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The Mayo Classification System for Traumatic Brain Injury Severity

JAMES F. MALEC,[1] ALLEN W. BROWN,[2] CYNTHIA L. LEIBSON,[3] JULIE TESTA FLAADA,[1] JAYAWANT N. MANDREKAR,[4] NANCY N. DIEHL,[1] and PATRICIA K. PERKINS[3]

ABSTRACT

Purpose: To develop a single TBI severity classification system based on commonly used TBI severity measures and indicators that (1) maximally uses available positive evidence to classify TBI severity in three categories: (a) Moderate-Severe (Definite) TBI, (b) Mild (Probable) TBI, (c) Symptomatic (Possible) TBI; (2) reflects current clinical knowledge and relevance; and (3) classifies a larger number of cases than single indicator systems with reasonable accuracy. Main Findings: The study sample of a defined population consisted of 1501 unique Olmsted County residents with at least one confirmed TBI event from 1985 to 1999. Within the sample, 1678 TBI events were confirmed. Single measures of TBI severity were not available in a large percentage of these events, i.e., Glasgow Coma Scale (GCS) was absent in 1242 (74.0%); loss of consciousness, absent in 178 (70.2%), post-traumatic amnesia (PTA), absent in 974 (58.1%), head CT, not done in 827 (49.3%). The Mayo Classification System for TBI Severity was developed to classify cases based on available indicators that included death due to TBI, trauma-related neuroimaging abnormalities, GCS, PTA, loss of consciousness and specified post-concussive symptoms. Using the Mayo system, all cases were classified. For the Moderate-Severe (Definite) TBI classification, estimated sensitivity was 89% and estimated specificity was 98%. Conclusions: By maximally using relevant available positive evidence, the Mayo system classifies a larger number of cases than single indicator systems with reasonable accuracy. This system may be of use in retrospective research and for determination of TBI severity for planning postacute clinical care.

Key words: brain injury, classification

INTRODUCTION

SEVERITY CLASSIFICATION in traumatic brain injury (TBI) has been of longstanding interest because of its relationship to acute and postacute medical care and outcome (Cifu et al., 1997; Crepeau and Scherzer, 1993; Ezrachi, 1991; Levin, 1995). In most research studies and often in clinical care, TBI severity is classified according to single indicators such as the Glasgow Coma Scale (GCS), duration of post-traumatic amnesia (PTA), and duration of loss of consciousness (LOC). Although the predictive validity of these measures is well-established (Klonoff et al., 1986; Levin et al., 1979, 1990; Wilson et al., 1991; Brown et al., 2005; Carlsson et al., 1968; Whyte et al., 2001; Brooks and McKinlay, 1983; Dikmen et al., 1990; Sherer et al., 2002), each may be influenced by

Departments of [1]Psychiatry and Psychology, [2]Physical Medicine and Rehabilitation, [3]Epidemiology, [4]Biostatistics, Mayo Clinic College of Medicine, Rochester, Minnesota.

factors unrelated or indirectly related to the severity of TBI. With the advent of roadside sedation, concern has been raised about the effect of early sedation on initial GCS scores (Zafonte et al., 1996). Intoxication at the time of injury also suppresses GCS (Kelly et al., 1997). Systemic or psychologic shock as well as organ system failure and fractures associated with polytrauma can extend PTA and may affect acute assessment of GCS and LOC. Time post-injury when the GCS is recorded may affect the score; however, time of measurement is often not routinely noted in the medical record. Unless specifically collected as part of a standardized clinical or research protocol, one or more of these injury severity indicators is often not recorded in the patient's medical record. Neuroimaging furnishes a directly observable anatomical indicator of TBI severity but is not obtained in all cases, particularly for patients who appear on initial examination to have milder injuries, are not hospitalized, or do not receive immediate medical attention.

The vast majority of TBIs are not severe. Therefore, a TBI severity classification system should distinguish clinical characteristics of the least as well as the most severe injuries. TBI may be present in cases in which none of the indicators previously reviewed are recorded. Such cases typically come to clinical attention when a patient with a history of head trauma reports "postconcussive" symptoms such as feeling dazed, dizziness, headache, or nausea (Evans, 2006; Malec, 1999). Neuroimaging techniques—such as magnetic resonance imaging (MRI), positron emission tomography (PET), and tensor imaging—may assist in diagnosis by revealing lesions that are not identified by standard screening computed tomography (CT) scan. However, these more advanced imaging modalities are also commonly normal after less severe injury. An additional consideration in interpreting "postconcussive" symptoms is that these symptoms are not specific to TBI.

Considering the unreliability of some TBI severity indicators and the frequency of missing documentation in the medical record, we sought to develop a system for severity classification that capitalizes on positive evidence available within the medical record for each case. A focus on positive evidence was expected to increase reliability of the classification system. For instance, the absence of notation about loss of consciousness may indicate that loss of consciousness did not occur, was brief, or was significant but not recorded. Rather than use the absence of information about loss of consciousness as an indication of less severe injury, the proposed classification defers to other available positive indicators. Conversely, documentation of extended loss of consciousness provides substantial evidence of a Moderate-Severe TBI even in the absence of other evidence. The classification system described in this paper is conservative in that positive evidence is required for categorization at each level of TBI severity and more objective evidence is required for classifications of increasing severity.

The proposed system may be of value in classifying TBI severity in retrospective research studies as well as estimating injury severity in cases presenting postacutely for medical or rehabilitation care. The primary objectives of this project were to incorporate commonly used TBI severity measures and indicators to develop a single system that (1) maximally uses available positive evidence to classify TBI severity in three categories: (a) Moderate-Severe (Definite) TBI, (b) Mild (Probable) TBI, (c) Symptomatic (Possible) TBI; (2) reflects current clinical knowledge and relevance; and (3) classifies a larger number of cases than single indicator systems with reasonable accuracy.

METHODS

Study Setting

Development of this classification system occurred as part of population-based studies of TBI incidence and survival in Olmsted County, Minnesota. These studies were approved by the Mayo Clinic and the Olmsted Medical Center Institutional Review Boards. Olmsted County (2000 census population, 124,277) provides a unique opportunity for investigating the natural history of TBI (Annegers and Coan, 2000; Annegers et al., 1980a,b, 1998; Brown et al., 2004; Nemetz et al., 1999). Rochester, the County seat, is approximately 80 miles from the nearest major metropolitan area and is home to one of the world's largest private medical centers, the Mayo Clinic. The Mayo Clinic and its two affiliated hospitals and the Olmsted Medical Center, a second group practice, and its affiliated hospital provide essentially all of the medical care delivered to local residents. Since 1907, every Mayo Clinic patient has been assigned a unique identifier, and all information from every contact (including emergency department, hospital, nursing home, and office and other outpatient encounters) is contained within a single dossier for each patient. The detailed information includes medical history, clinical assessments, consultation reports, surgical procedures, dismissal summaries, laboratory and radiology results, correspondence, and death certificates. Diagnoses assigned at each visit are coded and entered into continuously updated computer files. Under the auspices of the Rochester Epidemiology Project (REP), the diagnostic index and records linkage system were expanded to include the few other providers of medical care to local residents, including the Olmsted Medical Center. The result is the linkage of all inpatient and outpa-

tient medical records from all sources of medical care available to and utilized by members of a geographically defined population (Melton, 1996). The REP provides the capability for population-based studies of disease risk factors and outcomes that is unique in the United States.

Case Definition and Identification

The present study was limited to the most recent update of the REP TBI cohort, i.e., events that occurred from January 1, 1985 through December 31, 1999. As a first step in constructing this cohort, the REP diagnostic index was used to generate a list consisting of all Olmsted County residents with any diagnosis suggestive of TBI. The list of potential cases consisted of 45,791 unique individuals. A 17.0% random sample ($n = 7800$) was selected for review of their complete community-based medical records from date first seen until date last seen by any REP provider. The record review was conducted to confirm the diagnosis and characterize confirmed events. Trained nurse abstractors under the direction of a board-certified physiatrist (A.B.) and neuropsychologist (J.M.) performed the review.

TBI was defined as a traumatically induced injury that contributed to physiological disruption of brain function. Confirmed events were those for which there was documentation of any of the following: concussion with LOC, traumatic amnesia (either retrograde or anterograde); neurological signs of brain injury including impact seizures or seizures due to the TBI, evidence of intracerebral, subdural, or epidural hematoma, cerebral or hemorrhagic contusion, or brain stem injury; penetrating brain injury; skull fracture; leakage of cerebrospinal fluid; or specified post-concussive symptoms (i.e., dizziness, confusion, blurred vision, double vision, headache, nausea, or vomiting that lasted greater than 30 min and that was not attributable to pre-existing or co-morbid conditions). Individuals for whom the clinical diagnosis was based on history alone (i.e., who did not present for medical care for either the event or for sequelae) were not considered as cases. Applying these criteria in the review of the sample of 7800 individuals with any diagnosis suggestive of TBI resulted in the identification of 1501 unique individuals who experienced a total of 1678 confirmed events.

Development of the Mayo Classification System for TBI Severity

All confirmed events were further characterized by severity using all available clinical data including emergency room, hospital, and office visit notes, radiological imaging findings, surgical records, and autopsy results. Initial review of available data showed that impact seizure, seizure related to TBI, brain surgery, infections occurring with TBI, hydrocephaly, and leakage of cerebral spinal fluid provided no unique information regarding TBI severity. In all cases, these variables were associated with other more common (e.g., hemorrhage, contusion) indications of Moderate-Severe TBI. Consequently these variables were eliminated from the classification system. Retrograde amnesia did not add information to descriptions of anterograde amnesia, i.e., PTA. Furthermore, review of specific records suggested that estimates of retrograde amnesia were less reliable than estimates of PTA. Therefore, retrograde amnesia was also eliminated from the system. Following this initial refinement of the classification system, criteria described in Table 1 were applied to the 1678 identified occurrences

Table 1. Mayo TBI Severity Classification System

A. Classify as Moderate-Severe (Definite) TBI if one or more of the following criteria apply:
   1. Death due to this TBI
   2. Loss of consciousness of 30 minutes or more
   3. Post-traumatic anterograde amnesia of 24 hours or more
   4. Worst Glasgow Coma Scale full score in first 24 hours <13 (unless invalidataed upon review, e.g., attributable to intoxication, sedation, systemic shock)
   5. One or more of the following present:
      - Intracerebral hematoma
      - Subdural hematoma
      - Epidural hematoma
      - Cerebral contusion
      - Hemorrhagic contusion
      - Penetrating TBI (dura penetrated)
      - Subarachnoid hemorrhage
      - Brain Stem Injury

B. If none of Criteria A apply, classify as Mild (Probable) TBI if one or more of the following criteria apply:
   1. Loss of consciousness of momentary to less than 30 minutes
   2. Post-traumatic anterograde amnesia of momentary to less than 24 hours
   3. Depressed, basilar or linear skull fracture (dura intact)

C. If none of Criteria A or B apply, classify as Symptomatic (Possible) TBI if one or more of the following symptoms are present:
   - Blurred vision
   - Confusion (mental state changes)
   - Dazed
   - Dizziness
   - Focal neurologic symptoms
   - Headache
   - Nausea

TBI, traumatic brain injury.

to categorize them at one of three levels of injury severity and probability: (1) Moderate-Severe (Definite) TBI; (2) Mild (Probable) TBI; (3) Symptomatic (Possible) TBI.

Measures and Indicators

Death due to TBI. Cause of death was determined by review of the medical record and death certificate if available. "Death due to TBI" was recorded only in cases in which other causes of death were excluded.

TBI-related intracranial abnormality. The classic study by Williams and associates demonstrated that the presence of intracranial abnormalities on head CT scan indicate a more severe injury than may be signified by the GCS alone (Williams et al., 1990). In their study, the outcomes for survivors of TBI with GCS of 13 or greater who had abnormal head CT scans were more like those with moderate injuries than those with clearly mild injuries. Others (Marshall et al., 1992; Uzzell et al., 1987) have also provided evidence of the value of CT scan in the TBI classification and prognostication. In the current project, the presence of a trauma-related intracranial abnormalities (in a few cases abnormalities unrelated to TBI, e.g., occult tumor, were observed) on CT scan was considered to indicate TBI of at least moderate severity or clinically definite TBI.

Glasgow Coma Scale. The relationship of GCS to TBI outcome has been well-documented in the previous literature (Klonoff et al., 1986; Levin et al., 1979, 1990; Wilson et al., 1991). A score of 13–15 on the GCS is considered to indicate Mild TBI; 9–12 Moderate; and 3–8 Severe (Rimel et al., 1982).

Loss of consciousness. While GCS characterizes the depth of disturbance of consciousness, the length of time that a patient is unreliably responsive has also traditionally been used as an indicator of TBI severity. LOC, usually characterized as time from injury until the patient is able to reliably follow commands, correlates with cognitive and functional measures of outcome (Brown et al., 2005; Carlsson et al., 1968; Whyte et al., 2001). Unconsciousness of 30 min or less has typically been used to define Mild TBI (Evans, 2006; Kay et al., 1993) with greater duration indicating TBI of increasing severity.

Post-traumatic amnesia. Duration of PTA as an indicator of TBI severity and its relationship to outcome has also been well documented in previous studies (Brooks and McKinlay, 1983; Brown et al., 2005; Dikmen et al., 1990; Sherer et al., 2002). For the current project, we followed the clinical tradition, adopted formally by the American Congress of Rehabilitation Medicine definition of Mild TBI (Kay et al., 1993), and classified subjects with PTA of less than 24 h as Mild and those with PTA greater than 24 h as Moderate-Severe.

Skull fracture. Skull fracture may be an indicator of more severe injury and is frequently associated with the development of intracranial hematoma (Graham et al., 2006; Mendelow et al., 1983). In the absence of any other indication of Moderate-Severe TBI, the presence of linear or depressed skull fracture with dura intact and no intracranial abnormality was considered to indicate a Mild TBI.

"Postconcussive" symptoms. Symptoms that include blurred vision, temporary confusion, feeling dazed, dizziness, focal neurologic symptoms, headache, or nausea may signify at least Mild TBI even in the absence of any other indication of brain injury (Evans, 2006; Malec, 1999). On the other hand, none of these symptoms are specific to TBI. For this reason, we classified occurrences in which the only recorded evidence of possible brain injury was one or more specified "postconcussive" symptoms as *Symptomatic* (*Possible*) *TBI* to imply the possibility but not the certainty of Mild TBI.

Subjects

The sample consisting of 1501 unique Olmsted County residents with at least one confirmed event 1985–1999 included 833 (55.5%) males and 668 (44.5%) females with an age range of less than one month to 102.5 years (mean = 27.7 years; SD = 22.1 years).

RESULTS

Absence of Positive Evidence

The classification system was based on the presence of positive evidence of injury severity. Documentation of specific single injury severity indicators was not available in the majority of cases. Of the 1678 confirmed events, GCS was not rated in 1242 (74.0%). LOC was either not present or not recorded in 1178 (70.2%). PTA was not present or not recorded in 974 (58.1%). Head CT was not done in 827 (49.3%).

Classification

The classification criteria described in Table 1 were applied to the 1678 identified events. This process resulted in the classification of 139 occurrences as Moderate-Severe (Definite) TBI, 633 occurrences as Mild (Probable) TBI, and 906 occurrences as Symptomatic (Possible) TBI (Fig. 1). Table 2 compares classification

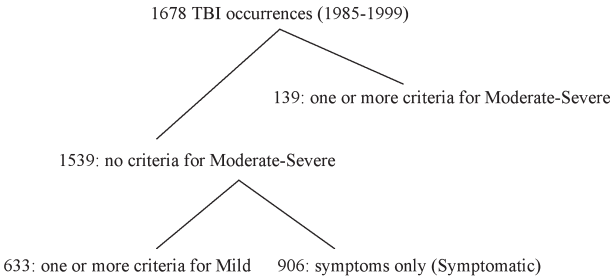

FIG. 1. Classification of 1,678 occurrences of TBI with Mayo TBI severity system.

using the Mayo system with classification using GCS alone, PTA alone, or LOC alone. The percentage of Moderate-Severe cases among the total cases classified is very similar although a slight bias toward recording LOC and PTA in more severe cases may be evident. The most apparent differences between the Mayo system and the single indicator classification schemes are (1) the large number of cases which are unclassified because GCS, PTA or LOC is absent, and (2) the lack of a method to distinguish probable from possible brain trauma among milder cases using these single indicators.

Reliability of Moderate-Severe Classification

Using the Mayo system, most occurrences of Moderate-Severe TBI could be classified on the basis of Death due to TBI or the presence of TBI-related neuroimaging abnormalities. Death due to TBI (Criterion A1) accounted for 38 of the 139 Moderate-Severe occurrences (27.3%). Trauma-related intracranial abnormalities on CT scan (Criterion A5) accounted for 84 (60.4%) additional occurrences. In 33 of these 84 occurrences intracranial abnormalities was associated with one or more of Criteria A2, A3, or A4. However, in 51, the classification was made on the basis of Criterion A5 alone. In these occurrences, information relevant to other criteria was negative or missing.

Of the remaining 17 occurrences (12.2%) classified as Moderate-Severe in which neuroimaging information was either negative or missing, three met two or three of criteria A2–A4. Of the remaining 14, eight were classified on the basis of loss of consciousness (A2) alone; three on Glasgow Coma Scale (A4) alone; and three on PTA (A3) alone.

Estimated false positives. Death due to TBI is perhaps the most incontrovertible evidence of severe brain injury. Although the presence of intracranial abnormalities evident on a CT scan may represent a range of injury severity, it seems reasonable to conclude that trauma significant enough to cause such radiographic findings represents an injury of at least moderate severity or a clinically definite TBI. Of the 139 subjects classified as Moderate-Severe, 125 were classified on the basis of death, CT abnormality, or at least two of the other criteria. Fourteen others were classified on the basis of only one from among the GCS, PTA, or LOC criteria. These 14 have the potential to be false positive classifications for Moderate-Severe TBI.

Estimated false negatives. CT scan was not done in 160 of the 633 Mild occurrences. There is potential for some of these to be false negative classifications, that is, these occurrences may have met Criterion A5 for Moderate-Severe injury if the CT scan had been done. CT scan was done and negative for intracranial injury in an additional 472 occurrences classified as Mild. 51 events were classified as Moderate-Severe on the basis of positive CT scan only with no other indication of Moderate-Severe TBI. Thus CT scan was positive for intracranial injury in 51 of 523 (51 + 472) or 9.7% of occurrences in which a CT scan was done and there was no other evidence of Moderate-Severe injury. Applying this estimation to the 160 occurrences classified as Mild in which CT scan was not done suggests that about 10% or 16 may have had a positive CT scan if the scan been performed.

TABLE 2. COMPARISON OF MAYO CLASSIFICATION SYSTEM WITH CLASSIFICATION BY GCS, PTA, OR LOC ALONE

	GCS	*PTA*	*LOC*	*Mayo*
Moderate-severe	<13 = 38 (8.8% of classified)	>24 h = 71 (10.1% of classified)	>30 min = 74 (14.8% of classified)	139 (8.3% of classified)
Mild	>12 = 395 (91.2% of classified)	<24 h = 633 (89.9% of classified)	<30 min = 426 (85.2% of classified)	633 (37.7% of classified)
Symptomatic				906 (54.0% of classified)
Total classified	433	704	500	1678
Total unclassified	1245	974	1178	0

GCS, Glasgow Coma Scale; PTA, post-traumatic amnesia; LOC, loss of consciousness.

These 16 are potentially false negatives for Moderate-Severe TBI classification. Table 3 presents these contrasts between actual and estimated Moderate-Severe and Mild classifications.

Sensitivity, specificity, and accuracy estimates. It is not possible to calculate sensitivity and specificity of the Mayo system with precision in the absence of a *gold standard* for TBI severity. PTA, GCS, or LOC have all been used as the *gold standard* for TBI severity in previous research. However, as reviewed in the introduction to this paper, factors other than brain trauma may limit the accuracy of these indicators. In the absence of an established *gold standard*, approximate values for sensitivity and specificity were computed using estimates of false negative and false positive rates described previously. Results (Table 3) suggest that, for the Moderate-Severe classification, sensitivity is approximately 89% (125/141), specificity is approximately 98% (617/631), and accuracy is approximately 96% (125 + 617 = 742/772).

Reliability of Mild and Symptomatic Head Injury Classifications

Of the 633 cases classified as Mild, 389 (61.5%) met more than one criteria. Eleven (1.7%) were classified as Mild based only on the presence of LOC of 30 minutes or less (B1); 197 (31.1%) only on the presence of PTA less than 24 h (B2); and 36 (5.7%) on the single criterion of skull fracture without intracranial injury (B3). Once the Moderate-Severe group is identified, it is reasonable to classify those remaining who meet one or more of Criteria B1 to B3 as having sustained brain trauma of Mild severity or clinically probable TBI. Therefore, in the Mild classification, the potential for false positives seems low. However, the potential for false negatives is much higher. Arguably any of the 904 presenting with "postconcussive" symptoms only or the 14 potential false positives for Moderate-Severe injury could be false negatives for Mild TBI.

DISCUSSION

A large percentage of missing values and indicators characterizes the medical records of many episodes of emergency and acute care for TBI. This was clearly the case in our review of records for patients seen for TBI in Olmsted County from 1985 through 1999. For reasons reviewed in the introduction to this paper, single indicators of injury severity (e.g., GCS, PTA, LOC) may be unreliable. These considerations encouraged the development of a classification system for TBI severity that capitalizes on available positive evidence to provide a gross determination of injury severity. The Mayo system has considerable construct validity since it is based on indicators which each have an established relationship to TBI severity. Comparison with classification based on traditional measures (i.e., GCS, PTA, LOC) shows that the percentage of cases characterized as Moderate-Severe with these traditional measures is very similar to the percentage identified with the Mayo system (Table 2). However, the Mayo system allows for the classification of a much larger percentage of cases. In the absence of a *gold standard*, it is not possible to determine sensitivity and specificity of the Mayo system with precision. Nonetheless our initial attempt to approximate sensitivity, specificity and accuracy of the Moderate-Severe classification suggests that these values are satisfactory for that classification.

The Mayo system was structured to conservatively reflect the severity of brain trauma based on the strength of available evidence. Cases of Moderate-Severe injury are those with relatively strong evidence of definite brain trauma. Mild cases are those with weaker evidence of probable TBI. Symptomatic cases are those with only equivocal documented evidence of the occurrence of possible TBI.

The standard for prospective research in which TBI severity is a considered factor must be the rigorous and consistent application of clearly defined injury severity criteria to each studied case. In prospective research, finer gradations of severity may be appropriately investigated

Table 3. Estimated True and False Negative and Positive Classifications for Moderate-Severe Classification

	Estimated Moderate-Severe	*Estimated Mild*	*Total*
Actual Mayo Moderate-severe Classification	125 probably true positives for Moderate-Severe	14 possible false positives for Moderate-Severe	139
Actual Mayo Mild Classification	16 possible false negatives for Moderate-Severe	617 probable true negatives for Moderate-Severe	633
	141	631	772

than are provided by the Mayo system. In contrast, retrospective research is often compromised by missing injury severity values and indicators. In this type of research, the Mayo system should be of value to describe study subjects.

The Mayo system may also be useful in postacute clinical evaluations of patients with TBI. The broad distinction between Mild and Moderate-Severe typically provides sufficient information for initial postacute medical and rehabilitation triage. The additional distinction provided by the Mayo system between those with clearer evidence of probable Mild brain trauma and those for whom the recorded evidence of possible brain trauma is limited to a defined set of "postconcussive" symptoms (i.e., Symptomatic TBI) should be useful in considering options for clinical treatment and management. In clinical evaluations, patients, and if available, their significant others are routinely queried about the occurrence of unconsciousness, amnesia or other change in mental status following head injury. The absence of any of these indicators of brain trauma raises strong suspicion that reported symptoms are due to other factors. The distinction between Mild (Probable) TBI and Symptomatic (Possible) TBI becomes particularly relevant considering that over 90% of cases fall into one of these two categories.

In summary, the Mayo Classification System for TBI Severity reflects current clinical knowledge to provide a single method for classification of TBI severity in three categories: (a) Moderate-Severe (Definite) TBI, (b) Mild (Probable) TBI, and (c) Symptomatic (Possible) TBI. By maximally using relevant available positive evidence, the Mayo system classifies a larger number of cases than single indicator systems. Comparisons with traditional single measure systems and approximate calculations of sensitivity and specificity suggest that the Mayo system accomplishes this classification with reasonable accuracy.

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Address reprint requests to:
James F. Malec, Ph.D.
Tertiary Psychiatry and Psychology
Mayo Clinic College of Medicine
Rochester, MN 55901

E-mail: malec.james@mayo.edu