JOURNAL OF NEUROTRAUMA
Volume 9, Supplement 1, 1992
Mary Ann Liebert, Inc., Publishers

The Diagnosis of Head Injury Requires a Classification Based on Computed Axial Tomography

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ABSTRACT

The introduction of structural imaging of the brain by computed tomography (CT) scans and magnetic resonance imaging (MRI) has further refined classification of head injury for prognostic, diagnosis, and treatment purposes. We describe a new classification scheme to be used both as a research and a clinical tool in association with other predictors of neurologic status.

INTRODUCTION

SPECIFIC ANATOMICAL PATTERNS of brain injury have differing prognoses when the severity of the initial impact injury is accounted for. From the general classification of head injury into mass lesion and diffuse injury (Gennarelli et al., 1982), a more systematic understanding of the heterogeneous nature of brain injury has evolved over the last decade. The revolutions brought about by the introduction of structural imaging of the brain, first with computed axial tomographic scanning (CT) and, more recently, with magnetic resonance imaging (MRI), have permitted the development of more discrete classifications of head injury, not only for prognostic purposes but also as tools to assist in diagnosis and treatment.

In 1979 a number a neurosurgical centers and the Office of Biometry and Field Studies of the National Institute of Neurological Disorders and Stroke joined together to begin the pilot Traumatic Coma Data Bank (TCDB) (Marshall et al., 1983). At that time, an extensive data collection form was designed to collect CT scan information about head injury. However, the more traditional classification into diffuse and mass lesion was utilized, although the traditional types of intracranial hemorrhagic lesions were categorized. During the pilot TCDB, it became apparent that the category "diffuse injury" lumped together a number of heterogenous patterns on CT, which was not generally helpful in either predicting outcome or patient management.

In 1983 the full-phase TCDB was funded, and an opportunity was made available to modify the CT scan data collection form, as well as the means by which head injury was categorized or classified. The data bank investigators had become acutely aware that pooling the patient data appeared to aggregate groups of patients with diffuse injury who had varying risks of intracranial hypertension and other intracranial complications. A second factor motivating this development of a new classification was our recognition that certain CT scan findings, particularly in patients who did not appear to be severely injured, were ominous and remaining generally unrecognized by the neurosurgical community (Teasdale et al., 1984; Toutant et al., 1984; van Dongen et al., 1983). While the Traumatic Coma Data Bank had as its focus patients with severe head injury defined as a Glasgow Coma Scale score of 8 or less following resuscitation, the investigators decided to develop a CT scan classification that would be more generally applicable to patients with not only severe injuries but also moderate injuries. It was the investigators' intent to develop a classification that, while simple, would both guide early management and, when used in conjunction with other risk factors, aid in the prediction of outcome.

Several basic assumptions were made in the development of this new classification. First, considerable evidence had accumulated that the volume status of the brain as estimated by assessment of the mesencephalic cisterns, the cortical sulci, ventricular size, and the degree of brain shift were important factors in determining the outcome from head injury (Teasdale

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et al., 1984; Toutant et al., 1984; van Dongen et al., 1983). Based on these empiric observations and our clinical experience that a substantial number of patients with compression or absence of the mesencephalic cisterns or significant midline shift on the initial CT scan were being treated as if their CT scans were normal because their clinical status was good, led us to emphasize these factors in the classification. Second, the investigators also recognized that a single CT scan offered only a "snapshot" of the pathoanatomical state of the brain at one moment in time. Since serial CT scans were required within the data bank, changes in the tissue and the volume status of the brain could be assessed over time within the data bank, as they are in community practice. Nevertheless, particular emphasis was placed on utilizing the first CT scan during or after resuscitation because of the need to make early therapeutic decisions. In patients who are operated on for mass lesions, CT scanning done during the postoperative period would allow assessment not only of the adequacy of evacuation but also of what the patient's future management needs might be.

Finally, it was hoped that such a classification would identify subsets of patients who might be candidates for new therapies, and allow for comparison of specific subgroups utilizing a variety of treatments to determine the efficacy of treatment or lack thereof.

METHODS

One thousand and thirty patients were admitted to the TCDB hospitals in the period from January 1, 1984 to September 30, 1988. The following classification was applied to patients with closed nonpenetrating injuries: a description of the importance of varying CT scan findings in patients with penetrating injuries appears elsewhere in this volume (Aldrich et al., 1991). Of the initial 1,030 patients, 284 were excluded from this analysis because they suffered a gunshot wound to the brain, were brain dead on admission, or died during resuscitation before CT scanning could be carried out, which left 746 patients for analysis. All investigators agreed that in patients who survived their initial resuscitation CT scanning would be carried out within the first minutes following admission, when possible. An extensive CT scan form was used to collect the data, but a smaller number of factors were used to classify the patients (Table 1). The classification shown here emphasized the volume status of the brain, as reflected particularly in the status of the mesencephalic cisterns and the degree of midline shift.

Quality assurance studies were carried out by the Office of Biometry and Field Studies and the TCDB investigators, using an identical set of scans read in each of the centers. Uniform definitions for the degree of midline shift and for the assessment of ventricular symmetry, to choose two examples, were applied in all of the centers. One individual in each institution read all of the scans, allowing for a high level of internal consistency, and interCenter comparisons were made intermittently by the TCDB investigators.

Finally, a written manual with clear definitions in each of the categories for the CT scan form was available and frequently utilized.

Stringent criteria for each of the diagnostic categories were applied. Thus, for example, diffuse injury with no visible pathologic changes (diffuse injury I) means that the CT scan must be entirely normal for a patient's age.

TABLE 1. DIAGNOSTIC CATEGORIES OF TYPES OF ABNORMALITIES VISUALIZED ON CT SCANNING

Diffuse injury I (no visible pathologic change)	No visible intracranial pathologic change seen on CT
Diffuse injury II	Cisterns are present with shift 0–5 mm and/or Lesion densities present No high or mixed density lesion > 25 ml May include bone fragments and foreign bodies.
Diffuse injury III (swelling)	Cisterns compressed or absent with shift 0–5 mm No high or mixed density lesion > 25 ml
Diffuse injury IV (shift)	Shift > 5 mm No high or mixed density lesion > 25 ml
Evacuated mass lesion	Any surgically evacuated lesion
Non evacuated mass lesion	High or mixed density lesion > 25 ml, not surgically evacuated
Brain dead	No brainstem reflexes Flaccidity Fixed and nonreactive pupils No spontaneous respirations with a normal $PaCO_2$ Spinal reflexes permitted

The heavy emphasis on the status of the mesencephalic cisterns and the degree of shift produced a classification in which a considerable variation in other structural changes within the brain can occur for patients within a given category of the classification. For example, diffuse injury II contains a variety of patterns of diffuse injury, although the status of the mesencephalic cisterns and the lack of significant shift are uniformly characteristic of such patients. Therefore, a patient with a small superficial contusion and a minimal degree of shift would be included, along with patients who have multiple small areas of hemorrhage within the deep parenchyma of the brain. Each of the CT scans performed on a patient were read and classified according to this nomenclature. However, the final diagnosis for each patient was based not only on the CT scan's appearance but also on the events that determined patient outcome. To illustrate the application of the classification, a particular patient is described.

A 43-year-old man was admitted with a severe closed head injury. The initial CT scan demonstrated a small area of intraparenchymal hemorrhage (less than 10 ml) in the right frontal region, no displacement of the midline, and no compression of the mesencephalic cisterns. Initially, this patient would have been categorized as having diffuse injury II. However, within 16 hr the patient's right frontal hemorrhage enlarged to 60 ml and required surgical evacuation. The patient's classification would then be changed to the evacuated mass lesion category, with a secondary diagnosis of intraparenchymal hemorrhage.

To test the association between the new classification and a variety of other risk factors, a number of statistical approaches were applied. Initially, a Monte Carlo scheme with the Kruskal-Wallis statistic was utilized, because of small numbers for some of the groups and the need for a methodology to allow for empirical randomization (Hosmer and Lemeshow, 1989).

A series of logistic regression equations were applied to determine whether a better prediction of the patient's clinical course and outcome could be obtained using the postresuscitation motor score alone or with the new classification. The motor score was chosen because in some instances there were missing observations in the Glasgow Coma Scale and previous data bank studies had indicated that the correlation between motor score and GCS was 0.90. In addition, logistic regressions were developed for predictive models, with a particular emphasis on patients with diffuse injury III because of the investigators' overall interest in intracranial hypertension.

RESULTS

As anticipated, there was a striking relationship between the initial CT scan diagnosis and outcome (Table 2). This classification, which heavily weighted the volume status of the brain in its varying categories is therefore very useful in directing attention to this relationship. Table 2 illustrates the outcome, utilizing the new classification scheme and the Glasgow Outcome scale.

Noteworthy is the observation in patients with diffuse injury III that the highest intracranial pressure (ICP), and not the Glasgow Coma Scale, or age, is the most important single determinant of outcome in these patients (Table 3) in contradistinction to all other categories of brain injury. This clearly illustrates that the volume status of the brain, as demonstrated by CT scanning, is a vitally important piece of information in determining the risk of death and morbidity in such patients, and suggests that the success or failure of the treatment of intracranial hypertension will determine the patient's outcome in many instances within this classification.

The utility of this classification as a means of predicting outcome is illustrated in Table 4. Note here that when the age of the patient is known, an accurate prognostic statement can be made for the overwhelming majority of the patients with diffuse injury II, based on the initial CT scan. When the clinical status,

TABLE 2. NUMBER OF PATIENTS (%) BY DISCHARGE GLASGOW OUTCOME SCALE (GOS) AND INTRACRANIAL DIAGNOSIS

GOS (discharge)	*Diffuse injury I no visible pathologic change*	*Diffuse injury II*	*Diffuse injury III (swelling)*	*Diffuse injury IV (shift)*	*Evacuated mass*	*Nonevacuated mass*	*Brainstem injury*	*Unknown*	*Total*
Good	14 (27.0)	15 (8.5)	5 (3.3)	1 (3.1)	14 (5.1)	1 (2.8)	0 (0)	0 (0)	50 (7.0)
Moderate	18 (34.6)	46 (26.0)	20 (13.1)	1 (3.1)	49 (17.7)	3 (8.3)	0 (0)	1 (5.9)	138 (18.5)
Severe	10 (19.2)	72 (40.7)	41 (26.8)	6 (18.8)	72 (26.1)	7 (19.4)	1 (33.3)	0 (0)	209 (28.0)
Vegetative	5 (9.6)	20 (11.3)	35 (22.9)	6 (18.8)	34 (12.3)	6 (16.7)	0 (0)	0 (0)	106 (14.0)
Dead	5 (9.6)	24 (13.5)	52 (34.0)	18 (56.2)	107 (38.8)	19 (52.8)	2 (66.7)	16 (94.1)	243 (32.5)
Total	52 (100)	177 (100)	153 (100)	32 (100)	276 (100)	36 (100)	3 (100)	17 (100)	746 (100)

TABLE 3. POTENTIAL PREDICTORS OF MORTALITY FOR INTRACRANIAL DIAGNOSIS OF DIFFUSE INJURY III (SWELLING) BY PREDICTOR P—VALUE AND GOODNESS-OF-FIT P—VALUE

Predictor	*Prediction p value*	*P value goodness-of-fit*[a]
Highest ICP (first 72 hr)	<0.001	0.038
Pupil reactivity (postresuscitation)	<0.001	0.610
Lowest ICP (first 72 hr)	0.023	0.930
Best motor (postresuscitation)	0.510	0.970
Age	0.680	0.970

[a] By the Hosmer-Lemeshow test, p value for each row for model fit including predictors in its row and above (the higher the p value, the better the fit).

as assessed by the motor score, is included, even sharper predictions of outcome are possible.

The subclassification of the mass lesion group by volume and by the classic categories of extradural, subdural, and intraparenchymal hemorrhages was useful in recognizing the very different prognoses for these types of mass lesions (Table 5). Although use of volume categories of 15 ml in the temporal fossa and of 25 ml elsewhere for defining intracerebral hemorrhage is clearly arbitrary, it was operationally effective in identifying patients at risk for brainstem compression.

DISCUSSION

The TCDB's classification of severe head injury is both applicable and useful in the categorization of such patients (Luerssen et al., 1988). This classification demonstrates that patients without overall increases in brain volume, as assessed by CT scan, are at much lower risk of dying. The rather similar mortality between patients in the diffuse injury categories III and IV (diffuse injury with swelling, and diffuse injury with shift) to those who have mass lesions suggests that these two categories of diffuse injury are analogous to the definition of patients with sizable hemorrhagic lesions and that the overall increase in intracranial volume is an important factor in determining mortality and morbidity.[7]

Head injury is a dynamic illness, and what is present on the first CT scan may look materially different after surgical intervention or the natural progression of the disease. Frowein (1987) has demonstrated that intraparenchymal hemorrhages and the mass effect associated with them increase by approximately 40% during the first 24 hr following injury. There are pitfalls, therefore, in applying a static technique (i.e., CT scans done at specific points in time) to describe a dynamic process. A classification scheme such as that described here must, therefore, be constantly reassessed and reapplied.

An additional feature of this classification is its applicability to patients with more moderate injuries. The ability to classify moderate head injury radiographically to identify patients who appear to be at low risk on the basis of clinical examination, but who have ominous CT scans, should make "surprising, catastrophic outcomes" less frequent in the future. For patients with less severe injuries, the absence in this classification of any description of skull fracture is a detriment. It is important to emphasize that in the less severely injured patient skull fracture is an important predictor of the likelihood of the development of an intracranial mass lesion, but it is of no predictive significance in patients with severe head injury.

Finally, this new classification also appears to offer the opportunity to compare more stringently patients entered into clinical trials and in whom new therapies are utilized.

THE FUTURE

The classification described here was developed as part of a major research effort but that should not detract from its inherent utility as a clinical tool. Although the investigators initially considered more elaborate schemes that took into account the number of superficial and deep contusions and were more specific in categorizing both the volume of intracranial hematomas and their location, it soon became clear that a more simple

TABLE 4. OUTCOME OF DIFFUSE INJURY II AT LAST EVALUATION BY GOS AND AGE (%)

GOS (at last visit)	*Age (Years)* ≤40	>40	*Total*
Good	15 (10.0)	0 (0)	15 (8.5)
Moderate	44 (28.7)	2 (8.3)	46 (26.0)
Severe	63 (41.1)	9 (37.5)	72 (40.7)
Vegetative	17 (11.1)	3 (12.5)	20 (11.3)
Dead	14 (9.1)	10 (41.7)	24 (13.6)
Total	153 (100)	24 (100)	177 (100)

TABLE 5. NUMBER OF PATIENTS (%) BY TYPE OF EVACUATED MASS LESIONS, GOS AT LAST CONTACT, AND AGE

		Age (years)		
Type of Lesion	*GOS*	*≤40*	*>40*	*Total*
Type of evacuated mass lesion				
Evacuated	Good	6 (15.4)	0 (0.0)	6 (13.3)
Epidural	Moderate	13 (33.3)	2 (33.3)	15 (33.3)
Hematoma	Severe	10 (25.6)	0 (0.0)	10 (22.2)
	Vegetative	5 (12.8)	1 (16.7)	6 (13.3)
	Dead	5 (12.8)	3 (50.0)	8 (17.8)
	Total	39 (100)	6 (100)	45 (100)
p = 0.10				
GOS at last contact				
Evacuated	Good	4 (4.0)	0 (0.0)	4 (2.5)
Subdural	Moderate	14 (14.0)	4 (6.8)	18 (11.3)
Hematoma	Severe	31 (31.0)	10 (6.9)	41 (25.8)
	Vegetative	12 (12.0)	4 (6.8)	16 (10.1)
	Dead	39 (39.0)	41 (69.5)	80 (50.3)
	Total	100 (100)	59 (100)	159 (100)
p < 0.001				
Age				
Evacuated	Good	4 (7.5)	0 (0.0)	4 (5.6)
Intracerebral	Moderate	14 (26.4)	1 (5.6)	15 (21.1)
Hematoma	Severe	18 (34.0)	3 (16.7)	21 (29.6)
	Vegetative	7 (13.2)	5 (27.8)	12 (16.9)
	Dead	10 (18.9)	9 (50.0)	19 (26.8)
	Total	53 (100)	18 (100)	71 (100)
P < 0.001				

classification would have more general application and be more rapidly and easily utilized. It is important to emphasize that this new classification scheme is not viewed as a substitute for other extremely important clinical information, including the neurologic status as assessed by the Glasgow Coma scale, the pupils, or age, to name just a few classic variables. On the contrary, such a classification was designed to be used with these other predictors to allow for more powerful determinations of patient status.

This classification must be viewed as a start in the development of a reliable and rational means of categorizing the clinical course and pathoanatomical picture of patients with acute brain injury. As we learn more about the metabolic substrate of this complex disorder, it will clearly be appropriate to utilize this classification with actual determinants of metabolic activity, just as the present classification is utilized with age and the motor score. Because of the rapidity with which brain imaging can presently be performed and its tremendous importance in determining the initial steps in treatment, however, it is certain that the content of structural imaging studies of the brain will be tremendously important in classifying brain injury for the foreseeable future. While at the present time MRI in the management of head injury is "confined mainly to the subacute and chronic stages" (Lipper and Kishore, 1989), it is likely that, as the technical difficulties that presently prevent the routine use of MRI in unconscious patients are overcome, this modality will be the method of choice and, when coupled with spectroscopic applications of MRI, is likely to permit further advances in the treatment of these patients.

ACKNOWLEDGMENT

This work was supported by the Pilot Traumatic Coma Data Bank under Contracts N01-NS-9-2306, 2307, 2308, 2309, 2313, and the Traumatic Coma Data Bank (TCDB) under Contracts N01-NS-3-2339, N01-NS-3-2340, N01-NS-3-2341, N01-NS-3-2342, N01-NS-6-2305 from the National Institute of Neurological Disorders and Stroke (NINDS). The TCDB Manual of Operations, which includes the TCDB data forms, is available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 (NTIS Accession No. PB87 228060/AS).

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