A new classification of head injury based on computerized tomography

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✓ A new classification of head injury based primarily on information gleaned from the initial computerized tomography (CT) scan is described. It utilizes the status of the mesencephalic cisterns, the degree of midline shift in millimeters, and the presence or absence of one or more surgical masses. The term "diffuse head injury" is divided into four subgroups, defined as follows: Diffuse Injury I includes all diffuse head injuries where there is no visible pathology; Diffuse Injury II includes all diffuse injuries in which the cisterns are present, the midline shift is less than 5 mm, and/or there is no high- or mixed-density lesion of more than 25 cc; Diffuse Injury III includes diffuse injuries with swelling where the cisterns are compressed or absent and the midline shift is 0 to 5 mm with no high- or mixed-density lesion of more than 25 cc; and Diffuse Injury IV includes diffuse injuries with a midline shift of more than 5 mm and with no high- or mixed-density lesion of more than 25 cc. There is a direct relationship between these four diagnostic categories and the mortality rate. Patients suffering diffuse injury with no visible pathology (Diffuse Injury I) have the lowest mortality rate (10%), while the mortality rate in patients suffering diffuse injury with a midline shift (Diffuse Injury IV) is greater than 50%. When used in conjunction with the traditional division of intracranial hemorrhages (extradural, subdural, or intracerebral), this categorization allows a much better assessment of the risk of intracranial hypertension and of a fatal or nonfatal outcome. This more accurate categorization of diffuse head injury, based primarily on the result of the initial CT scan, permits specific subsets of patients to be targeted for specific types of therapy. Patients who would appear to be at low risk based on a clinical examination, but who are known from the CT scan diagnosis to be at high risk, can now be identified.

Key Words • Traumatic Coma Data Bank • head injury • coma • intracranial pressure • computerized tomography • grading system

NEUROSURGEONS and others interested in treating head-injured patients have traditionally categorized head injury on the basis of focal or nonfocal lesions or, more recently, on the basis of diffuse versus focal or mass lesions. These categorizations, while helpful in subdividing head injury into two major groups, have significant limitations in terms of prognosis. It is generally recognized that patients with diffuse injury have a lower mortality rate than do patients with mass lesions. However, this type of pooling of patient data might mask groups of patients with diffuse injury who are at risk from intracranial hypertension and who in fact have a high mortality rate.

A general lack of recognition of the importance of
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certain computerized tomography (CT) findings, parti-
cularly in patients who appear to be at low risk based
on their clinical examination, led us to develop a new
classification of head injury. This classification was de-
designed on the basis of our experience in the pilot phase
of the Traumatic Coma Data Bank (TCDB) study.3
Despite the fact that the TCDB included only patients
with severe head injury, the present categorization lends
itself to inclusion of other grades of head injury as well.
For example, among patients with more moderate in-
juries, an "unexpected" adverse outcome occurs not
infrequently because the benign clinical status and lack
of a mass lesion on the initial CT scan are interpreted
as indicating that the patient is at little risk of develop-
ing intracranial hypertension. It is for this group of pa-
tients that a more refined classification, such as the one
described here, would be useful.
A significant number of patients in the United States
who have compression or absence of the mesencephalic
cisterns on their initial CT scan are treated as if their
CT scans were normal because their clinical evaluation
is good. Probably hundreds and perhaps thousands of
these patients have a catastrophic outcome each year.
Thus, a new classification is needed that can identify
patients at particular risk for developing intracranial
hypertension. Such a classification would allow for early
prediction of outcome when only a few factors, such as
age, clinical status, and CT findings, are known. Fur-
thermore, the frequency of intracranial hypertension
has been shown to be high in patients who are operated
on for mass lesions. In such patients, it is possible that
a CT scan performed immediately or within 24 hours
after surgery might be extremely useful in predicting
the likelihood of that patient developing intracranial
hypertension and might better identify the need for
continuous monitoring of the intracranial pressure
(ICP) in such patients.
The development of a new classification of head
injury was considered to be important in order to
permit a more accurate description of the kinds of
injuries the patients have suffered and to assess the
relationship between the pattern of brain injury deter-
mined by CT and, in part, by clinical examination. The
diagnostic categories of this new classification and their
definitions are presented in Table 1. The intent of this
new classification was twofold: 1) to allow a more
accurate classification of severe head injury so that
subsets of patients at particular risk for deterioration
could be identified; and 2) to allow more accurate
predictive statements at the time of the patient's initial
evaluation regarding the likelihood of a fatal or nonfatal
outcome.
It is not the purpose of the new classification scheme
to replace the Glasgow Coma Scale (GCS) or any other
measure of injury severity. We wish to show that the
new classification, when used in conjunction with es-
tablished predictors, provides a more accurate basis
upon which to predict outcome than that provided by
the established predictors alone. The new classification
provides virtually complete coverage of severe head
injuries, in contrast to the traditional categories of
intracranial hemorrhages, which gives only partial cov-
verage. Only 17 (2%) of 746 patients in our study were
classified as having an "unknown" diagnosis, 16 of
whom died.
A more accurate categorization of such injuries
would ultimately allow for the initiation of new ther-
apies in some subgroups of severely injured patients
and make decisions regarding further treatment more logical
if, for example, the CT diagnosis and some other factors,
such as the patient's age, indicated an unsalvageable
patient. Early in the study, it was the view of the TCDB
investigators and the Biometry and Field Studies
Branch of the National Institute of Neurological Dis-
orders and Stroke that such a classification might also
be useful in a more general sense for describing subsets
of patients with more modest injuries who are at risk
of a poor outcome.

Clinical Material and Methods

Protocol
In the period from January 1, 1984, through Septem-
ber 30, 1987, 1030 patients were admitted to the TCDB
hospitals. Of these, 284 were excluded from this analysis
because they had suffered gunshot wounds of the brain
or were brain-dead on admission, leaving 746 patients
with severe head injury available for the present analy-
sis. Severe head injury was defined as a GCS score of 8
or less following nonsurgical resuscitation. A format for
the description of the major CT findings was established
during the pilot phase of the TCDB study.3 Based on
our analysis and experience with this initial CT Scan
Form, a new CT collection instrument and a manual

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
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<tbody>
<tr>
<td>Diagnostic categories of types of abnormalities visualized on CT scanning*</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Category</td>
</tr>
<tr>
<td>Diffuse Injury I (no visible pathology)</td>
</tr>
<tr>
<td>Diffuse Injury II (swelling)</td>
</tr>
<tr>
<td>Diffuse Injury III (shift) evacuated mass lesion</td>
</tr>
<tr>
<td>Diffuse Injury IV (shift) nonevacuated mass lesion</td>
</tr>
</tbody>
</table>

* CT = computerized tomography.
for its use were developed for the full-phase TCDB study. Particular emphasis was placed on the appearance of the mesencephalic cisterns and on the degree of midline shift. Mechanisms for the determination of these changes were tested during the initial phase of the TCDB study.

All patients considered to be salvageable at the time of admission to the four TCDB hospitals underwent CT scanning, usually within the first hours following admission. While the CT Scan Form was used to permit a comprehensive description of the CT findings, a much smaller number of factors were used to classify the patients into the diagnostic categories shown in Table 1. The accuracy of the CT diagnoses was ensured by several methods. Quality assurance trials were carried out among the centers involved in the pilot phase of the TCDB study on a series of scans sent to each center. A second set of scans was reviewed during the early part of the full-phase TCDB study as well. Methodological changes including exact criteria for measuring shift and for ventricular asymmetry were made during the pilot phase of the TCDB study to ensure that all definitions and categories were applied in a uniform fashion. All scans in each institution were read by one individual, which permitted a high level of internal consistency. The center interpretations were compared during a series of reviews carried out by the TCDB principal investigators. A manual providing stringent definitions for each category on the CT Scan Form was developed and utilized by all the centers.

**Diagnostic Categories: Examples**

Examples of CT scans for each of the diagnostic categories are shown in Figs. 1 to 6. It is important to emphasize that "diffuse injury with no visible pathol-

**Fig. 1.** Computerized tomography scans showing examples of Diffuse Injury II: diffuse injury with limited shift or mass effect (left); diffuse injury with multifocal hemorrhages (center); and diffuse injury marked by deep central hemorrhage (right). The right scan shows a hemorrhage in the midbrain without effacement into the mesencephalic cisterns.

**Fig. 2.** Admission computerized tomography scan of a patient with Diffuse Injury III: diffuse injury with swelling, showing virtual obliteration of the cisterns without midline shift or mass effect. This 23-year-old patient was a victim of a motorcycle accident with an admitting Glasgow Coma Scale score of 7.
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patients at progressively higher risk for intracranial hypertension and death.6,10,11

It is important to emphasize that the category of Diffuse Injury II describes the status of the mesencephalic cisterns and the degree or lack of midline shift, even though a variety of pathological pictures may be present. Three specific examples of Diffuse Injury II are illustrated: Fig. 1A illustrates a small superficial contusion with a minimum degree of midline shift, Fig. 1B shows the petechial hemorrhages of the brain characteristic of diffuse axonal injury, and Fig. 1C demonstrates a deep contusion or intraparenchymal hemorrhage in the brain stem which produced no disturbance of the mesencephalic cisterns. Thus, within each of these new diagnostic categories, a variety of pathological processes may be present.

The need for a classification scheme to be strictly defined yet capable of responding to a change in patient status is illustrated in Figs. 5 and 6. Figure 5A illustrates the preoperative CT appearance of a patient with a small intracerebral hemorrhage in the right posterior frontal region and a contralateral small subdural hematoma. In this patient, the mesencephalic cisterns were initially normal and therefore, in spite of the presence of two distinct lesions, the patient would have been classified as having a Diffuse Injury II. However, the subdural hematoma subsequently enlarged to 75 cc and surgery was undertaken, at which time both lesions were removed. The patient’s diagnostic category was

Fig. 3. Admission computerized tomography scan of a patient with Diffuse Injury IV: diffuse injury with shift, showing a 22-mm shift of midline from left to right and obliteration of the perimesencephalic cisterns. This 18-year-old man was involved in a motor-vehicle accident and his Glasgow Coma Scale score on admission was 4.

Fig. 4. Admission computerized tomography scan of a patient in the "evacuated mass lesion" category showing a large intracerebral hemorrhage which required surgical evacuation.

Fig. 5. Computerized tomography scans of a patient with multiple lesions. Left: Admission scan showing pathology initially not considered to need surgical treatment. Right: Scan obtained 18 hours after admission showing progressive enlargement of both the subdural hematoma and the intracerebral hemorrhage. Based on this appearance, evacuation was carried out.

Fig. 6. A demonstration of the dynamic aspects of brain injury on the computerized tomography scans of a 26-year-old man who was struck by an automoblie. Left: Initial scan showing open cisterns and no midline shift. Right: Follow-up scan obtained 13 hours later showing significant midline shift and development of a surgical subdural hematoma.
then changed to acute subdural hematoma with a secondary diagnosis of intraparenchymal hemorrhage. Figure 6 illustrates a substantial change in the CT picture within 12 hours, requiring a change in patient categorization. Thus, the dynamic nature of the patient's injury can only be characterized by serial scans, but the concept that these categories are of value in predicting the patient's course still holds.

**Statistical Analysis**

The association between the GCS score and the new classification ("unknowns" omitted) was first tested by the Monte Carlo approach (that is, empirical randomization) using the Kruskal-Wallis statistic; for this, the StatXact program was employed with 10,000 randomizations. The Monte Carlo approach was indicated because of the small numbers in some of the groups in the classification. Logistic regression was used to show the improvement obtainable by the use of the new classification (excluding brain-stem and unknown injuries) both above that using best postresuscitation motor score and alone. Motor score was used instead of the GCS score as a predictor because of missing observations in the GCS categories. The correlation between motor score and GCS score in our study was 0.90, the highest of the GCS subscores. Logistic regression was also used to develop a prediction model for Diffuse Injury III (swelling).

**Results**

There is a striking direct relationship between outcome and initial CT scan diagnosis ($p = 0.0002$) (Table 2). Given the fact that the diagnostic categories in large measure are a reflection of changes in brain volume, it is tempting to conclude that what one is seeing is an early indicator of the degree of intracranial hypertension that is likely to occur in such patients. It is important to recognize that the degree of change in brain bulk is a function of a series of complex phenomena including the degree of impact injury, the presence or absence of ischemia or ischemic hypoxia prior to CT scanning, and perhaps a host of other factors not yet identified.

Other factors are needed in addition to the CT classification for prognostic purposes, as evidenced by the outcome differences by age for a single category, Diffuse Injury II (Table 3). For this diagnosis, 39% of the patients under the age of 40 years had a good or moderate outcome versus 8% for those over 40 years; conversely, the older age group had over fourfold risk of death in comparison to the younger age group.

The CT diagnosis was a highly significant independent predictor of mortality ($p = 0.0001$) when age and motor score were included in the model. This three-factor predictor model showed excellent fit to data ($p = 0.86$; values close to 1 indicate good fit). On the other hand, when CT diagnosis was not included, the fit was poor ($p = 0.041$). Evidently, the improvement in prediction increased the sensitivity of the model (ability to predict deaths) by 6% (from 53% to 59%), but specificity was virtually unchanged. This is understandable since the specificity of the two-factor prediction model was already very high (87%). The models themselves are not presented because, as has been shown elsewhere, a truly comprehensive model takes into account additional factors such as eye opening, hypotension, and others.

There was a strong linkage between the ultimate outcome and the degree of brain swelling and the degree of midline shift as seen on the CT scans of patients

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**TABLE 2**

*Outcome at discharge in relation to intracranial diagnosis*

<table>
<thead>
<tr>
<th>Outcome at Discharge</th>
<th>Diffuse Injury I</th>
<th>Diffuse Injury II</th>
<th>Diffuse Injury III</th>
<th>Diffuse Injury IV</th>
<th>Evacuated Mass</th>
<th>Nonevacuated Mass</th>
<th>Brain-Stem Injury</th>
<th>Unknown</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
</tr>
<tr>
<td>good</td>
<td>14 27.0</td>
<td>15 8.5</td>
<td>5 3.3</td>
<td>1 3.1</td>
<td>14 5.1</td>
<td>1 2.8</td>
<td>0</td>
<td>0</td>
<td>50 7.0</td>
</tr>
<tr>
<td>moderate</td>
<td>18 34.6</td>
<td>46 26.0</td>
<td>20 13.1</td>
<td>1 3.1</td>
<td>49 17.7</td>
<td>3 8.3</td>
<td>0</td>
<td>0</td>
<td>138 18.5</td>
</tr>
<tr>
<td>severe</td>
<td>10 19.2</td>
<td>72 40.7</td>
<td>41 26.8</td>
<td>6 18.8</td>
<td>72 26.1</td>
<td>7 19.4</td>
<td>1 3.3</td>
<td>0</td>
<td>209 28.0</td>
</tr>
<tr>
<td>vegetative</td>
<td>5 9.6</td>
<td>20 11.3</td>
<td>35 22.9</td>
<td>6 18.8</td>
<td>34 12.3</td>
<td>6 16.7</td>
<td>0</td>
<td>0</td>
<td>106 14.0</td>
</tr>
<tr>
<td>dead</td>
<td>5 9.6</td>
<td>24 13.5</td>
<td>52 34.0</td>
<td>18 56.2</td>
<td>107 38.8</td>
<td>19 52.8</td>
<td>2 66.7</td>
<td>16</td>
<td>94.1  243 32.5</td>
</tr>
<tr>
<td>totals</td>
<td>52 100</td>
<td>177 100</td>
<td>153 100</td>
<td>32 100</td>
<td>276 100</td>
<td>36 100</td>
<td>3 100</td>
<td>17</td>
<td>100 746 100</td>
</tr>
</tbody>
</table>

* Outcome classified by the Glasgow Outcome Scale. For a description of Diffuse Injury I to IV, see Table 1.

**TABLE 3**

*Outcome of Diffuse Injury II at last evaluation by patient age*

<table>
<thead>
<tr>
<th>Outcome (At Last Visit)</th>
<th>Age (yrs)</th>
<th>≤ 40</th>
<th>&gt; 40</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
</tr>
<tr>
<td>good</td>
<td>15 10.0</td>
<td>0</td>
<td>0</td>
<td>15 8.5</td>
</tr>
<tr>
<td>moderate</td>
<td>44 28.7</td>
<td>2</td>
<td>8.3</td>
<td>46 26.0</td>
</tr>
<tr>
<td>severe</td>
<td>63 41.1</td>
<td>9</td>
<td>37.5</td>
<td>72 40.7</td>
</tr>
<tr>
<td>vegetative</td>
<td>17 11.1</td>
<td>3</td>
<td>12.5</td>
<td>20 11.3</td>
</tr>
<tr>
<td>dead</td>
<td>14 9.1</td>
<td>10</td>
<td>41.7</td>
<td>24 13.6</td>
</tr>
<tr>
<td>totals</td>
<td>153 100</td>
<td>24</td>
<td>100</td>
<td>177 100</td>
</tr>
</tbody>
</table>

* Outcome classified by the Glasgow Outcome Scale. For a description of Diffuse Injury II, see Table 1.
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with nonsurgical lesions. As an adequate sample size was available in the category of Diffuse Injury III (swell-
ing), a logistic regression equation was developed in this
group to determine the factors that might be helpful
during the first 72 hours in sharpening the 6-month
outcome mortality rate prediction in such patients. As
shown in Table 4, the most powerful predictor of
outcome in patients with Diffuse Injury III (swelling)
was the highest ICP. In contrast, within the other groups
(not shown), age and motor scores were the most pow-
erful predictors. Further serving to emphasize the ad-
verse consequences of high ICP in these patients, those
in Diffuse Injury III group with good motor scores did
relatively less well than the TCDB cohort as a whole in
which postresuscitation GCS scores closely correlated
with outcome.

There is, of course, an interdependence between the
degree of motor dysfunction and the status of the brain
stem and the cisterns seen on CT scan. However, for
the specific diagnostic categories used here, the CT scan
often appeared to be a more accurate predictor of the
ultimate course of patients with absent or compressed
cisterns than the patient’s initial clinical examination if
the latter revealed a less severe injury. This was also our
experience in the pilot phase of the TCDB study,6

It is beyond the scope of this article to deal with the
specific question as to the reversibility of the CT scan
findings based on therapeutic intervention. However, it
is important to note that, within the TCDB, a substan-
tial reduction in mortality from elevated ICP has been
reported in a preliminary fashion in patients with absent
or compressed cisterns who had less severe injuries
(GCS scores of 6, 7, or 8). This suggests, at least for
some patients, that early intervention for intracranial
hypertension might play an important role in prevent-
ing deterioration, a vegetative outcome, or death.

Discussion

The CT classification introduced here appears to
have significant application in the clinical care of the
acutely head-injured patient. The very strong relation-
ship between the CT scan appearance, mortality, and
the frequency of elevated ICP in the population indi-
cates that the CT findings are strongly predictive of
the likelihood of intracranial hypertension and that there
is a relationship, perhaps not completely defined, be-
tween the degree of intracranial hypertension and the
likelihood of death. Undoubtedly other factors, partic-
ularly the actual impact injury in the severely injured
patient, determine the postinjury course. However, in
patients with less substantial biomechanical injuries, it
appears likely that early intervention might prevent the
development of other insults and improve both mortal-
ity and the overall quality of life. Certainly, the rather
low mortality rate for institutions utilizing systematic
treatment schemes for patients with GCS scores of 6,
7, or 8, when compared to results in hospitals with a
much smaller experience in the care of such patients,
suggests that therapeutic intervention does matter.

This new categorization offers the possibility of early
identification of patients at risk as well as earlier pre-
diction of severely head-injured patients falling into
broad outcome categories. While this concept needs to
be tested in a large series of patients for whom predic-
tions are made within 24 hours using the limited infor-
mation that would then be available, our preliminary
experience in one center with this approach is promis-
ing.

The new classification of head injury also permits
the early identification of patients potentially at high
risk from intracranial hypertension and allows the
neurosurgeon the option of early intervention. Such a
classification also allows the identification of specific
subsets of patients from within the overall grouping of
diffuse injury who have remarkably similar courses and
mortality rates when compared to patients with extrar-
axial and intra-axial mass lesions; these include patients
with diffuse injury with swelling (Diffuse Injury III) and
diffuse injury with midline shift (Diffuse Injury IV).
Diffuse Injury categories III and IV appear to be anal-
ogous in many ways to patients harboring acute, sizable
hemorrhagic lesions and are logical groups for clinical
trials to test the efficacy of presently available as well
as new therapies. Furthermore, although the frequency
of diffuse head injury with midline shift (Diffuse Injury
IV) was relatively low, its very high mortality rate in
head-injury centers that are experienced in the care of
such patients suggests that these patients represent a
target group in which innovative therapies might first
be tested.5

References

severe head injury with early diagnosis and intensive

of the type of intracranial lesion on outcome from severe

New York: John Wiley & Sons, 1989


This work was additionally supported by National Institute of Neurological Disorders and Stroke Contracts NO1-NS-9-2306, 2307, 2308, 2309, and 2313 for the Pilot Traumatic Coma Data Bank.

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