EAD injuries are a major cause of death and disability and are the most common cause of death in the 15- to 24-year age group. Outcome after severe head injury is determined by the extent of the primary impact–related damage and secondary damage produced by various insults to the injured brain. Disturbances of the cerebrovascular circulation often occur after head injury and can contribute to the occurrence of these secondary insults. Knowledge of any disturbance is therefore critical for the diagnosis and management of the head-injured patient. Transcranial Doppler (TCD) ultrasound, introduced in 1982, is noninvasive and allows investigation of aspects of the cerebral vasculature. The major arteries of the circle of Willis can be insonated through the intact cranium, with systolic flow velocity, diastolic flow velocity, and time-averaged mean flow velocities measured in centimeters/second. Ratios such as the pulsatility index (PI), which is an indicator of cerebrovascular resistance, can also be calculated.

Transcranial Doppler ultrasound examinations are frequently used in the intensive therapy units of hospitals as part of the management strategy for head-injured patients. Initial TCD measurements are usually obtained in the first 24 hours after injury, often without specifying the exact time of measurement. A small number of studies have been conducted in which TCD measurements were obtained in patients while they were in the emergency room. In these studies the exact time between injury and the TCD measurements was recorded in only four patients.

The early stages of cerebrovascular events have been studied in animals and significant changes in cerebral hemodynamics are often found during the first 1 to 2 hours. A porcine model of head injury showed that on impact there was a dramatic increase in intracranial pressure (ICP) and cerebral blood volume, which decreased over the next 30 minutes to within the normal range and then increased again over the next 1 to 2 hours. It is not known if similar changes occur in humans.

Most head-injured patients do not arrive at a neurological center until more than 3 hours postinjury because many require an interhospital transfer. Therefore, early changes in cerebral hemodynamics that take place in the first 1 to 2 hours after head injury have not been recorded. Transcranial Doppler ultrasound examinations performed while patients are in the emergency room may have a role in determining treatment priorities, especially in those with multiple injuries.

**Object.** This study was designed to investigate the incidence of early abnormalities in the cerebral circulation after head injury by relating the results of the initial computerized tomography (CT) scan with transcranial Doppler (TCD) ultrasound readings to see if the side of injury and the outcome can be predicted by using these modalities.

**Methods.** Transcranial Doppler ultrasound measurements were obtained in the emergency room in 22 head-injured patients less than 3 hours after injury. The middle cerebral artery (MCA) was insonated using a standard technique. The TCD measurements in each MCA were examined individually; of 39 measurements, 22 (56%) showed a low mean blood flow velocity, 27 (69%) demonstrated a high pulsatility index (PI), and 18 (46%) showed both abnormalities. The side of the cerebrovascular abnormality measured by TCD ultrasound did not appear to be an accurate predictor of the side of the injury as determined on the initial CT scan. Of 13 patients in whom either a space-occupying hematoma or signs of swelling were shown on the initial CT scan, 10 (77%) had an increased PI in one or both MCAs, which is an indication of high flow resistance.

**Conclusions.** Transcranial Doppler ultrasound examinations performed while patients are in the emergency room may have a role in determining treatment priorities, especially in those with multiple injuries.

**Key Words.** head injury • transcranial Doppler ultrasound • middle cerebral artery • pulsatility index • mean blood flow velocity
Early TCD ultrasound after head injury

scans were used to see if from these studies we can predict the side of injury and outcome.

**Clinical Material and Methods**

Patients who had suffered a serious head injury (Glasgow Coma Scale [GCS] \([GCS] \leq 8\) or Abbreviated Injury Scale [AIS] \([AIS] \geq 3\)) were admitted to the Royal London Hospital on weekdays between 9 a.m. and 5 p.m. between April 1996 and June 1997 via the Helicopter Emergency Medical Service. Patients with an open head injury or head wound that prevented the TCD examination from being performed were excluded, as were patients who were undergoing cardiopulmonary resuscitation. In this initial study, equipment, technical staff, or access to the patient were not always available in the resuscitation room. Of the 64 patients brought in via helicopter during this period who met the preceding criteria, 22 were successfully examined while in the emergency room. Recordings were obtained from one side only in five patients. The median age of the patients was 30.5 years (interquartile range 24–45 years), and there were 19 males and three females.

Transcranial Doppler ultrasound monitoring was performed while patients were in the emergency room. A trans link 9900 machine (Rimed, Raananna, Israel) with a 2-MHz pulsed transducer was used. Tracings from both middle cerebral arteries (MCAs) were recorded according to the technique described by Aaslid, et al.\(^1\) The 2-MHz ultrasound probe was applied to the scalp through the thin bone in the temporal fossa. Peak and mean velocities were recorded in centimeters/second and the PI (peak systolic flow velocity / diastolic flow velocity) was calculated. Age-adjusted normal values for the mean blood flow velocity were calculated according to the method described by Ringelstein.\(^2\) The lower limit of the normal range was taken as 2 standard deviations below the mean. The normal value for the PI does not vary with age.\(^3\)

The severity of head injury in this study has been classified according to the GCS and AIS scores.\(^4\) The age, sex, and initial GCS score of each patient were recorded. On discharge from the hospital or death the AIS score of the head was calculated. This is an anatomically based system in which individual injuries are classified by body region on a 6-point severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable). Intracranial damage is given an AIS score of 3 or greater.\(^5\) Scores of 3 or more are used to define serious, severe, critical, and currently untreatable head injuries. The type of head injury was determined from the initial CT scan\(^6\) and classified according to the method described by Marshall, et al.\(^7\) All CT scans were independently reviewed by a Consultant Neurosurgeon. The time of injury and the time of the TCD study were recorded, and the blood pressure was noted at the time of the TCD measurement.

Prehospital treatment of patients with severe head injury by the London Helicopter Emergency Medical Service system frequently involves immobilization, sedation, and intubation because this corrects hypoxia, reduces secondary brain injury, and allows safe transport of agitated patients, especially if spinal injuries are suspected.\(^8\) Early anesthesia administration frequently means that only the GCS score taken at the scene of the accident is available, but this measurement may be made too soon after the injury to be a good indicator of its severity.\(^9\) Although the GCS score is used alone as an admission criterion for most studies of severe head injury, in our study we also used the AIS score of the head to classify the severity of damage and to include patients with a severe head injury whose neurological status had not deteriorated to a GCS score of 8 or less before early intubation.

Statistical analysis included calculations of the correlation coefficients by using commercially available software (Statview; Abacus Concepts, Inc., Berkeley, CA), and chi-square tests were used where appropriate.

**Results**

The initial GCS scores and the AIS scores of the head for each patient are shown in Fig. 1. The mechanism of injury varied, with 14 patients (64%) having been involved in a motor vehicle accident, six (27%) having fallen, and two (9%) having been injured in other incidents. All patients had undergone intubation and ventilation by the time of the examination.

The times from injury to TCD measurement are shown in Fig. 2. The median time from injury to TCD measurement was 83.5 minutes (interquartile range 69–94, full range 53–187 minutes). The blood pressure at the start of the TCD examination is shown in Fig. 3: the median systolic blood pressure was 145 mm Hg (interquartile range 130–160 mm Hg), and the median diastolic blood pressure was 80 mm Hg (interquartile range 70–95 mm Hg).

The abnormalities found on TCD ultrasound examination varied, either showing a low mean blood flow velocity, a high PI, or both. Of the 22 patients examined, 19 (86%) had abnormalities in either their left or right MCAs.
In the 17 patients in whom recordings were obtained in both left and right MCAs, 12 (70%) had abnormal readings on both sides, in three (17%) the readings were abnormal on one side, and in two (11%) the readings were normal. Of the five patients in whom unilateral TCD recordings were obtained, four underwent measurement on the side of injury, all of which measurements were abnormal. One patient underwent measurement on the side opposite to the brain injury, and this study was normal. The side of the cerebrovascular abnormality measured by TCD ultrasound did not appear to be an accurate predictor of the side of injury as seen on the initial CT scan, as is shown in Fig. 5. The specific CT scan details for each patient are shown in Table 2.

Of the 15 patients in whom TCD recordings were obtained from both left and right MCAs and in whom CT scans were available, six (40%) exhibited abnormalities on the side(s) of the injury. Of the five patients in whom unilateral TCD recordings were obtained, four underwent measurement on the side of injury, all of which measurements were abnormal. One patient underwent measurement on the side opposite to the brain injury, and this study was normal. The side of the cerebrovascular abnormality measured by TCD ultrasound did not appear to be an accurate predictor of the side of injury as seen on the initial CT scan, as is shown in Fig. 5. The specific CT scan details for each patient are shown in Table 2.

Thirteen patients had either space-occupying hematomas or brain swelling, and 10 (77%) of these had an increased PI as an indicator of high flow resistance (Fig. 6). Three (33%) of the nine patients with no hematomas or brain swelling had an increased PI. This distribution was not statistically significant (Fisher’s exact probability, p = 0.34).

There was a negative correlation between the mean blood flow velocity and the PI (r² = 0.27, p < 0.01). Other correlations between the AIS score and the PI, and the GCS score and the PI were not statistically significant. Correlations between the AIS score and the mean blood flow velocity, and the GCS score and the mean blood flow velocity were also not statistically significant (p > 0.05).

Discussion

In previous studies a correlation has been reported between blood flow velocity within 24 hours of admission and severity of injury. It has been shown that initial levels of flow velocity in the MCA in severely head injured patients were much lower than those seen in moderate and minor head injury. Daily TCD recordings obtained postinjury have shown that the flow velocities will remain low (a grave sign), may become normal, or may rise above normal levels of 100 cm/second or more, decreasing gradually over a few days. The more severe the head injury the
longer the duration of low flow velocity. Measurement of MCA blood flow velocity provides information about changes in cerebral hemodynamics and increased ICP.

In this study we have used TCD ultrasound to show that changes occur in MCA blood flow velocity early after severe head injury. The authors of previous TCD studies have not been able to examine the head-injured patients this soon after injury. Burger and Hassler performed TCD examinations in head-injured patients while in the emergency room but they did not specify the time from injury and reported results in only three patients. These authors found increases in the PI and decreases in the average flow velocity in patients with hematomas and brain swelling and concluded that TCD examinations in the emergency room could facilitate the initial management decisions.

The patients reported on in this study have shown changes in cerebral hemodynamics within the 1st, 2nd, and 3rd hour postinjury. In two patients the TCD examinations were obtained within the 1st hour postinjury. The patient in Case 7 showed a decreased mean blood flow velocity and a high PI 55 minutes postinjury. The patient in Case 18 showed a decreased blood flow velocity with normal PI 53 minutes postinjury.

The MCA blood flow velocity cannot be considered to be a direct reflection of cerebral blood flow because of the complex nature of vascular resistance. The admission MCA blood flow velocities recorded in the emergency room may be helpful in confirming the severity of the head injury, especially if the patient is intubated and ventilated. Because the arterial blood pressure can be easily determined, changes in MCA flow velocity may be helpful to indicate compromised cerebral perfusion. A low mean blood flow velocity that is identified soon after injury may therefore guide the choice of blood pressure targets that should be used during the resuscitation.

FIG. 4. Upper: Chart showing mean blood flow velocity measurements for each patient. Horizontal lines pointing left and right indicate the side of the measurements. Dotted lines show age-adjusted normal values calculated as 2 standard deviations below the mean. Lower: Chart showing PI recordings obtained from the MCA of each patient in the emergency room. Horizontal lines pointing left and right indicate the side of the measurements. Dotted line shows the upper limit of the normal range.
tensive resuscitation” before hemorrhaging is surgically
controlled may improve outcome, but if the patient has
suffered a head injury, this kind of resuscitation is likely
to increase secondary brain injury. The TCD examinations
performed in patients while in the emergency room may
help define a group for whom higher blood pressure tar-
gets should be used for fluid resuscitation.

The PI is a measure of cerebrovascular resistance (see
Clinical Material and Methods). Homberg, et al., have
suggested a correlation between ICP and the PI. Intra-
cranial pressure monitoring provides information about
the cerebral perfusion pressure (CPP): (CPP = mean arte-
rical pressure - ICP) and it has been shown that when
CPP falls because of raised ICP or reduced arterial pres-
sure, the diastolic flow velocity decreases more than the
systolic flow velocity. The difference in flow velocity
causes an increase in the PI from the normal value of
approximately 1 to values of greater than 2. Many head-injured patients suffer not only from the pri-

As CPP decreases further (at very high ICPs) cerebral
circulatory arrest occurs and the MCA velocity waveform
goes through a characteristic sequence of changes; the
diastolic velocity falls to zero and is followed by an alter-
ating flow pattern that is anterograde in systole and ret-
rograde in diastole. This flow pattern is a predictor of
early brain death. An alternating flow pattern was not
seen in any of the patients in this study. Increases in blood
flow velocity have also been associated with posttraumat-
ic hyperemia and vasospasm. None of the patients in
this series showed an increase in blood flow velocity.

Transcranial Doppler ultrasound examinations per-
formed early after injury while the patient is in the emer-
gency room may help when a decision has to be made
about the sequence of radiological studies. The choice is
frequently between whether a patient should undergo a CT
scan to look for an intracranial hematoma or be taken
directly to the operating room for the surgical control
of the internal hemorrhaging. If the patient undergoes scanning
and is found to have a normal brain, this has delayed the
control of the internal hemorrhaging, although performing
lengthy surgical procedures before scans are obtained
could delay the removal of the intracranial hematoma.
The choice between CT scanning and hemorrhage control
is usually based on factors such as the mechanism of injury,
GCS score, and localizing neurological signs, which alter
the odds of a surgically correctable head injury. Trans-
cranial Doppler measurements obtained while the patient
is in the emergency room may provide an additional fac-
tor because, for example, a normal TCD will indicate a
decrease in the odds of significant brain injury.

Many head-injured patients suffer not only from the pri-
Early TCD ultrasound after head injury

CT scan injury

<table>
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<tr>
<th>TCD abnormality</th>
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<th>Right</th>
<th>Left</th>
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<td>3</td>
<td>1</td>
</tr>
<tr>
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<td>0</td>
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Table 2
Details of CT scans obtained in 22 patients with head injuries*

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<tr>
<th>Case No.</th>
<th>Basal Cisterns</th>
<th>Midline Shift</th>
<th>Hematoma Type</th>
<th>Hematoma Size</th>
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<th>IVH</th>
<th>Injury Location</th>
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<td>&lt;25 ml‡</td>
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<td>rt temp parietal</td>
</tr>
<tr>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>diffuse</td>
</tr>
<tr>
<td>7</td>
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<td>&lt;5 mm</td>
<td>SDH &amp; ICH</td>
<td>both &gt;25 ml§</td>
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<td>no</td>
<td>lt frontotemp pariatal</td>
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<td>lt</td>
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<td>no</td>
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<td>lt frontal</td>
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<tr>
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<td>&lt;25 ml§</td>
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</tbody>
</table>

* EDH = extradural hematoma; ICH = intracranial hematoma; IVH = intraventricular hemorrhage; NA = not applicable; SAH = subarachnoid hemorrhage; SDH = subdural hematoma; temp = temporal.
† Patient died in resuscitation room; no CT scans obtained.
‡ Evacuated hematoma.
§ Unevacuated hematoma.

Transcranial Doppler examinations performed in the emergency room have the potential to assist early decision making, especially in the choice between the often conflicting treatment priorities in patients with multiple injuries.
Conclusions

Changes in MCA blood flow velocity are seen in the 1st, 2nd, and 3rd hour after severe head injury. The most common change is a rise in the PI above the normal range. Transcranial Doppler recordings obtained this early after head injury have not been reported previously, although TCD has the potential to aid decision making in the early treatment of patients with multiple injuries. The role of this technique in the immediate evaluation of these patients requires further investigation.

References


J. C. McQuire, J. C. Sutcliffe, and T. J. Coats