saturation through the use of pulse oximetry and ventilation status via waveform capnography. End-tidal capnography is also paramount in preventing hyperventilation of TBI patients. ALS providers can now measure expired carbon dioxide levels and change the ventilation depth and rate accordingly, with a goal of keeping the carbon dioxide level at 35–45 mmHg. Patients who demonstrate a unilateral, large, and unreactive pupil; decorticate or decerebrate posturing; bradycardia; and/or abrupt decline in mental status are candidates for hyperventilation, but only to the extent of maintaining end-tidal carbon dioxide levels of 30–35 mmHg. Furthermore, capnography can also function as an early warning system to aid in the identification of nonintubated patients who are hypoventilating, thus allowing the health care provider to initiate airway or ventilation interventions before hypoxia occurs.

Moving forward, injury prevention needs to play a greater role. Unfortunately, most EMS agencies lack adequate funding for day-to-day operations, especially in rural areas, and they have little or no funding for prevention strategies. Local governments must be willing to adequately fund their EMS systems to improve care in their communities and to prevent injuries through education.

A recent grant from the National Institutes of Health was

awarded with the goal of enrolling 25,000 TBI patients in Arizona over the next 9 years. The specific aim of this study is to determine if statewide implementation of the international adult and pediatric EMS TBI guidelines will significantly reduce morbidity and mortality in patients with moderate or severe TBI [15]. Hopefully this large trial will provide definitive evidence for the treatment of TBI patients in the prehospital environment.

While prehospital management of severe TBI remains challenging due to a lack of randomized controlled trials, expert consensus recommends that adequate airway management (with prevention of hypoxia, hypocapnia, or hypercapnia), prevention of hypotension, and control of hemorrhage are critical to improving survival from severe TBI [16]. As knowledge continues to evolve, the EMS community in North Carolina will continue to optimize patient care by incorporating new information into future protocols and procedures. NCMJ

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