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Diagnostic Value of the Glasgow Coma Scale for Traumatic Brain Injury in 18,002 Patients with Severe Multiple Injuries

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Abstract

Although patients with severe multiple injuries may have other reasons for unconsciousness, traumatic brain injury (TBI) in these patients is frequently defined by the Glasgow Coma Scale (GCS). Nevertheless, the diagnostic value of GCS for severe TBI in the multiple-injured patient is unknown. Therefore, we investigated the diagnostic value of GCS to identify severe TBI in multiple-injured patients. The records of 18,002 severely injured adult (ISS >16) patients from the Trauma Register of the German Society for Trauma Surgery were analyzed and initial GCS and Abbreviated Injury Scale $_{head}$ (AIS_{head}) were recorded. A severe TBI was defined by an $AIS_{head} \geq 3$. On the other hand, unconsciousness was defined by an initial GCS ≤ 8. By these criteria, 6546 patients (36.3%) were unconscious, and 8746 patients (48.6%) had severe TBI. Nine percent of all cases ($n=1643$) had a GCS ≤ 8 without severe TBI. Only 56.1% of patients with severe TBI ($n=4903$) had been unconscious. Decreasing levels of unconsciousness (as defined by GCS) showed consistent rising prevalence of severe TBI (correlation coefficient $r=-0.52$). Approximately 20% of all multiple-injured patients arriving in the emergency department with an initial GCS of 15 had severe TBI ($AIS_{head} \geq 3$). The diagnostic value of GCS ≤ 8 for severe TBI in patients with multiple injuries has low sensitivity (56.1%) but higher specificity (82.2%). Our study indicates that the GCS (as defined ≤ 8) in unconsciousness patients with multiple injuries shows only a moderate correlation with the diagnosis of severe TBI. Nevertheless, the main reason for unconsciousness in patients with multiple injuries is TBI, since only 9% of these patients had another reason for unconsciousness. However, due to the poor sensitivity of GCS, we suggest the use of the anatomical scoring system with $AIS_{head} \geq 3$ to define severe TBI in patients with multiple injuries.

Key words: Abbreviated Injury Scale; Glasgow Coma Scale; Injury Severity Score; multiple trauma; traumatic brain injury; unconsciousness

Introduction

Various definitions and classifications of traumatic brain injury (TBI) have been published. In 1974 the Glasgow Coma Scale (GCS), based on clinical observations, was developed and used as a functional scale for the assessment of coma and impaired consciousness (Teasdale and Jennett, 1974). Shortly after its publication, the GCS was broadly accepted as an instrument to classify the severity of TBI because it was easy to use and reproducible. It was used to classify the severity of TBI as mild (GCS 13-15), moderate (GCS 9-12), and severe (GCS ≤ 8) (Rimel et al., 1979, 1982). However, Stein (2001) found that patients with a GCS of 13 had pathological findings on cranial computed tomography (CT) in 337 of 997 (33.8%) cases, and in 97 of 899 (10.8%) patients an operation was indicated (Stein, 2001). In 1995, Cook and colleagues showed that the severity of TBI was misclassified when the GCS alone was used. The development of general prognostic scoring systems, such as the Trauma and Injury Severity Score (TRISS), identified a gap between prognosis and outcome in patients with severe TBI but normal GCS (Boyd et al., 1987; Cook et al., 1995).

In contrast to the GCS, which quantifies the physiological or functional consequences of TBI, the Injury Severity Score (ISS) based on the Abbreviated Injury Scale (AIS) is an anatomical scoring system. The AIS is a hierarchical system of

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injuries, in which the severity of each injury is graded on a scale of 1 to 6 points (Baker et al., 1974). Injuries of grade 3 or higher were usually considered to be relevant or severe. We have been able to show that TBI of this grade had a measurable impact on hospital mortality (Lefering et al., 2008). The definition of TBI in clinical trials is usually based on the functional classification (GCS) and sometimes in trauma registries on the anatomical classification (AIS), which requires diagnostic imaging. Since anatomical information is initially not available, however, AIS cannot be used for triage decisions. But the correlation of impaired consciousness as defined by GCS and TBI severity (AIS) in the multiple-injured patient is not yet known (Lobato et al., 1991; Marion and Carlier, 1994; Reilly et al., 1975).

Nevertheless, there is an overlap of unconsciousness and TBI severity. However, an unknown number of cases with severe TBI exists that initially did not show any signs of altered sensory perception, which is also known as the "talk and die" syndrome (Goldschlager et al., 2007; Reilly, 2001). In addition, there are multiple other reasons for unconsciousness not related to TBI, such as severe hemorrhage, inadequate oxygenation, hypoglycemia, or intoxication with alcohol or drugs.

However, the GCS is still the most commonly used score for classification of TBI severity in large trauma registries worldwide (Brickley and Shepherd, 1995; Hudak et al., 2005; Marion and Carlier, 1994; Sternbach, 2000; Vos et al., 2001). In this study, we analyzed the Trauma Register of the German Society for Trauma Surgery (TR-DGU) to evaluate the diagnostic value of the GCS for identifying severe TBI in patients with severe multiple injuries.

Methods

Trauma registry

The Trauma Register of the German Society for Trauma Surgery (TR-DGU) was founded in 1993 to collect data about patients with severe multiple injuries in Germany (Ruchholtz, 2000). The TR-DGU is a European multicenter cooperative organization with prospective, standardized, and anonymous documentation of severely injured patients from more than 145 trauma centers. In Germany data from 20% of all German trauma centers are collected on a voluntary basis in the TR-DGU, treating approximately 20% of all multiple-injured patients in Germany annually. Participating hospitals receive extended audit reports annually. Data about pre-hospital treatment, emergency management, and subsequent intensive care are entered into a web-based data collection system with multiple checks. Data are analyzed by the Institute for Research in Operative Medicine (IFOM) at the University of Witten/Herdecke in Cologne, Germany. Anonymity is guaranteed for both individual patients and participating hospitals. No consent was sought from patients, because the registry is part of the legally required measures for quality assurance in German hospitals, and anonymous data are available routinely in hospital files.

All injuries are coded according to the AIS (Baker et al., 1974). Data are checked for valid ranges and reliability. Trauma scores including ISS (Baker et al., 1974), TRISS (Boyd et al., 1987), and Revised Trauma Score (RTS) (Champion et al., 1989) are derived from raw data and have been used to adjust for baseline variation in inter-hospital comparisons and subgroup analyses.

Patients

Between January 1993 and December 2007, a total of 35,664 severely injured patients were documented in the TR-DGU (see Appendix). The present investigation considers only 19,958 adult patients admitted primarily with ISS ≥ 16 points. The other 15,706 patients were secondarily admitted to trauma centers or had missing ISS data. Additionally 882 patients were excluded below the age of 16, 75 patients with missing age data, and 999 patients with incomplete data about GCS. The final dataset consisted of data from 18,002 severely injured patients with and without TBI.

Abbreviated Injury Scale

In 1974, Baker and colleagues published the ISS, an anatomically based score system, which was based on the AIS. The AIS was initially a set of 73 blunt injuries published in 1971 by the American Medical Association Committee on Medical Aspects of Automotive Safety to provide safety data for automotive engineers. Since then the list of injuries has been extended and updated (Copes et al., 1988), the last major revision being made in 2005. The present analysis of DGU-TR data is based on the 1998 update of the AIS version from 1990 (Association for the Advancements of Automotive Medicine, 1990). The actual AIS codebook consists of approximately 2000 diagnoses.

The severity level by AIS is expressed empirically as follows: 1 = minor; 2 = moderate; 3 = severe, not life-threatening; 4 = severe and life-threatening; 5 = critical, survival uncertain; and 6 = not survivable, or untreatable. To calculate the ISS, the maximum AIS severity for each of the following six body regions was determined: head (including neck), face, chest, abdomen, extremities (including pelvis), and soft tissue. The severity scores of the three most seriously injured body regions were then squared and added, to calculate the ISS (Baker et al., 1974). In a case with level 6 injury in any one body region, the ISS is automatically set to 75 points. The ISS ranges from 1 to 75, where higher scores indicated greater severity with a worse outcome.

In our analysis we used ISS severity coding. Severe TBI was defined as ISS region 1 ($AIS_{head/neck}$) ≥ 3 (Baker et al., 1974; Cook et al., 1995). This definition covers all injuries belonging to the head and neck regions of ISS, including skull, brain, and cervical spine injuries. In order to exclude severe isolated spine injuries without TBI of this composed ISS region ($AIS_{head/neck}$), we excluded all isolated spine injuries by detailed diagnosis (AIS codebook). This subgroup of the $AIS_{head/neck}$ group without spine injuries was called traumatic brain injury group.

Statistical analysis

Data are presented as mean (SD) for continuous variables and numbers with percentages in case of counts and categorical variables. The diagnostic power of the GCS for severe TBI was calculated using sensitivity, specificity, and positive and negative predictive values. Sensitivity is the percentage of patients correctly classified with TBI, and specificity is the percentage of patients correctly classified without TBI. The predictive values describe the proportion of correct predictions if presence or absence of unconsciousness (GCS ≤ 8) was used to predict the presence or absence of a TBI ($AIS_{head} \geq 3$).

Statistical analysis was aided by the Statistical Package for the Social Sciences (SPSS™ v13, Chicago, IL).

Results

The mean age of the study group ($n=18{,}002$) was 43(±20) years, and 73.7% ($n=13{,}267$) were male patients. Mean ISS was 30 (±12) points, and the hospital mortality was 19.4% ($n=3474$). Blunt trauma was responsible in most cases (96%; $n=17{,}282$). Over half of the patients (62%) were intubated after injury. The patients were ventilated for 8 (+/-12) days; on average ICU duration of stay was 12 (+/-15) days, with length of hospital stay of 27 (+/-29) days. Table 1 shows the characteristics of patients with and without severe TBI. The following preclinical intubation rates were observed for GCS subgroups in our collective: GCS 3-8 94%, GCS 9-12 64%, GCS 13-14 44%, and GCS 15 33% were intubated on admission. Regarding only those cases with severe TBI (AIS head ≥3), than after intubation rates were recorded: GCS 3-8 94%, GCS 9-12 60%, GCS 13-14 38%, and GCS 15 31%.

Traumatic brain injury and unconsciousness

A total of 6546 (36.3%) multiple-injured patients were unconscious, as defined by GCS ≤8. A TBI (AIS_{head} ≥3 subgroup w/o spine injuries) was found in 8746 cases (48.6%). Figure 1 shows the overlap between unconsciousness and TBI. Only about half of the multiple-injured patients with severe TBI presented with unconsciousness (56%, see also sensitivity in Table 2). On the other hand, patients without severe TBI were also sometimes unconscious; almost every tenth multiple-injured patient presenting with unconsciousness (GCS ≤8) had no severe TBI ($n=1643$; 9%).

Interestingly, 21.3% ($n=3843$) of all multiple-injured patients with severe TBI initially presented with no unconsciousness. Sensitivity of the GCS for severe TBI in the multiple injured is 56.1% [95%CI 55.0–57.1] and specificity is 82.2% [95%CI 81.5–83.0]. The predictive diagnostic values of initial GCS ≤8 for prediction of severe traumatic brain injury in multiple-injured patients are summarized in Table 2. A more detailed association between GCS and TBI is shown in Figure 2. With a decreasing degree of consciousness, there is a nearly linear increase in the risk of TBI. However, even multiple-injured patients with the highest GCS levels (15) presented in 20.1% ($n=1200$) with a severe TBI.

The proportion of unconsciousness in patients with TBI of varying severity according to AIS is shown in Figure 3. There is only a marginal increase in the number of unconsciousness for patients with AIS grade 2 compared to AIS 1.

The correlation between anatomical severity (AIS) and functional severity (GCS) of TBI measured by GCS ≤8 was −0.52 (Spearman's rank correlation, $p<0.001$).

Unconsciousness in patients without TBI

Unconscious patients without TBI ($n=1643$) more frequently had signs of relevant bleeding. Preclinical shock, defined as systolic blood pressure of 90 mmHg or below, was found in half of the cases (51%, 841/1643), as compared to 26% (2259/8746) in patients with TBI, and 14% (1265/9256) in patients without TBI but with a GCS >8 (all $p<0.05$). The mean volumes of fluid given before treatment began were 2052 mL, 1429 mL, and 1490 mL, respectively, and mean volumes of blood transfused during the early in-hospital resuscitation phase before ICU admission were 6.0, 2.5, and 3.0, respectively (all $p<0.05$). Fourteen percent of the patients in this subgroup (234/1643) were given a mass transfusion of at least 10 units of packed red blood cells. Cardiopulmonary resuscitation was also performed more frequently in the group of unconscious patients without TBI (8.4% [138/1643] vs. 6% [513/8746] vs. 0.7% [66/9256]).

Mortality

Unconscious patients (GCS ≤8) had a hospital mortality rate of 40%, which is at least four times higher compared to patients with a lesser degree of unconsciousness (GCS 13-15) (Table 3). The mortality rate in patients with TBI was about twice as high as in patients without a TBI. If patients with TBI were unconscious, mortality was more than three times higher than in conscious patients with severe TBI. Not surprisingly, the mortality rate continuously increases with the severity of the TBI (Table 2).

Discussion

The GCS is commonly used to define TBI and to grade its severity. It has also repeatedly proved to be an independent prognostic factor for survival in severely injured patients and has been included in several scoring systems such as the RTS and TRISS (Boyd et al., 1987; Cayard et al., 1983; Foreman et al., 2007; Jennett and Bond, 1975; Marshall et al., 1983; Vos et al., 2001). Although it was not designed for the purpose, it is also part of most organ failure or prognostic scoring systems in intensive care. The worldwide acceptance of the GCS is the result of it being easy to use with low intra-rater and inter-rater variability (Marion and Carlier, 1994).

However, as we know not every patient with a TBI is unconscious. Symptoms may develop some time after the

Table 1. Characteristics of Patients with and without Severe TBI

	TBI (n=*8746*)	*No TBI* (n=*9256*)
Age (yr)	44.7 (±20.7)	40.7 (±17.9)
Male sex	72.4%	74.5%
Pre-existing disease	28.3%	26.6%
Blunt trauma	97.3%	94.6%
Traffic-related crash	62.0%	66.8%
ISS	32.7 (±13.2)	27.0 (±10.3)
ISS≥25	75.1%	51.2%
Glasgow Coma Scale	8.1 (±4.6)	12.8 (±3.6)
Pre-hospital intubation	72.4%	50.5%
Pre-hospital systolic BP (mmHg)	119 (±38)	114 (±31)
Shock (BP≤90 mmHg)	20.9%	22.7%
Transport by helicopter	42.6%	42.0%
Pre-hospital time (min)	72 (±43)	72 (±39)
Emergency room time (min)	74 (±44)	77 (±46)
Duration of intubation (days)	9.0 (±12.6)	6.8 (±11.4)
ICU duration of stay (days)	12.9 (±15.9)	11.4 (±13.8)
Hospital duration of stay (days)	22.9 (±26.7)	30.7 (±29.2)
24 h mortality	12.5%	6.9%
Hospital mortality	27.3%	11.4%

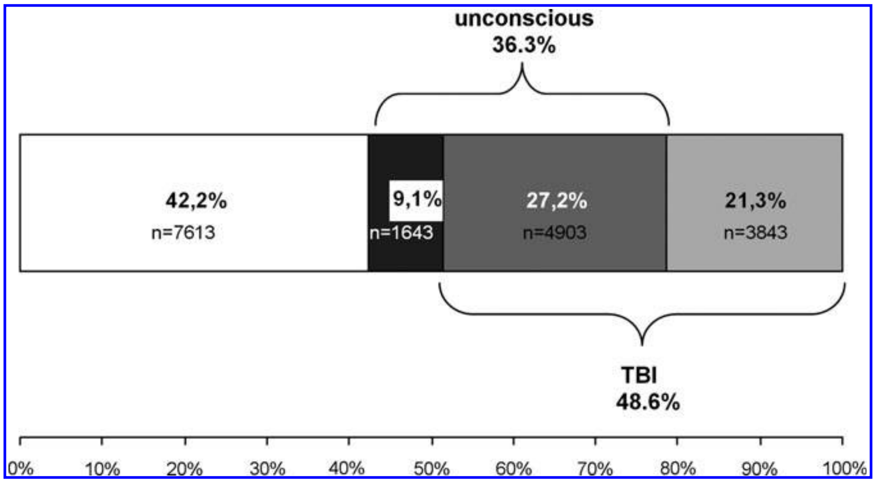

FIG. 1. Overlap of unconsciousness (Glasgow Coma Scale ≤8) and severe TBI Abbreviated Injury Scale $_{head}$ ≥3 in the study population of 18,002 cases.

trauma and the so-called walk-and-die patients are well known (Lobato et al., 1991; Reilly, 2001; Reilly et al., 1975). Basically the emergency physician at the scene of accident is not able to determine the presence of severe TBI but only unconsciousness. Thus the diagnostic value of initial GCS for severity classification of TBI, especially in multiple-injured patients, is unknown. Cook and colleagues (1995) mentioned the problem of the GCS to identify severe TBI, and found that patients may not be assessed adequately in prognostic systems such as TRISS or RTS (Boyd et al., 1987).

In fact the value of the GCS as a diagnostic tool in conjunction with severity classifications such as the AIS has not yet been elucidated. In this study, therefore, we focused on the diagnostic value of the GCS. A GCS of 8 and below is often used to classify a severe traumatic brain injury (Marshall et al., 1981; Rimel et al., 1979). Our analysis shows that this cut-off point is somewhat defined arbitrarily (Fig. 2). Moreover, we determined the sensitivity and specificity of the initial GCS score to identify severe TBI in patients with multiple injuries using AIS as the gold standard for diagnosis of TBI. Unconsciousness (GCS ≤8) in patients with multiple injuries shows a low sensitivity for severe TBI (56.1%), but a higher specificity (82.2%). Since only approximately one half of those patients with TBI were unconscious (sensitivity), the GCS score is not sufficient to define TBI in trauma registries. As demonstrated with similar pre-hospital intubation rates, the presence of a severe TBI is not influencing intubation rates on admission. The main parameter for preclinical intubation seems to be unconsciousness.

Table 2. Characteristic of Pre-Hospital Unconsciousness (GCS≤8) to Predict Severe TBI

Characteristic	*No. of patients*	*Value [%]*	*95% Cl*
Sensitivity	4903/8746	56.1%	[55.0–57.1]
Specificity	7613/9256	82.2%	[81.5–83.0]
Positive PV	4903/6546	74.9%	[73.9–76.0]
Negative PV	7613/11456	66.5%	[65.6–67.3]

Prediction with 95% confidence intervals [95%CI]; PV, predictive value.

The assessment of GCS on admission to the hospital is often misleading since many severely injured patients are already intubated and have been given analgesics, narcotics, or sedatives. Therefore, the initial suggestion to assess the GCS after an interval of 6 h is not suitable for patients with multiple severe injuries (Jennett et al., 1977; Marion and Carlier, 1994). In our study the emergency physician documents the first GCS when he arrives at the scene of accident. According to the data in the Trauma Register, the average time from accident until arrival at the scene is about 20 min. The average time until hospital admission is 72 minutes, but assessment of GCS at that time is difficult because of intubation and sedation. This should be considered when our results are compared to those of others. Moreover, the diagnosis of TBI may be influenced by coexisting multiple injuries and, therefore, differ in patients with isolated TBI. In this study, we only investigated patients with multiple injuries (ISS > 16). This effect is also shown in Table 3, demonstrating a lower mortality in patients with AIS head 1-3 then in patients with no injury to the head. Patients with no head injury in our register are more likely to have other life-threatening injuries of the body because all have at least an ISS > 16.

Because published definitions vary in the classifications of TBI severity, we defined the Abbreviated Injury Scale region head (AIS_{head}) as the gold standard in the diagnosis of TBI. Since neck injuries do not influence TBI directly, we excluded the subgroup of AIS_{neck}. While our unpublished results show that the difference between the two definitions of $AIS_{head/neck}$ and TBI are negligible, we wanted to create a more precise definition (TBI = AIS $_{head\ w/o\ neck}$) by excluding the subgroup of AIS $_{neck}$ (Grote, unpublished data).

Since the patients in our study suffered from multiple injuries, we focused only on severe TBI, in contrast to other studies (e.g., IMPACT analysis) (Maas et al., 2007; Styrke et al., 2007). Furthermore, we did not investigate different treatment strategies or the prognostic value of the GCS. Nevertheless, in isolated moderate and severe TBI, other investigators found a strong prognostic value of late GCS and pupil reactivity (Marmarou et al., 2007). In contrast, we present data for the diagnostic value of the GCS for severe TBI in patients with multiple injuries. In addition, we previously

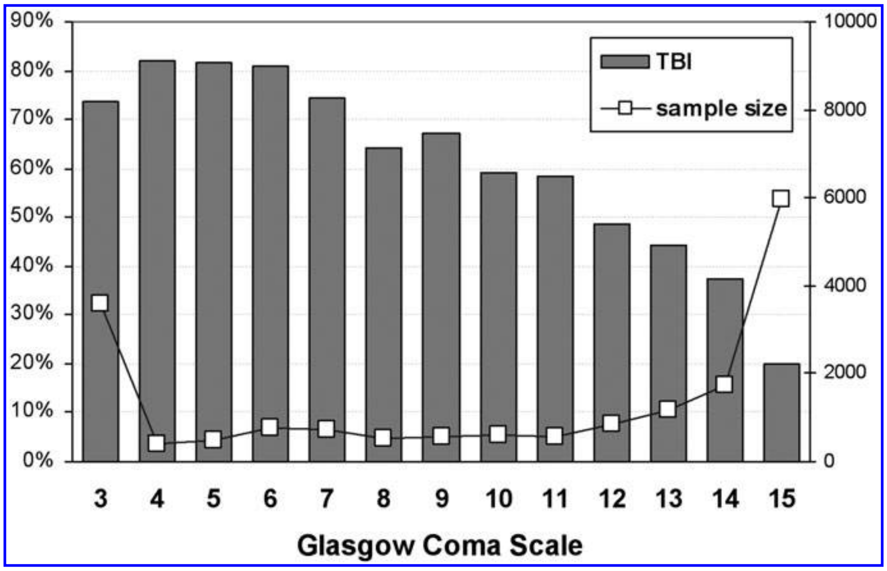

FIG. 2. Prevalence of traumatic brain injury (TBI) for different levels of unconsciousness as measured by the Glasgow Coma Scale (GCS). Left side, percent TBI; right side, sample size.

showed that an AIS level 3 or higher has a measurable impact on mortality (Lefering et al., 2008).

In a multivariate analysis, Demetriades and colleagues (2004) identified that the severity of TBI (AIS), GCS, age, and mechanism of injury are significant independent risk factors for death. In another analysis, they calculated a predictive model for the outcome after TBI using these variables (Demetriades et al., 2006). However, these analyses were restricted to isolated TBI only.

Since 21.3% ($n = 3843$) of all multiple-injured patients with severe TBI presented initially in our analysis with consciousness, we suggest that CCT scanning is mandatory in patients with multiple injuries and should depend on clinical examination, mechanism of injury, and/or additional risk factors. In our study, every tenth (9%) severely injured patient was unconscious on initial presentation but had eventually no TBI. This may be due to other factors influencing consciousness like hypoglycemia, cardiac arrest, severe hypoxemia, severe hemorrhagic shock, severe metabolic acidosis, or intoxication from alcohol or drugs (Marion and Carlier, 1994). We identified severe hemorrhagic shock as a major cause of impaired consciousness in this subgroup. We assumed that severe hemorrhage occurred when patients received massive volume replacement or early blood transfusion on admission. About two thirds of these unconscious patients without TBI had relevant blood losses, which might explain their unconsciousness. But nevertheless, some patients just might have had a mild TBI with transient symptoms of altered consciousness.

A major limitation of our study is the fact that the use of drugs and alcohol is not documented in the TR-DGU database. In our own collective only a small number of

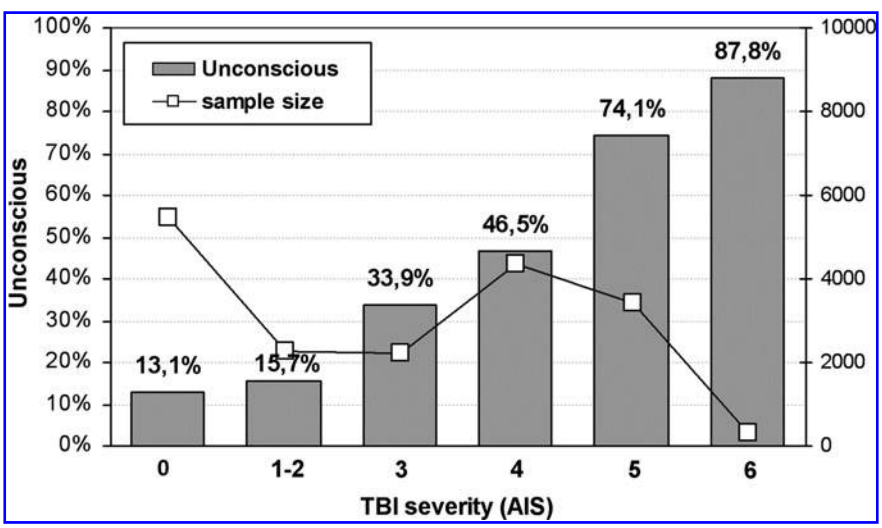

FIG. 3. Unconsciousness (Glasgow Coma Scale ≤8) in patients with different severity of traumatic brain injury (TBI) measured by Abbreviated Injury Scale ($AIS_{head\ w/o\ neck}$).

Table 3. Hospital Mortality in Patients with Unconsciousness and TBI

Condition	No. of patients	Mortality (%)
Unconscious (GCS ≤8)	2605/6546	39.8
GCS 9-12	410/2574	15.9
GCS 13-14	260/2910	8.9
GCS 15	396/5972	6.6
No head injury	878/7730	11.4
Traumatic brain injury (AIS head 3-6)	2391/8746	27.3
TBI with unconsciousness	1936/4903	39.5
TBI without unconsciousness	455/3843	11.8
AIS head = 0	735/5461	13.5
AIS head = 1-2	143/2269	6.3
AIS head = 3	228/2205	10.3
AIS head = 4	644/4334	14.9
AIS head = 5	1670/3422	48.8
AIS head = 6	251/311	80.7

AIS, Abbreviated Injury Severity Score; GCS, Glasgow Coma Scale.

intoxications (2%) had been identified in patients with multiple injuries.

The GCS is of limited use for defining severe TBI in patients with multiple injuries. Fifteen years ago, Moskopp and colleagues (1995) had already indicated the need for a new and valid scale to measure the severity of TBI. Technical improvements in radiological techniques inspired Marshall and colleagues (1993) to propose a severity classification for TBI based on CT findings (Cayard et al., 1983). Magnetic resonance based classification systems have also been proposed, using midline shift and other specific findings (Frisching et al., 2001; Moskopp et al.,1995; Woertgen et al., 1999). However, these study groups have been small. Since the most frequently used definition for TBI severity is the GCS, we investigated 18,002 multiple injured patients to test the diagnostic accuracy for TBI severity. In addition, the diagnosis of TBI might also be influenced in the future by biochemical markers, such as concentrations of the astroglial protein S-100B or the glial fibrillary acidic protein (Raabe et al., 1999; Woertgen et al., 1999). In the future the anatomical, functional, and biochemical TBI severity scales need to be compared in order to find the most precise diagnostic tool for the initial assessment of TBI. So far, it is known that the release of these proteins 36 h after traumatic brain injury correlates well with mortality in TBI (Pelinka et al., 2004). Using S-100B also helped to identify that even patients with minor TBI may need CCT scan (Biberthaler et al., 2006). However, since 60% of severely injured patients in Germany already receive a whole-body CT scan and biochemical markers are also released in small amounts from muscle tissues, they may not become an important diagnostic tool in the multiple-injured patient (Huber-Wagner et al., 2009).

Conclusion

Our study indicates that the GCS (as defined ≤8) in unconsciousness patients with multiple injuries shows only a moderate correlation with the diagnosis of severe TBI. TBI must always be considered in patients with multiple injuries even with GCS 15. Due to poor sensitivity of the GCS (sensitivity 56.1%, specificity 82.2%), we suggest using the anatomical scoring system with AIS_{head} to define severity of TBI in patients with multiple injuries.

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Author Disclosure Statement

The authors declare that they have no conflict of interests.

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(*Appendix follows*→)

Appendix. Hospitals Participating in the TR-DGU, 1993–2007

Universitätsklinik der RWTH Aachen, Zentralklinikum Augsburg, Kreiskrankenhaus Bad Hersfeld, Charité—Campus Virchow-Klinikum Berlin, Martin-Luther-Krankenhaus Berlin, Klinikum Berlin-Buch, BG-Unfallklinik Berlin-Mahrzahn, Krankenanstalten Gilead Bielefeld, BG-Klinik Bochum Bergmannsheil, Knappschaftskrankenhaus der Ruhr-Universität Bochum, Friedrich-Wilhelms-Universität Bonn, Zentralkrankenhaus Sankt-Jürgen-Straße Bremen, Zentralkrankenhaus Bremen Ost, Klinikum Bremerhaven-Reinkenheide, Allgemeines Krankenhaus Celle, Klinikum Chemnitz, Klinikum Dessau, Klinikum Lippe-Detmold, Krankenhaus Dresden-Neustadt, Technische Universität Dresden, Krankenhaus Dresden-Friedrichstadt, Heinrich-Heine-Universität Düsseldorf, Klinikum Erfurt, Kreiskrankenhaus Eschwege, Universitätsklinikum Essen, Evang. Krankenhaus Lutherhaus Essen, BG Unfallklinik Frankfurt/Main, Universitätsklinik Frankfurt/Main, Klinikum Frankfurt/Oder, Klinikum Fürth, Johanniter-Krankenhaus Geesthacht, Städtisches Klinikum Görlitz, Klinik an Eichert Göppingen, Georg-August-Universität Göttingen, Universität Graz (Austria), Allg. Unfallvericherungsanstalt Graz (Austria), Kreiskrankenhaus Grevenbroich, Universitätsklinik Groningen (Netherlands), Kreiskrankenhaus Gummersbach, BG-Unfallkrankenhaus Hamburg, Kreiskrankenhaus Hameln, Medizinische Hochschule Hannover, Krankenhaus Hannover-Nordstadt, Friederikenstift Hannover, Ev. Krankenhaus Hattingen, Orthopädishe Universitätsklinik Heidelberg, St. Bernward Krankenhaus Hildesheim, Universität des Saarlandes Homburg/Saar, Waldviertel Klinikum Horn (Austria), LKH Judenburg-Knittelfeld (Austria), Städt. Klinikum Karlsruhe, Christian-Albrechts-Universität Kiel, Chirurgischer Lehrstuhl der Universität zu Köln, Städt. Klinikum Köln-Merheim, Allg. öff. Krankenhaus Krems/Donau (Austria), Städt. Klinikum St. Georg Leipzig, Universität Leipzig, Ev. Krankenhaus Lengerich, Allg. öffentl. Krankenhaus Linz (Austria), Ev. Krankenhaus Lippstadt, Universitätsklinikum Lübeck, BG Unfallklinik Ludwigshafen, St.-Marien-Hospital Lünen, Krankenhaus Altstadt, Städt. Klinikum Magdeburg, Otto-von-Guericke-Universität Magdeburg, Johannes-Gutenberg-Universität Mainz, Universitätsklinikum Mannheim, Universität Marburg, Klinikum Minden, Krankenhaus Maria Hilf Mönchengladbach, Chirurgische Klinik Innenstadt der Ludwig-Maximilians-Universität München, Städt. Krankenhaus München-Harlaching, Westfälische Wilhelms-Universität Münster, BG-Unfallklinik Murnau, Lukaskrankenhaus der Städt. Kliniken Neuss, Marienhospital Osnabrück, Vogtland Klinikum Plauen, Klinikum Remscheid, Klinikum Rosenheim, Sana-Krankenhaus Rügen, St. Johanns-Spital-Landeskrankenhaus Salzburg (Austria), Diakonissenkrankenhaus Schwäbisch Hall, Kreiskrankenhaus Soltau, Johanniter-Krankenhaus der Altmark Stendal, Kreiskrankenhaus Traunstein, BG-Unfallklinik Tübingen, Bundeswehrkrankenhaus Ulm, Universitätsklinik Ulm, Klinikum der Stadt Villingen-Schwenningen, Klinikum Weiden/Opfz., Asklepios Kreiskrankenhaus Weißenfels, Donauspital Wien (Austria), Ferdinand-Sauerbruch-Klinikum Wuppertal, Julius-Maximilians-Universität Würzburg, Universitätsspital ETH Zürich (Switzerland), Rettungsstelle Zusmarshausen

Hospitals are listed in alphabetical order by city.