

Chapter 38

TRAUMATIC BRAIN INJURY IN THE MILITARY

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INTRODUCTION

Traumatic brain injury (TBI) sustained in battle was described as early as Homer's *Iliad*, written approximately 3,000 years ago, before the Hippocratic era.¹ Homer is believed to have discussed at least 147 neurological injuries in the *Iliad*, of which 78% were fatal, ranging from lethal penetrating brain injury to fully survivable events such as concussion and syncope.¹ TBI remains a significant issue in modern warfare, with frequent diagnosis in both combat and training environments. The primary concerns for operational forces are the acute management of symptoms, impact

on warfighting tasks, and susceptibility to secondary injury. Additionally, because of the logistical challenges associated with management of any injury or disease in an operational environment, the military continues to invest in improving the state of the science and delivering optimized TBI care in a modular and scalable fashion. The Department of Defense (DoD) requires "Readiness of the Force," which relies on prevention of TBI, early and effective clinical management, and constant pursuit of advances in understanding and treating the condition.

BACKGROUND AND SCOPE

The DoD's Defense and Veterans Brain Injury Center (DVBIC) tracks and reports the number of active duty service members (SMs) worldwide who sustain a TBI for the first time. Tracking began in 2000 and continues, with an overall annual peak incidence in 2011 at 32,829. Numbers have declined since then, with the most recent annual incidence of 17,707 in 2017. In total, from 2000 through 2017, at least 379,519 TBIs were sustained by active duty, guard, and reserve members of the armed forces.²

DoD Instruction 6490.11, *DoD Policy Guidance for Management of Mild Traumatic Brain Injury/Concussion in the Deployed Setting*,³ published in 2012, and updated in 2018, provided unified guidelines to all the services for management of mild TBI in the deployed setting. Previously, the DoD relied on SMs to

report symptoms; with this policy, the DoD shifted to event-based reporting instead of patient-based presentation for evaluation of concussion. The DoD now uses event-driven protocols to maximize the chances of identifying a TBI or a potential TBI. No longer does the SM need to self-identify as having symptoms; rather, if an event is deemed potentially concussive, a medical evaluation is mandated (Exhibit 38-1). The Military Acute Concussion Evaluation (MACE), selected as a screening tool, provides guided questions to determine whether or not a concussion occurred. While the requirement for a potentially concussive event (PCE), or the role of policy to mandate concussion evaluation, could change in the future, the goal is to build systems that do not rely on self-identification by the SM.

DEMOGRAPHICS AND EPIDEMIOLOGY

Department of Defense Definition of Traumatic Brain Injury

In 2007, the DoD published a definition and injury stratification for TBI that was consistent with the Centers for Disease Control and Prevention, the National Institutes of Health, and the World Health Organization. This memorandum was updated and re-signed by the Assistant Secretary of Defense for Health Affairs in 2015.⁴ As data rapidly emerges from the TBI research portfolio, most groups are considering new ways to define and stratify TBI. However, the current DoD definition of TBI is as follows: "A traumatically induced structural injury or physiological disruption of brain function, as a result of an external force, that is indicated by new onset or worsening of at least one of the following clinical signs immediately following the event:

1. any period of loss, or a decreased level, of consciousness;

2. any loss of memory for events immediately before or after the injury (posttraumatic amnesia);
3. any alteration in mental state at the time of the injury (eg, confusion, disorientation, slowed thinking, alteration of consciousness/mental state)."⁴

The Department of Veterans Affairs (VA)/DoD Clinical Practice Guideline⁵ (CPG) includes the above and the following two items:

4. neurological deficits (eg, weakness, loss of balance, change in vision, praxis, paresis/plegia, sensory loss, aphasia) that may or may not be transient; or
5. intracranial lesion.

The definitions also say that, among other external forces, a blast or explosion may be considered a cause of TBI.

EXHIBIT 38-1

MANDATORY REPORTING FOR POTENTIALLY CONCUSSIVE EVENTS

Events Requiring Concussion Evaluation

- Involvement in a vehicle collision or rollover.
- A blow to the head during activities such as training, sporting/recreational activities, or combatives.
- Within 50 meters of a blast (inside or outside).

Command-Directed (Examples)

- Repeated exposures to the events listed above.
- In accordance with protocols for environmental sensors (eg, helmet sensor, blast gauge).

Severity Range: Mild, Moderate, Severe, Penetrating

Severity of TBI, per the DoD definition, is determined by the presence and duration of an altered state, which can include alteration of consciousness, loss of consciousness, or posttraumatic amnesia at the time of injury (Table 38-1). In the DoD definition, concussion is synonymous with mild TBI; these terms will be used interchangeably in this chapter. It should be noted that mild TBI can in some cases result in significant persistent symptoms and functional impairment, despite having the “mild” label. While penetrating head injury can be readily categorized as such by physical examination, closed head injury can be subtler, and severity categories are further defined by the parameters in Table 38-1.

Defining Postinjury Periods

There is variability in the literature about timing and definitions after head injury. The VA/DoD CPC⁵

for mild TBI uses the following stages, based upon work group consensus. These definitions will be used throughout this chapter:

- **Immediate period:** 0 to 7 days postinjury.
- **Acute period:** 1 to 6 weeks postinjury.
- **Post-acute period:** 7 to 12 weeks postinjury.
- **Chronic:** more than 12 weeks postinjury.

Of note, the Berlin consensus statement on concussion in sport (see discussion below) uses different terminology, as well as different time frames—namely, the use of the term “persistent symptoms,” defined as the period beyond which normal clinical recovery is expected, and identified as over 10 to 14 days in adults and over 4 weeks in children.⁶ This re-characterization of acute and post-acute concussion with a shorter timeline, as described in the Berlin consensus statement, is consistent with the direction that the DoD and many other groups are moving toward. For the DoD, this shift toward shorter timelines first appeared in the 2014 clinical recommendation on progressive return to activity,⁷ with timelines that deviated from DoD Instruction 6490.11.³ When reviewing literature on concussion, it is therefore imperative to be aware of how TBI, severity levels, and duration of postconcussion symptoms are defined, and that this aspect of concussion characterization is evolving rapidly based on emerging science.⁸ Greater standardization of definitions and terminology over time will not only improve communication about direct patient care, but also allow research to move forward in a more synchronized fashion.

Military Incidence by Numbers, Severity, and Service

The vast majority of TBI in the military, as in the civilian setting, is mild TBI (concussion), and as of February 2017 accounted for 85.9% of TBI in the DoD (Table 38-2). Although incidence has some correlation

TABLE 38-1

DEPARTMENT OF DEFENSE TRAUMATIC BRAIN INJURY SEVERITY CRITERIA

	Mild/Concussion	Moderate	Severe
CT scan	Normal (CT is not indicated for most mild TBI patients)	Normal or abnormal structural imaging	Normal or abnormal structural imaging
Loss of consciousness	0–30 minutes	>30 minutes and <24 hours	> 24 hours
Alteration of consciousness	A moment–24 hours	>24 hours (if >24 hours, severity is based on other criteria)	
Posttraumatic amnesia	0–1 day	>1 day < 7 days	> 7 days

CT: computed tomography; TBI: traumatic brain injury

TABLE 38-2
DEPARTMENT OF DEFENSE WORLDWIDE TRAUMATIC BRAIN INJURY NUMBERS, 2000–2016

Severity	Air Force	Army	Marine Corps	Navy	Total
Penetrating	560	3,119	766	620	5,065
Severe	439	2,251	627	453	3,770
Moderate	4,370	18,060	5,396	5,125	32,951
Mild	42,167	172,366	42,643	40,302	297,478
Not classifiable	1,602	15,632	2,127	2,467	21,828
Total	49,138	211,428	51,559	48,967	361,092

Data source: Defense and Veterans Brain Injury Center.

with operational tempo and troop volume, including the 2011 peak, TBI diagnoses have not returned to the numbers seen before Operations Enduring Freedom and Iraqi Freedom.³ This may be indicative of not just an increased rate, or higher risk exposures, but also of increased awareness by patients and clinical providers in conjunction with the mandatory DoD reporting requirements. However, these composite numbers do not tell the full story because each SM is counted in the surveillance data only once per lifetime, which likely results in some level of underreporting of TBIs within the DoD. Further, the often mentioned ratio of 80% of DoD TBIs occurring in the nondeployed (garrison) environment is based on the assumption that the injury occurred where and when the diagnosis was made. This likely skews data toward more injuries occurring in garrison than in the combat environment, despite the surveillance methodology that counts diagnoses made within 30 days of a deployment as occurring during deployment.

Regasa et al reported that prior studies indicated a TBI rate during deployment ranging from 12% to 22.8%.⁹ However, the researchers went on to demonstrate that analysis of the data showed SMs were 8.4 times as likely to be diagnosed with a TBI in the 4 weeks after deployment as compared to predeployment.⁷ The risk decreased over the next 40 weeks, then leveled off at 1.7 times the predeployment rate. This correlation is not causal, and the authors note it could result from underreporting in theater or increased injury rates for unknown reasons after deployment. Another analysis of military TBI data from the Armed Forces Health Surveillance Branch, published in the Medical Surveillance Monthly Report (MSMR),¹⁰

divided TBI diagnoses by occurrence (prior to, during, or after deployment) and found that injury rates during deployment were 1.5 times that of predeployment, and 1.2 times that of the postdeployment group. This data is consistent with the work of Regasa et al, showing an increased prevalence both during and after deployment. The MSMR article further showed that combat-specific and armor/motor transport occupations had a higher postdeployment prevalence than other jobs when compared to predeployment. It is important to note that diagnoses in the 4 weeks after redeployment coincide with mandatory screening and may represent increased recognition of the injury rather than increased incidence. Additional research is needed to better understand the timing and location of these injuries.

Incidence Among Civilians

The Centers for Disease Control and Prevention estimates that from 2002 to 2006, TBI caused 1,365,000 emergency department visits, 275,000 hospitalizations, and 52,000 deaths.¹¹ However, it also reports that only 1 in 9 concussions are believed to be captured by typical surveillance methods. Falls represented the highest percentage (35.2%) of external cause of injury in the general population in this time period. Motor vehicle injuries were the most common cause of TBI-related deaths, with the greatest numbers occurring in those aged 20 to 24. Also noted in this time period was a 62% increase in fall-related TBIs among children seen by emergency departments. This data might represent influences such as public awareness that were also represented in the DoD data.

MANAGEMENT IN DEPLOYED SETTINGS

Concussion Management in the Deployed Setting

This section will focus on the challenges of managing concussion, especially with growing awareness of the complexity and evolving nature of TBI in the acute period. Moderate, severe, and penetrating TBIs are managed in accordance with protocols defined by Tactical Combat Casualty Care (TCCC) clinical practice algorithms (discussed later in this chapter). An emerging concept in the immediate/acute assessment of concussion is understanding the neurometabolic cascade and its manifestation in multiple domains, including cognitive, vestibular, and oculomotor. However, the timing of metabolic demand and injury/recovery curves within the brain are not fully understood. As described in 2014 by Giza et al,¹² the neurometabolic cascade is a complex process of ionic, metabolic, and physiologic events, including an acute outpour of K⁺ and influx of Ca⁺⁺, with drops in glucose and cerebral blood flow, leading to altered neurotransmitters and glutamate, and chronic pathophysiology with axonal injury, inflammation, and toxic accumulations.

Consequently, multiple domains must be tested, and evaluations must be repeated after the brain is provided an opportunity to rest. In the military, this challenge is met through a combination of concussion management algorithms. A medical staff member may initiate the assessment, or per DoD policy, operational commanders may be required to refer an SM who was exposed to a PCE (see Exhibit 38-1). The algorithms start with “red flag” signs and symptoms (Exhibit 38-2). Separate red flags geared toward combat medics or corpsmen, rather than to providers, allow for a lower threshold for consultation or evacuation. Surveillance for these red flags is conducted secondary to TCCC protocols and may lead to provider consultation or hospital transport. Importantly, the DoD has invested in capabilities for point-of-injury assessment and monitoring (discussed further in the research section of this chapter). At the provider level, the red flags define the need for neuroimaging (noncontrast head computed tomography [CT] in the immediate injury period) or referral to specialty services.

If there are no red flags, the MACE is initiated (Figure 38-1). The MACE is a standardized screening and assessment document performed on all SMs who experienced a PCE, with a section for a scripted history of the event. This section of the MACE is critical not only for documentation within the health record, but also for the SM’s records as he or she transitions from active duty service. As discussed earlier, accurate

entry into the electronic health record using the most current International Classification of Diseases (ICD) code is also important for maintaining good surveillance data. If the MACE determines that a concussive event occurred, then the additional sections are com-

EXHIBIT 38-2

RED FLAGS FOR TRAUMATIC BRAIN INJURY AS LISTED IN DEPARTMENT OF DEFENSE CLINICAL MANAGEMENT ALGORITHMS

Red flags for TBI are different at the corpsman/medic level than provider level, with a lower threshold for consultation or evacuation.

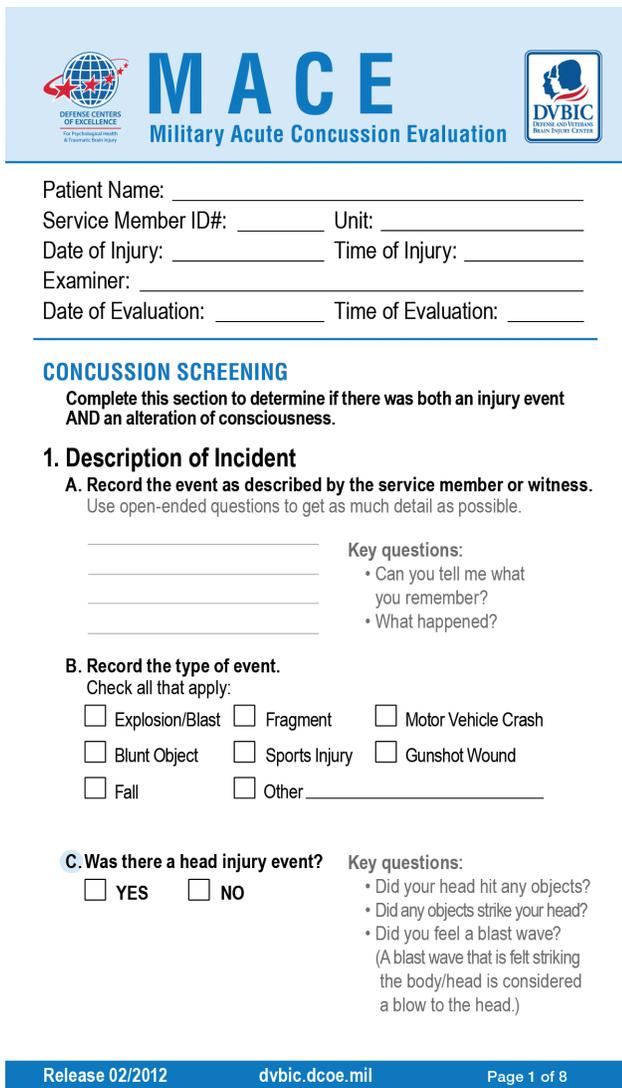
Corpsman/Combat Medic Red Flags

- Loss of consciousness
- ≥ 2 potentially concussive events within 72 hours
- Unusual or combative behavior
- Unequal pupils
- Seizures
- Repeated vomiting
- Double vision/loss of vision
- Worsening headache
- Weakness on one side of the body
- Unable to recognize people/disoriented to place
- Abnormal speech

Provider Red Flags

- Progressively declining level of consciousness
- Progressively declining neurological status
- Pupillary asymmetry
- Seizures
- Repeated vomiting
- Clinically verified GCS <15
- Neurological deficit: motor or sensory LOC >5 minutes
- Double vision
- Worsening headache
- Cannot recognize people or disoriented to place
- Slurred speech
- Unusual behavior

GCS: Glasgow Coma Scale
 LOC: loss of consciousness
 TBI: traumatic brain injury



MACE
Military Acute Concussion Evaluation

DEFENSE CENTERS OF EXCELLENCE
For Psychological Health & Veterans Brain Injury

DVBIC
DEFENSE AND VETERANS BRAIN INJURY CENTER

Patient Name: _____
 Service Member ID#: _____ Unit: _____
 Date of Injury: _____ Time of Injury: _____
 Examiner: _____
 Date of Evaluation: _____ Time of Evaluation: _____

CONCUSSION SCREENING
 Complete this section to determine if there was both an injury event AND an alteration of consciousness.

1. Description of Incident
A. Record the event as described by the service member or witness.
 Use open-ended questions to get as much detail as possible.

Key questions:

- Can you tell me what you remember?
- What happened?

B. Record the type of event.
 Check all that apply:

Explosion/Blast Fragment Motor Vehicle Crash
 Blunt Object Sports Injury Gunshot Wound
 Fall Other _____

C. Was there a head injury event? **Key questions:**

YES NO

- Did your head hit any objects?
- Did any objects strike your head?
- Did you feel a blast wave?
 (A blast wave that is felt striking the body/head is considered a blow to the head.)

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Figure 38-1. Military Acute Concussion Evaluation pocket card.
 Reproduced from: <https://dvbic.dcoe.mil/material/mace-military-acute-concussion-evaluation-pocket-card>.

pleted. Assessment and treatment of other injuries and symptoms is initiated per standard medical protocols. (The MACE pocket card is available at the Defense and Veterans Brain Injury Center website, <https://dvbic.dcoe.mil/material/mace-military-acute-concussion-evaluation-pocket-card>.) The next (forthcoming) version of the MACE, the MACE 2, will complement the Sport Concussion Assessment Tool edition 5 (SCAT 5), a product of the Berlin consensus work group.⁶ The MACE 2 will be a multimodal assessment capability, and aid in standardized assessment of all the known concussion symptom clusters or subtypes. The most significant additions are supported by questions and assessments, targeting identification of symptom

manifestations of vestibular effects, oculomotor effects, migraine, and anxiety, similar to those seen in sports concussion management.⁸

Once a concussion diagnosis is made, results of the MACE are used to continue through the concussion management algorithms, and treatment depends on the clinical findings. However, at a minimum, all SMs exposed to a PCE in a deployed location are evaluated with the MACE and provided 24 hours of rest/recovery time, symptom management, and reevaluation (including exertional testing) once they are symptom free.

This initial management of concussion may be conducted by a medic or corpsman in conjunction with a licensed provider. However, the algorithm presents a stepwise approach for progressive levels of care, from medic/corpsman through primary care, to specialty providers (eg, neurology, physical/occupational therapy, neuropsychology) within the deployed environment. If an SM does not recover within the anticipated timelines, as detailed by the algorithms, they are referred to a specialty provider for comprehensive management. Current DoD policy and clinical guidance require any SM sustaining more than one concussion within a 12-month period to be managed with more conservative protocols. If diagnosed with a second concussion, the SM receives a minimum of 7 days of recovery following symptom resolution, and then must pass exertional testing prior to return to duty. For a third concussion within 12 months, the SM undergoes a “recurrent concussion evaluation” prior to return to duty. This comprehensive evaluation is conducted by a multidisciplinary team of providers and includes a history and examination, including balance assessment; neuroimaging (as necessary); neuropsychological assessment; and a functional assessment.

Vignette 38-1. A 19-year-old male Army soldier, military occupational specialty 11B (infantry), was involved in an improvised explosive blast that directly hit his Humvee while out on patrol. The soldier recalled seeing a flash of light and debris, and was thrown against the side of vehicle, then felt dazed and confused for about 10 minutes. He developed a moderate-severity holocranial headache along with nausea, photophobia, and a constant ringing in his ears. He was able to ambulate independently but felt off balance and reported feeling “not quite right.” Initial evaluation at the forward operating base 2 hours after the blast by the 68W (medic) was done according to the concussion algorithm, and because no red flags were present, the MACE protocol was followed. Concussion was confirmed and the score was 23/green/B (cognitive/neurological/symptoms). The soldier was educated about acute concussion and expectation for recovery, and given a handout with information about concussion symptoms and recovery. His platoon leader was notified that the soldier would be required to have a minimum of 24 hours of rest after becoming symptom free.

The following day, the soldier was evaluated by the unit's physician assistant and felt much better after a good night's sleep. His headache and nausea had resolved and his balance and hearing were back to baseline. His MACE score was now 26/green/A, and exertional testing was performed without any recurrence of symptoms. He was progressed over the next 5 days through the return-to-activity stages without difficulty and returned to full duty.

Traumatic Brain Injury With Polytrauma

Prehospital trauma care performed on the battlefield can differ markedly from that performed in the civilian sector. The TCCC guidelines were developed as a result, adjusting the previous Advanced Trauma Life Support model to meet the specific considerations of combat wounds, such as early use of the extremity tourniquet for exsanguination and allowing patients suffering from uncontrolled hemorrhage to remain in a permissive hypotensive state. (Refer to Chapter 33, Tactical Medicine, for a complete discussion about TCCC principles in the operational environment.) TCCC guidelines are maintained by the Joint Trauma System (JTS), which serves as the DoD's Center of Excellence for Trauma. The JTS and associated committees meet frequently to update the guidelines, which specifically include discussion of moderate, severe, and penetrating TBI. The algorithm for the management of concussion/mild TBI in the deployed setting is generated by the DVBCIC, but it is included with the other TCCC guidelines and is used in conjunction with the MACE. The JTS uses the DoD Trauma Registry to conduct performance improvement projects that guide the committees on recommendations and updates to both CPGs and equipment.

Treating TBI in the prehospital environment begins with an understanding of the mission, including the probability of injuries, as well as limitations when operating austere and outside of a medical treatment facility. Many factors must be considered to develop a unique mission plan that includes specific equipment needs. Planning is key to providing optimal care, especially in the most complex conditions; it is the foundation for the best possible outcomes achievable, even with minimal equipment. When planning for possible head injuries, the provider should know the location and capabilities of DoD, partner nation, and host nation medical facilities within the area of operations, particularly the location of neurosurgical assets and neuroimaging, which will not be available at all evacuation points. Providers should conduct independent research to learn about the area of operations, such as reviewing TRAVAX.com,¹³ a website providing location-based health information, and other independent information sources. Following mission planning, it is essential to become familiar with, and pack for, the available prehospital medical equipment

(Class VIII). Deployable units have unit-level packing lists that serve as the minimal required equipment to treat trauma casualties; special provisions should be considered to plan for head injuries and the Class VIII equipment required to treat them in the prehospital setting.

Hemorrhage is the number one cause of preventable death on the battlefield,¹⁴ and the TCCC guidelines place significant emphasis on first responder actions and skills to stop bleeding. Hemorrhage and the associated treatments can be a confounding factor to the treatment of TBI in the prehospital setting, particularly in polytrauma patients when the TBI is triaged secondary to addressing massive hemorrhage. As a result, providers receiving patients throughout the continuum of care must realize TBI may not have been addressed until the patient is hemodynamically stabilized, which may not have occurred by the time a patient arrives to the next level of care.

The prehospital provider's challenge is to administer lifesaving care while taking into account all considerations to prevent or reduce the possibility of secondary brain injury. The TCCC guidelines allow patients with uncontrollable hemorrhage to remain in a hypotensive state, permitting the patient's systolic blood pressure to remain at 90 mm Hg by palpation, or evaluation of perfusion through mentation. However, recent literature¹⁵ suggests that allowing moderate to severe TBI patients to remain in a hypotensive state is associated with increased probability of secondary brain injury and sequelae. Even a single episode of hypotension during the prehospital or early hospital phases of TBI management is associated with dramatic increases in mortality.

These findings refocus the prehospital provider on the importance of perfusion and the brain's immediate and enduring requirement for oxygenation. The role of supplemental oxygenation is not entirely clear in this population. While some animal studies have shown worsened axonal injury in simulated aeromedical evacuation after TBI,^{16,17} the impact on functional outcomes in humans is not fully known. Multiple factors must be weighed when determining timing of transport to definitive care, and monitoring the posttraumatic inflammatory response (both local and systemic) may be helpful in timing determinations and prevention of secondary brain injury.¹⁸ Operational considerations such as working at altitude in mountainous environments must also be integrated into medical decision-making. For example, at Fort Carson, an Army post at 6,000 feet elevation at the base of 14,000-foot mountains, a mild TBI patient who has otherwise recovered after concussion may experience recurrence of symptoms with increased exertion, particularly at higher altitudes.

After the initial trauma survey is complete, the provider will conduct a comprehensive head-to-toe evaluation, and TBI red flags should alert the provider to immediate necessary actions. Serial follow-on clinical assessments should be performed and documented. Early assessment is critical if increased intracranial pressure is clinically suspected. While the benefits of neuroimaging are well accepted, it is typically unavailable in the forward military operating environment, so use of the Glasgow Coma Scale (GCS) (Table 38-3) guides early determination of TBI severity. It is important to capture both the initial and a postresuscitation GCS score because resuscitation interventions can change the patient’s status.

Identification of pupillary asymmetry can be an indicator of elevated intracranial pressure, providing a high index of suspicion for brain stem compression on the third cranial nerve with impending herniation. Bruising behind the ears (Battle sign) or around the eyes (“raccoon eyes”), as well as cerebrospinal fluid otorrhea and rhinorrhea, are typically associated with basilar skull fractures. Blunt trauma and falls should prompt consideration of manual spinal immobilization during treatment and application of a rigid cervical collar. If clinical evidence supports immobilization with a spinal board, additional precautions should be considered to pad the board and casualty because pressure necrosis may take place within hours of initial immobilization. Elevating the head of the bed between 30 and 60 degrees is optimal for casualties with suspected elevated intracranial pressure.

CONCUSSION MANAGEMENT IN NONDEPLOYED SETTINGS

Algorithms for Garrison Concussion Management

In 2013, the Army began requiring parallel efforts (event-driven protocols) to evaluate and manage concussion in the garrison environment, using a set of algorithms from point of injury through 7 days.¹⁹ Unlike the deployed practice that includes a comprehensive concussion algorithm beyond the initial 7 days, the garrison version uses the VA/DoD CPG⁵ after the first week. An additional difference is that in the garrison algorithms, only SMs with a diagnosed concussion have mandatory downtime, while in the deployed environment all SMs exposed to a PCE are given 24 hours downtime. However, consistent with changes captured in the Berlin consensus statements, all concussion management in the DoD is moving toward the progressive return to activity guideline⁷ in combination with the MACE 2, as discussed above, and updated clinical management guidelines for both deployed and garrison settings. This is a shift from the

TABLE 38-3
GLASGOW COMA SCALE*

Response	Score
Eye response (E)	4 = spontaneous
	3 = to sound
	2 = to pressure
	1 = none
Verbal response (V)	5 = oriented
	4 = confused
	3 = words
	2 = no words, only sounds
Motor response (M)	1 = none
	6 = obeys commands
	5 = localizing
	4 = normal flexion
	3 = abnormal flexion
	2 = abnormal extension
	1 = none

Key: Severe: GCS 3–8; Moderate: GCS 9–12; Mild: GCS 13–15

*The Glasgow Coma Scale (GCS) scoring assessment is currently in transition: the pain stimulus has been replaced with pressure at the finger tip, trapezius, or supraorbital notch. The impact of this change to protocols and guidelines has yet to be determined. The modification can be found on the GCS website: <https://www.glasgowcomascale.org/>. Additionally noted is the rating of non-testable (NT), which is applied when there is an identifiable limiting factor.

total rest required in the 2012 policy, and initiates individualized rehabilitation plans based on the patient’s unique presentation.

Return to Play: High School, College, and State Requirements

While sports concussion has some notable differences from combat-acquired TBI, there are many similarities, and much of the research done on sports concussion has been applied to military injuries. Guidance on return-to-play after sports concussion has evolved in the past 5 to 10 years, with increasing utilization of progressive return to play and normal activity. The guidance initially focused on slowing return to sports; later, increased attention was paid to the impact of cognitive stress on recovery from concussion, particularly as it pertained to student athletes. All 50 states and Washington, DC, now have some form of “when in doubt, sit them out” concussion laws,

and many states now have guidance or laws requiring preseason education for athletes, parents, coaches, and teachers.²⁰ Capabilities range from little leagues, with limited availability of clinical providers and associated funding, to high school systems that leverage athletic trainers, to the National Collegiate Athletic Association, which often mirrors professional sports with increasing capabilities from sideline to hospital system integration.

These trends are consistent with international guidance, most recently in 2017 with the 5th International Consensus Conference on Sports Concussion, held in Berlin, Germany.⁶ This guidance calls for supportive care during the initial recovery period, with gradual return to sport and school, based on symptom resolution and progressive increase in activity levels. The consensus also recommends referral to specialty rehabilitation care for persistent postconcussion symptoms, defined as those remaining after 10 to 14 days for adults or after 4 weeks for children. For these patients, providers should individualize an exercise program, target therapy toward specific disorders, and use cognitive behavioral therapy for any mood component.

Progressive Return to Activity

In 2014, the DVVIC published a clinical recommendation on progressive return to activity (Table 38-4) following acute concussion or mild TBI.⁷ Based on published literature and expert opinion, the guidelines are similar to the International Consensus⁶ on graduated return to sport. To monitor postconcussion symptoms and assess patients for graduated return to activity, the Neurobehavioral Symptoms Inventory (NSI), a self-report survey, is used throughout the DoD and VA. It asks concussed individuals to rate 22 symptoms from 0 to 4, with 0 as “rarely or never present” and 4 as “very severe.” The recommendation then provides for

TABLE 38-4
STAGES OF THE PROGRESSIVE RETURN TO ACTIVITY PROCESS

Stage	Description	Objective
1	Rest	Symptom resolution
2	Light routine activity	Introduce and promote limited effort
3	Light occupation-oriented activity	Increase light activities that require a combined use of physical, cognitive, and/or balance skills
4	Moderate activity	Increase the intensity and complexity of physical, cognitive, and balance activities
5	Intensive activity	Introduce activity of duration and intensity that parallels the service member's typical role, function, and tempo
6	Unrestricted activity	Return to pre-injury activities

six stages of recovery. Stage 1 is Rest (see Table 38-4), intended to minimize physical and cognitive exertion for the first 24 hours after concussion. Progression through the six stages occurs incrementally every 24 hours if symptoms are rated as none or mild (0–1). A critical component of the protocol is early education and expectation for recovery, which has proven to be effective in reducing the number and duration of symptoms.²¹ As noted previously, progressive return to activity complements updated assessment tools such as the SCAT 5 and MACE 2, used in combination to individualize rehabilitation plans.

MANAGEMENT OF POSTCONCUSSIVE SYMPTOMS

Clinical Practice Guideline for the Management of Concussion/Mild Traumatic Brain Injury

The TBI CPG, initially developed in 2009 and updated in 2016,⁵ provides evidence-based recommendations to help guide clinical decision-making. In addition, despite a lack of randomized clinical trials for treatment of postconcussive symptoms, best practices based on literature reviews, expert consensus, and common clinical practice are included to help guide management where evidence is insufficient for a definitive recommendation. The CPG provides algorithms for management of

symptoms persisting more than 7 days, as well as detailed information on clinical symptom management on multiple co-occurring conditions, including headache, dizziness and disequilibrium, visual symptoms, fatigue, sleep disturbance, cognitive symptoms, persistent pain, hearing difficulties, smelling changes, nausea, changes in appetite, and numbness. An evidence table is also provided, outlining the level of medical evidence for the various recommendations. The full guidelines are provided in great detail, with over 100 pages of text. Additional useful tools include a clinician summary, patient summary, and pocket card.⁵

Patient-Centered Care

Postconcussive symptoms are often broken down into physical, cognitive, and emotional/behavioral categories. Key to caring for individuals with postconcussive symptoms in the acute, postacute, and chronic time periods is patient-centered care. A patient's issues and symptoms can be as unique and complex as the individuals themselves. Severity of injury (mild, moderate, or severe) does not always correlate to severity of symptoms; outcomes are determined by individual factors in addition to the initial severity of injury. Moderate and severe brain injuries are most often cared for in inpatient hospital and rehabilitation center settings with subsequent outpatient rehabilitation care. Postconcussive care, however, is usually primary care based, with rehabilitation providers and other consultants treating only those with prolonged symptoms not responding to usual care, or those with significantly complex comorbidities. In recent years, the military has increased use of intensive outpatient programs for complex mild TBI patients, utilizing multiple disciplines, including rehabilitation, behavioral health, and complementary and alternative modalities, to address multiple issues in a time-intensive, focused manner, with the goal of improving functional outcomes.

Postconcussive symptoms are not specific to concussion; they are seen in a variety of other medical conditions, particularly psychological conditions that are often comorbid with chronic postconcussive symptoms.²² In fact, all of the symptoms listed on the NSI are seen at some percentage at baseline in a normal (nonclinical) population: rates of moderate or more severe symptoms in a nonclinical civilian sample who took the NSI ranged from 2.7% for taste/smell changes, to as high as 50% for fatigue, and 43% for concentration.²³ Misattribution of all symptoms to TBI can lead to unnecessary anxiety or other medical conditions being overlooked.

Most individuals will recover relatively quickly after concussion; however, previously reported recovery rates of 80% to 90% within 7 to 10 days after injury²⁴ may have been optimistic and skewed due to group data rather than individual outcomes. Despite a minority of patients with prolonged symptoms, most recover within 1 month, and those with chronic symptoms (>12 weeks) should have a multidisciplinary evaluation and treatment to aide recovery. Progressive return to activity, combined with individualized rehabilitation plans built around symptom clusters,⁸ can help minimize exacerbation of symptoms and avoid repeat injury during the early recovery phase. Those with prolonged symptoms require individualized progression

of activity because extended strict rest can also lead to increased social isolation and deconditioning, and may potentially exacerbate symptom reporting rather than improve recovery.²⁵

Data for Army soldiers suggests a different recovery trajectory after a concussion sustained during deployment. The Warrior Strong Study, which sampled soldiers returning from deployment in Afghanistan or Iraq to Fort Carson and Fort Bragg between 2009 and 2014, found that nearly 50% of those who had a deployment-related mild TBI reported one or more severe or very severe symptoms on the NSI 3 months after redeployment, compared to 25% of those without a concussion on that deployment.²⁶ The most common symptoms were sleep problems (30%), forgetfulness (21%), irritability (17%), and headaches (15%). Traditionally, vestibular and oculomotor symptoms were not assessed early in the course of treatment, which may skew historical data on symptom presentation for acute concussion. However, tools such as the Vestibular and Oculomotor Screening (VOMS), which can identify deficits in vestibular and oculomotor domains in acute concussion, are increasingly being used. These assessments, combined with individualized rehabilitation plans in the acute setting, are beginning to demonstrate earlier symptom recovery in both acute and chronic concussion.⁸

From the civilian literature, risk factors for prolonged symptoms and slower recovery include prior concussions,^{27,28} prior history of headaches,²⁸ and extremes of age (youngest²⁸ and oldest²⁹). Findings on gender are mixed, though several studies suggest a female predominance for prolonged symptoms, and a recent systematic review of the literature suggested that the teenage years were the most vulnerable time period, greater in girls than in boys.³⁰ Pre-injury mental health disorders are also a risk factor for prolonged symptoms.³⁰

In the military setting, comorbid posttraumatic stress has consistently been correlated with increasing persistence of postconcussive symptoms.³¹ In one systematic review the frequency of posttraumatic stress disorder (PTSD) in those with probable mild TBI ranged from 33% to 39%.³² The directionality of the interaction between mild TBI and PTSD is unclear; however, clinical experience shows that both conditions must be addressed for best outcomes. In military concussion centers, the behavioral health component is often embedded within the concussion clinic to provide interdisciplinary care. Two other factors associated with ongoing prolonged symptoms noted in the Warrior Strong Study were combat exposure and noncephalic pain.²⁶

Assessments for Common Postconcussive Symptoms

Sleep problems after concussion are common and can present in various ways. In a meta-analysis, 50% of patients experienced some form of sleep disturbance after TBI, including higher than normal population rates of insomnia (29%), hypersomnia (28%), and sleep apnea (25%).³³ These sleep disturbances are important to evaluate and address early. In the case of insomnia, early intervention is particularly important to mitigate bad habits that can perpetuate poor sleep onset and sleep maintenance. Circadian rhythm sleep-wake disorders are also seen at higher frequency after concussion. These disorders can manifest as insomnia, hypersomnia, or both, depending on the misalignment between the intrinsic circadian rhythm and the desired sleep-wake cycle (eg, delayed circadian rhythm “night owls” will struggle with evening insomnia and morning hypersomnia in the setting of typical military bedtime and wake time). This problem is particularly salient in a military population of young soldiers because young adults tend to have a more delayed circadian rhythm to begin with, which can be further compounded after concussion. Sleep apnea should also be considered in those with complaints of daytime somnolence, nonrefreshing sleep, or ongoing cognitive complaints. Both obstructive and central sleep apnea are more common in those who have experienced TBI, and the effects of sleep apnea on cognition appear to be amplified in this population, particularly in the areas of sustained attention and memory.^{34,35}

Cognitive symptoms after concussion can be associated with a variety of factors, including poor sleep, distraction from pain (such as headaches) or dizziness, and medication side effects, especially for those with polytrauma or concurrent musculoskeletal injury. Anxiety and mood disorders can significantly affect attention and concentration, which in turn impact memory, and can present as cognitive symptoms. However, comprehensive neuropsychological testing is not recommended in the first 30 days after mild TBI.⁵ Per the CPG,⁵ those who have ongoing symptoms beyond 30 days may be referred for neuropsychological testing, cognitive assessment for functional limitations, and treatment by rehabilitation therapists with expertise in TBI rehabilitation. Typically in the setting of prolonged cognitive symptoms, other treatable conditions related to memory and attention should be excluded (such as thyroid disorders, vitamin B12 deficiency, syphilis, sleep disorders, structural central nervous system lesions, and mood disorders) either clinically or by appropriate testing. Neuropsychological testing typically includes validity/performance measures, which

may include stand-alone or embedded measures to increase confidence in the validity of a test battery and overall assessment. Such measures look for consistency between test behavior or self-reported symptoms and known patterns of performance, such as better performance on difficult tasks than on easy tasks. In the mild TBI population, rates of failure on validity measures (or the confidence that the test is measuring a true concussion deficit versus intentional/unintentional artifact) can range from 17% to 58%,^{36,37} representing a significant portion of this population. Debate exists about the best approach to this patient population, in which measuring objective deficits and progress poses a true challenge, and concerns about secondary gain (emotional or financial, conscious or subconscious) can also be present. However, a functional approach to patient-centered goals, along with minimizing the perception of disability, is recommended by the VA/DoD CPG. Patients presenting with over-reporting of symptoms or invalid findings on objective testing must not routinely be discounted because the presentation may be subconscious or a “cry for help.” The CPG strategy offers a practical approach to challenging patients, and with buy-in and patient engagement in the rehabilitation process, realistic expectations can be set by the patient and the treatment team.

Comorbid psychological conditions are common after concussion, particularly in cases of combat-related concussion or a traumatic event such as assault or severe injury in an accident. Conditions range from adjustment disorder related to the changes in function after concussion, to frank depression, anxiety, or acute stress reaction/PTSD. Irritable mood can accompany any of these psychological conditions, and irritability can be worsened by poor sleep and aggravated by frontal lobe executive dysfunction. Therefore, early and ongoing monitoring for emotional and behavioral symptoms in the acute, post-acute, and chronic postconcussive periods are critical, as is ensuring appropriate referrals to address these symptoms, most commonly with cognitive behavioral therapy. Medication treatment is guided by the primary diagnosis and applicable CPGs for the condition. Of note, no medications have been approved by the Food and Drug Administration specifically for the treatment of postconcussive symptoms (behavioral or physical). The VA/DoD CPG states, “We recommend that the presence of psychological or behavioral symptoms following TBI should be evaluated and managed according to existing evidence based CPGs, and based upon individual factors and the nature and severity of symptoms.”⁵

Headaches attributed to traumatic injury to the head, by the International Classification of Headache

Disorders (3rd edition, beta version), are divided into acute (resolves within 3 months) and persistent (persists >3 months) conditions.³⁸ For mild TBI, headache onset must be within 7 days of the injury event or after discontinuation of medication that may impair the ability to sense the headache. Some experts expand this window to 30 days after the head injury event, and this longer timeframe was elected for use by the Defense Center of Excellence clinical recommendation for management of headache after concussion.³⁹ Headaches attributed to TBI may have a variety of clinical presentations. They can mimic any of the primary headache disorders, including (most often) migraine and tension type headaches, and (less often) neuralgic or other headache disorders. Secondary headache disorders unrelated to the concussion must also be considered (Exhibit 38-3 lists red flags for referral). Treatments, based upon the semiology of headache presentation, are the same as for the primary headache disorder.³⁹ With any chronic headache syndrome, caution should be used to avoid medication-overuse headaches (“rebound headache”), in which frequent analgesic use worsens the headache syndrome. If daily analgesics are required for a prolonged duration (more than a few weeks), consideration should be given to prophylactic headache therapy.

Studies have shown that 20% of patients with TBI and 47% of moderate brain injury patients complain of ongoing dizziness beyond 5 years post-injury.⁴⁰ Peterson⁴⁰ suggests that independent of severity or mechanism of injury, dizziness, migraine-associated dizziness, exercise-induced dizziness, spatial disorientation, and balance impairment⁴¹ are common complaints among TBI patients, with a rate between 30% and 80%. Patient descriptions of these problems can be challenging for diagnostic purposes; for example, patients may use the terms “woozy,” “light-headed,” “spacy,” or “feeling drunk.” The following four categories describing aspects of dizziness may be more useful to clinicians:

1. vertigo, the illusory sensation of motion;
2. visual disorientation, with complaints such as disorientation or nausea when walking down a supermarket aisle or being in a crowd, and motion sensitivity;
3. light-headedness, the symptom likened to those preceding syncope (a sensation just before fainting or loss of consciousness); and
4. imbalance, feelings of unsteadiness, or being prone to stumbling or falling.⁴²

Depending on the presentation and examination findings, additional consultation from neurology,

EXHIBIT 38-3

HEADACHE RED FLAGS AND INDICATIONS FOR REFERRAL

Red flags in evaluation of posttraumatic headaches for primary care providers to refer for emergency or specialty evaluation.

Indications for Emergency Referral

- Concussion red flags
- Thunderclap headache
- Sudden neurological deficit
- Persistent bleeding from nose, ears, or scalp
- Cranial fracture
- Infection resulting from a penetrating injury
- Cerebrospinal fluid leakage (nose or ears)
- Intracranial hemorrhage on CT

Indications for Specialty Referral

- Presence of systemic symptoms
- Associated neurological symptoms
- Onset after age 50
- Change in pattern of headache
- Valsalva precipitation
- Postural aggravation
- Papilledema
- TMJ disorder
- ENT disorder

CT: computed tomography
 TMJ: temporomandibular joint
 ENT: ear, nose, and throat
 Reproduced from: Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury. DCoE clinical recommendation, management of headache following concussion / mild traumatic brain injury: guidance for primary care management in deployed and non-deployed settings. <https://dvbic.dcoe.mil/material/management-headache-following-concussionmild-tbi-guidance-primary-care-management-deploye-0>. Published February 2016. Accessed May 24, 2018.

otolaryngology, audiology, or physical therapy may be indicated for complaints of vertigo, visual disorientation, or imbalance. For patients with lightheadedness, further evaluation for syncope or pre-syncope may be necessary, and autonomic dysfunction should be considered along with a cardiovascular evaluation. Along with balance and dizziness symptoms, tinnitus, peripheral hearing loss, or central auditory processing disorder may be present. Central auditory processing disorder, related to central nervous system disturbances can manifest as difficulties understanding what is heard, particularly in busy venues where multitasking or focused attention is required.⁴³

Visual function may also be affected after concussion, with accommodation disturbance and convergence insufficiency most commonly noted.^{44,45} As with the NSI symptoms, both of these conditions are seen in the general population but may become decompensated after concussion. Such visual disturbances may respond to treatments ranging from prescription lenses to vision rehabilitation in cases of prolonged symptoms.

Vignette 38-2. A 28-year-old male Special Forces soldier with 10 years' time-in-service and three prior combat deployments was evaluated after a fall while skiing during a training exercise with his unit. His last memory was riding up the chair lift. Witnesses reported that he had a bad landing after "catching air" while going over a small cliff, hit the back of his head, then rolled nearly 100 feet down the steep mountain. During the evaluation, which took place immediately, the soldier opened his eyes and moved all extremities normally, but was disoriented and asked the same questions repetitively. His GCS score was 14. Cervical spine precautions were put in place, and he was then evaluated emergently at a civilian hospital with both CT head and c-spine, which showed no acute findings.

However, he had ongoing musculoskeletal neck pain and headache and was given a week of convalescent leave to recover. Evaluation after the recovery week by his primary care physician noted ongoing symptoms of severe headaches with light sensitivity, sound sensitivity, nausea, and even occasional vomiting, especially with exertion. Progression of activity beyond stage 4 (moderate activity) was not successful even 3 weeks after the concussion, and the soldier became frustrated that he could not exercise to maintain his high level of fitness, nor perform his full work duties. Specifically, when he went to the gym, he was unable to lift weights and run as fast as he had previously, and he could not keep up with his Special Forces peers.

He was referred to the concussion/TBI clinic for further evaluation, where additional history revealed at least five prior concussions, including three prior blast concussions and two related to jumps, as well as a history of playing football in high school. In addition, he had significant blast exposures during a prior deployment in 2009, with hundreds of door breaches without definitive concussions, and he was involved in one ambush where three of his team members were killed in action. Recurrent nightmares and flashbacks were a common occurrence. However, he never reported or sought medical attention for previous symptoms; rather, he simply "soldiered on," performing well on his team until this recent injury.

Examination showed significant musculoskeletal tenderness in the paraspinal neck muscles and restricted range of motion secondary to pain, along with orthostatic tachycardia and convergence insufficiency. Magnetic resonance imaging (MRI) of the brain was normal, and MRI c-spine showed mild degenerative changes but was otherwise unremarkable. The soldier was referred for rehab services, including physical therapy to address the cervical symptoms, gradu-

ated return to exercise, optometry and occupational therapy for vision rehabilitation, and psychology to address his prior trauma as well as current adjustment to physical limitations. Cognitive rehabilitation for memory strategies as well as cognitive behavioral therapy for insomnia was provided to address memory and attention issues that were likely due to poor sleep, pain, and mood.

With these services, medications for his migrainous headaches, and better pacing of his activities, the soldier steadily improved, and 4 months after the ski accident he was able to return to full duty, using only abortive medications for rare headaches. After this experience, he also identified two team members who were also struggling with headaches and mood symptoms, prompting their evaluation and treatment, which resulted in the team becoming healthier and stronger for future missions.

Neuroimaging Beyond the Immediate Period

Neuroimaging is not required for the diagnosis of mild TBI, nor is it required for routine evaluation of mild TBI/concussion in all cases. In concussion, imaging is most often normal. Red flags should be used to guide the need for imaging in the immediate period after TBI, and the modality of choice during this time is a non-contrast CT head. Two common sets of criteria used to determine need for imaging in the immediate period are the New Orleans criteria⁴⁶ and the Canadian CT head rule.⁴⁷ The goal of imaging immediately after injury is to identify intracranial pathology that might require neurosurgical intervention or closer monitoring for intracranial bleeding that could increase and require urgent evacuation.

After the immediate period, the imaging modality of choice (if available and in the absence of contraindications) is MRI,⁴⁸ which is a more sensitive tool for detecting subtle structural lesions than CT head. The goals of imaging beyond the immediate period are to help understand persistent symptoms, guide specialist referral, and ensure accurate diagnosis if evaluation was delayed. MRI should include susceptibility weighted imaging/graded recall echo sequences, which are particularly sensitive for identifying areas of diffuse axonal injury or prior microhemorrhage.⁴⁸ Diffusion tensor imaging and functional MRI are modalities that hold promise for future use in subacute and chronic periods of TBI, but they are not yet widely available in routine clinical practice. Nuclear imaging studies such as positron emission tomography and single-photon emission computed tomography scans may be considered in cases where structural imaging is normal, but these modalities are best interpreted in a clinical context and in the setting of specialty neuroscience care.

RESEARCH AND FUTURE CONSIDERATIONS

The DoD research portfolio for TBI is gap-driven and tied to military requirements, meaning that funds are awarded based on the ability to study and answer military-specific research questions or develop a capability. This is different from the way in which most other federal research dollars are spent, such as through the National Institutes of Health (NIH), where the projects are investigator driven. The DoD currently has three general TBI focus areas: prevention (including blast and impact TBI), combat casualty care-related neurotrauma, and rehabilitation. The DoD also coordinates the TBI portfolio closely with the NIH and the VA, particularly in accordance with the National Research Action Plan (NRAP), as directed by a 2012 presidential executive order. Through the NRAP, federal agencies seek complementary, rather than overlapping, portfolios. The NRAP also seeks to maximize successful analysis of data from TBI studies

through a requirement to share all data from federally funded studies.

Priority areas within the DoD portfolio include longitudinal studies seeking to understand the progression of TBI and how the injury evolves over time. Point-of-injury screening, diagnosis, and monitoring capabilities are another military focus area. Devices capable of determining at the point of injury whether a closed head injury has resulted in bleeding, equivalent to a positive CT scan, are of particular interest and applicability to battlefield medicine; two devices were recently approved by the Food and Drug Administration for this indication. Simultaneously, the DoD is seeking to better understand the forces (blast or impact) associated with TBI and subclinical exposure to PCEs. The goal of this portfolio is to reduce exposure by modifying tactics, techniques, procedures, and equipment for tasks that put SMs at risk for a potential injury.

SUMMARY

The general management and rehabilitation of patients with TBI has evolved into a process of prevention, immediate identification and assessment, early education, graduated return to activity, and, for those with prolonged symptoms, an interdisciplinary evaluation coupled with progressive and targeted rehabilitation. Even in cases of mild TBI, care has progressed from limited if any treatment, to comprehensive evaluation with progressive advancement in physical and cognitive exertion, with the goal of full reintegration and return to duty.

The treatment model has advanced from limiting the severity of symptoms of the injury itself, to individualized rehabilitation based on each person's presentation, unique strengths, and comorbidities. A person's psychological, genetic, and physical traits cannot be uncoupled from the injury and its effects. Research on all aspects of TBI has increased since the conflicts in Iraq and Afghanistan began, and it has shaped the way care is provided. Ongoing research and clinical efforts will continue to benefit SMs and veterans in the future.

REFERENCES

1. Sahlas D. Functional neuroanatomy in the pre-hippocratic era: observations from the Iliad by Homer. *Neurosurgery*. 2001;48(6):1352–1357.
2. Defense and Veterans Brain Injury Center. DoD numbers for traumatic brain injury worldwide, totals, 2000–2017. http://dvbic.dcoe.mil/files/tbi-numbers/worldwide-totals-2000-2017_feb-14-2018_v1.0_2018-03-08.pdf. Accessed May 24, 2018.
3. US Department of Defense. *DoD Policy Guidance for Management of Mild Traumatic Brain Injury/Concussion in the Deployed Setting*. Washington, DC: DoD; 2012. DoD Instruction 6490.11. <http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/649011p.pdf>. Accessed August 23, 2018.
4. Woodson J. *Traumatic Brain Injury: Updated Definition and Reporting*. Washington, DC: US Department of Defense; 2015.
5. US Department of Veterans Affairs. *VA/DoD Clinical Practice Guideline: Management of Concussion-mild Traumatic Brain Injury (mTBI) (2016)*. <https://www.healthquality.va.gov/guidelines/Rehab/mtbi/>. Accessed May 23, 2018.
6. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51:838–847.

7. Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury. Progressive return to activity following concussion/mild traumatic brain injury. DCoE clinical recommendation. https://dvbic.dcoe.mil/files/resources/2013_PRA_Rehab_CR_FINAL.pdf. Published January 2014. Accessed May 24, 2018.
8. Kontos AP, Collins MW, Holland CL. Preliminary evidence for improvement in symptoms, cognitive, vestibular, and oculomotor outcomes following targeted intervention with chronic mTBI patients. *Mil Med*. 2018;183(suppl 1):333–338. doi: 10.1093/milmed/usx172.
9. Regasa LE, Thomas DM, Gill RS, Marion DW, Ivins BJ. Military deployment may increase the risk for traumatic brain injury following deployment. *J Head Trauma Rehabil*. 2016;31(1):E28–35.
10. Williams VF, Stahlman S, Hunt DJ, O'Donnell, FL. Diagnoses of traumatic brain injury not clearly associated with deployment, active component, US armed forces, 2001–2016. *MSMR*. 2017; 4(3):2–8.
11. Centers for Disease Control and Prevention. Annual number of TBIs. https://www.cdc.gov/traumaticbraininjury/pdf/tbi_blue_book_annualnumber.pdf. Accessed August 23, 2018.
12. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75:S24–S33.
13. Shorland Travax website. <https://www.travax.com>. Accessed May 24, 2018.
14. Eastridge BJ, Mabry RL, Seguin P, et al. Death on the battlefield (2001-2011): implications for the future of combat casualty care. *J Trauma Acute Care Surg*. 2012;73(6 Suppl 5):S431–S437.
15. Spaite DW, Hu C, Bobrow BJ, et al. Association of out-of-hospital hypotension depth and duration with traumatic brain injury mortality. *Ann Emerg Med*. 2017;70:522–530.
16. Proctor JL, Mello KT, Fang R, et al. Aeromedical evacuation-relevant hypobaric worsens axonal and neurologic injury in rats after underbody blast induced hyperacceleration. *J Trauma Acute Care Surg*. 2017;83(1 Suppl1):S35–S42.
17. Scultetus AH, Hague A, Chun SJ, et al. Brain hypoxia is exacerbated in hypobaric during aeromedical evacuation in swine with traumatic brain injury. *J Trauma Acute Care Surg*. 2016;81(1):101–107.
18. Goodman MD, Makley AT, Lentsch, et al. traumatic brain injury and aeromedical evacuation: when is the brain fit to fly? *J Surg Res*. 2010;164(2):286–293.
19. US Army. Traumatic brain injury. https://www.army.mil/standto/archive_2015-03-02. Published March 2, 2015. Accessed August 23, 2018.
20. American Association for Justice. State concussion laws. <https://www.justice.org/state-concussion-laws>. Accessed May 24, 2018.
21. Ponsford J, Willmott C, Rothwell A, et al. Impact of early intervention on outcome following mild head injury in adults. *J Neurol Neurosurg Psychiatry*. 2002;73:330–332.
22. King PR, Donnelly KT, Donnelly JP, et al. Psychometric study of the Neurobehavioral Symptom Inventory. *J Rehabil Res Dev*. 2012;49(6):879-88.
23. Sullivan KA, Lurie JK. Principal components analysis of the Neurobehavioral Symptom Inventory in a nonclinical civilian sample. *Appl Neuropsychol Adult*. 2017;24:522–531.
24. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport, held in Zurich, November 2008. *J Clin Neurosci*. 2009;16:755–763.
25. Thomas DG, Apps HN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: a randomized controlled trial. *Pediatrics*. 2015;135(2):213–223.
26. Schwab K, Terrio HP, Brenner LA, et al. Epidemiology and prognosis of mild traumatic brain injury in returning soldiers: a cohort study. *Neurology*. 2017;88(16):1571–1579.

27. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA*. 2003;290(19):2549–2555.
28. Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology*. 2013;80:2250–2257.
29. Benedict PA, Baner NV, Harrold GK, et al. Gender and age predict outcomes of cognitive, balance, and vision in a multidisciplinary concussion center. *J Neurol Sci*. 2015;353(1-2):111–115.
30. Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. *Br J Sports Med*. 2017;51(12):941–948.
31. Hoge CW, McGurk D, Thomas JL, Cox AL, Engel CC, Castro CA. Mild traumatic brain injury in US soldiers returning from Iraq. *N Engl J Med*. 2008;358:453–463.
32. Carlson KF, Kehle SM, Meis LA, et al. Prevalence, assessment, and treatment of mild traumatic brain injury and post-traumatic stress disorder: a systematic review of the evidence. *J Head Trauma Rehabil*. 2011;26(2):103–115.
33. Mathias JL, Alvaro PK. Prevalence of sleep disturbances, disorders, and problems following traumatic brain injury: A meta-analysis. *Sleep Med*. 2012;13:898–905.
34. Wilde MC, Castriotta RJ, Lai JM, Atanasov S, Masel BE, Kuna ST. Cognitive impairment in patients with traumatic brain injury and obstructive sleep apnea. *Arch Phys Med Rehabil*. 2007;88:1284–1288.
35. Wickwire EM, Williams SG, Roth T, et al. Sleep, sleep disorders and mild traumatic brain injury. What we know and what we need to know: Findings from a national working group. *Neurotherapeutics*. 2016;13(2):403–417.
36. Armistead-Jehle P. Symptom validity test performance in US veterans referred for evaluation of mild TBI. *Appl Neuropsychol*. 2010;17:52–59.
37. Whitney AW, Shepard PH, Whilliams AL, Davis JJ, Adams KJ. The Medical Symptoms Validity Test in the evaluation of Operation Iraqi Freedom-Operation Enduring Freedom soldiers: A preliminary study. *Arch Clin Neuropsychol*. 2009;24:145–152.
38. International Headache Society. International Classification of Headache Disorders, 3rd edition, beta version. <https://www.ichd-3.org/>. Accessed August 23, 2018.
39. Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury. DCoE clinical recommendation, management of headache following concussion/mild traumatic brain injury: guidance for primary care management in deployed and non-deployed settings. <https://dvbic.dcoe.mil/material/management-headache-following-concussionmild-tbi-guidance-primary-care-management-deploye-0>. Published February 2016. Accessed May 24, 2018.
40. Peterson MD. A case-oriented approach exploring the relationship between visual and vestibular disturbances and problems of higher-level mobility in persons with traumatic brain injury. *J Head Trauma Rehabil*. 2010;25(3):193–205.
41. Gottshall K. Vestibular rehabilitation after mild traumatic brain injury with vestibular pathology. *NeuroRehabilitation*. 2011;29(2):167–171.
42. Gizzi M, Rosenberg ML. The diagnostic approach to the dizzy patient. *Neurologist*. 1998;4(3):138.
43. Fausti SA, Wilmington DJ, Gallun FJ, Meyers PJ and Henry JA. Auditory and vestibular dysfunction associated with blast-related traumatic brain injury. *J Rehabil Res Dev*. 2009;46(6):797–810.
44. Barnett BP, Singman EL. Vision concerns after mild traumatic brain injury. *Curr Treat Options Neurol*. 2015;17(2):329.
45. Pearce KL, Sufrinko A, Lau BC, Henry L, Collins MW, Kontos AP. Near point of convergence after a sport-related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. *Am J Sports Med*. 2015;43(12):3055–3061.

46. Haydel M, Preston CA, Mills TJ, Luber S, Blaudeau E, DeBlieux PM. Indications for computed tomography in patients with minor head injury. *N Engl J Med.* 2000;343(2):100–105.
47. Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet.* 2001;357:1391–1396.
48. Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury. DCoE clinical recommendation, neuroimaging following mild traumatic brain injury in the non-deployed setting. <https://dvbic.dcoe.mil/material/neuroimaging-following-mild-tbi-non-deployed-setting-clinical-recommendation>. Published July 2013. Accessed May 24, 2018.

