Progressive hemorrhage after head trauma: predictors and consequences of the evolving injury

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Object. Progressive intracranial hemorrhage after head injury is often observed on serial computerized tomography (CT) scans but its significance is uncertain. In this study, patients in whom two CT scans were obtained within 24 hours of injury were analyzed to determine the incidence, risk factors, and clinical significance of progressive hemorrhagic injury (PHI).

Methods. The diagnosis of PHI was determined by comparing the first and second CT scans and was categorized as epidural hematoma (EDH), subdural hematoma (SDH), intraparenchymal contusion or hematoma (IPCH), or subarachnoid hemorrhage (SAH). Potential risk factors, the daily mean intracranial pressure (ICP), and cerebral perfusion pressure were analyzed. In a cohort of 142 patients (mean age 34 ± 14 years; median Glasgow Coma Scale score of 8, range 3–15; male/female ratio 4.3:1), the mean time from injury to first CT scan was 2 ± 1.6 hours and between first and second CT scans was 6.9 ± 3.6 hours. A PHI was found in 42.3% of patients overall and in 48.6% of patients who underwent scanning within 2 hours of injury. Of the 60 patients with PHI, 87% underwent their first CT scan within 2 hours of injury and in only one with PHI was the first CT scan obtained more than 6 hours postinjury. The likelihood of PHI for a given lesion was 51% for IPCH, 22% for EDH, 17% for SAH, and 11% for SDH. Of the 46 patients who underwent craniotomy for hematoma evacuation, 24% did so after the second CT scan because of findings of PHI. Logistic regression was used to identify male sex (p = 0.01), older age (p = 0.01), time from injury to first CT scan (p = 0.02), and initial partial thromboplastin time (PTT) (p = 0.02) as the best predictors of PHI. The percentage of patients with mean daily ICP greater than 20 mm Hg was higher in those with PHI compared with those without PHI. The 6-month postinjury outcome was similar in the two patient groups.

Conclusions. Early progressive hemorrhage occurs in almost 50% of head-injured patients who undergo CT scanning within 2 hours of injury, it occurs most frequently in cerebral contusions, and it is associated with ICP elevations. Male sex, older age, time from injury to first CT scan, and PTT appear to be key determinants of PHI. Early repeated CT scanning is indicated in patients with nonsurgically treated hemorrhage revealed on the first CT scan.

KEY WORDS • progressive hemorrhagic injury • traumatic brain injury • intracranial hemorrhage • timing of computerized tomography scanning

In the development of regionalized trauma care centers and emergency medical transport capabilities throughout North America, Europe, and elsewhere, many trauma patients currently arrive at a hospital emergency room within 1 to 2 hours of injury. In these settings, head-injured patients typically undergo their first cranial CT scan when the intracranial injury may be rapidly evolving. During this initial period, such patients are often intubated and sedated on an emergency basis for airway control or to relieve agitation, and thus their neurological examination is unreliable. Recognizing these facts, physicians at many trauma centers have adopted a policy of early repeated CT scanning within a few hours of the initial CT study to detect progressive IPCH before irreversible neurological deterioration occurs. The data provided by an early repeated CT scan, along with other measures such as ICP monitoring, is potentially crucial for triggering timely medical or surgical intervention to avert serious secondary cerebral insults.

Since a policy requiring repeated CT scanning within 4 to 8 hours of the initial CT study was adopted more than 7 years ago at the UCLA and Harbor–UCLA Medical Centers, it has become apparent that PHI is indeed common. Several investigators have previously reported that hemorrhagic lesions may increase in size after head injury. Most of these studies, however, addressed the issue of delayed ICH, not acute hemorrhagic progression within hours of injury.

In our study, PHI was defined as any intracranial hemorrhage or to relieve agitation, and thus their neurological examination is unreliable. Recognizing these facts, physicians at many trauma centers have adopted a policy of early repeated CT scanning within a few hours of the initial CT study to detect progressive IPCH before irreversible neurological deterioration occurs. The data provided by an early repeated CT scan, along with other measures such as ICP monitoring, is potentially crucial for triggering timely medical or surgical intervention to avert serious secondary cerebral insults.
rhagic lesion that had increased in size on a second CT scan obtained within 24 hours postinjury. The frequency of this phenomenon, its clinical significance, and the key factors associated with its occurrence were investigated. Potential risk factors for PHI include abnormalities in coagulation parameters such as PTT, PT, and platelet count, which have been associated with delayed40 and postoperative ICH.42 Ethanol intoxication has also been associated with coagulopathy6 and is known to impair platelet function.9 The effect of initial body temperature may also be important in PHI, given that both hypothermia and hyperthermia could potentially contribute to coagulation abnormalities.4,19 Early postinjury hypotension and hypoxia may also play a role by causing regional or global ischemic insults that in turn could be converted to areas of hemorrhagic infarction.21,45

Another key factor in progressive hemorrhage may be the timing of CT scans relative to the time of injury.10,21 With these considerations in mind, the purpose of this study was threefold: 1) to determine the incidence and nature of PHI in patients undergoing serial CT scans in the acute phase postinjury; 2) to define the risk factors for PHI; and 3) to determine the consequences of PHI with regard to the subsequent ICP and CPP course, the need for surgical intervention, and long-term outcome.

### Clinical Material and Methods

**Inclusion Criteria**

The UCLA Office for the Protection of Research Subjects approved the Brain Injury Research Center project; informed consent was obtained from the next of kin or legal guardians for all patients. Acutely head injured patients admitted to either UCLA or Harbor–UCLA Medical Centers were eligible for inclusion in the study if they were 16 years of age or older, had sustained a closed or penetrating brain injury with abnormal results on the initial CT scan, were prospectively enrolled in the UCLA Brain Injury Research Center study, and were prospectively enrolled in the UCLA Brain Injury Research Center project; in-
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Center project, and had undergone at least two CT scans within the first 24 hours postinjury.

**General Management Protocol**

Patients were admitted to the intensive care unit after initial stabilization or surgical evacuation of an ICH and were treated in accordance with the Level I Trauma Center protocol and the Guidelines for the Management of Severe Head Injury. Management goals included maintenance of ICP at less than 20 mm Hg and CPP above 70 mm Hg. In general, in patients in whom ICP remained below 20 mm Hg for 24 to 48 hours without the need for mannitol administration or ventricular drainage, the ICP monitor was removed.

**Defining PHI**

The first two CT scans were evaluated independently by two authors (either M.O. or J.H.L., followed by D.F.K.) for evidence of hemorrhagic progression of EDH, SDH, SAH, and IPCH. We defined PHI as an unambiguous increase in the full film appearance of lesion size; this amounted to a 25% or more increase in at least one dimension of one or more lesions seen on the first postinjury CT scan. In ambiguous cases, the report dictated by the neuroradiologist was used to determine the presence or absence of hemorrhagic progression. Patients in whom the dictated report noted no progression were classified as having a nonprogressive hemorrhage. Figure 1 shows sequential CT scans obtained in one patient to illustrate the definition of PHI in this investigation.

**Defining Progressive Shift and Swelling**

The first two CT scans were compared. Increased midline shift, hemispheric swelling, or progressive loss of basilar cisterns on the second CT scan was defined as “progressive shift and swelling.”

**Timing of CT Scans Relative to Time of Injury**

The time of injury was determined by paramedic and emergency room documentation. The time stamped on the first and second CT scan films was noted. These time points then allowed calculation of three time intervals as follows: 1) the time between injury and the first CT scan; 2) the time between injury and the second CT scan; and 3) the time between the first and second CT scans.

**Predictors of PHI**

Several continuous, categorical, and time parameters were chosen that might potentially contribute to PHI (Table 1). Three time intervals were assessed, as outlined earlier. The factors of patient age and sex were also assessed. The time intervals were used as continuous parameters. Blood samples routinely obtained in the emergency room were analyzed for coagulation parameters and ethanol levels. The normal range for PT is 23 to 33.4 seconds, for PTT it is 9.7 to 11.5 seconds, and for platelets it is 143,000 to 398,000/mm³. Blood ethanol levels were recorded and analyzed as continuous variables. The effect of the initial body temperature was analyzed by assessing the lowest and highest body temperature recorded from the time of injury until the second CT scan. Hypothermia was defined as a body temperature lower than 36°C. Body temperature was analyzed both as a continuous and categorical parameter. The administration of mannitol before the second CT scan was documented by emergency department personnel and used as a categorical variable. Early hypotension or hypoxia was defined as a systolic BP lower than 90 mm Hg or a PaO₂ lower than 60 mm Hg (or apnea), respectively, documented in the prehospital setting or before the second CT scan was performed. Resuscitation efforts and catecholamine administration in the emergency room can lead to significant variations of BP after initial hypotension. The difference between minimal and maximal systolic BP may be an indirect measure of the efforts at resuscitation and was therefore evaluated as a possible predictor of progressive hemorrhage.

**Impact of PHI**

The mean arterial BP and ICP were recorded hourly. To evaluate the effect of PHI on ICP, the patients’ daily hours during which ICP readings were higher than 20 mm Hg were calculated over time in patients in whom an ICP monitor was in place. An assumption was made that in those patients who did not have an ICP monitor in place or in whom the monitor had been removed the average daily ICP readings were lower than 20 mm Hg and the hours during which ICP was higher than 20 mm Hg were 0. Whether patients required a craniotomy for hematoma evacuation after the first or second CT scan was recorded. The discharge and 6-month Glasgow Outcome Scale scores were also compared in the patient groups with and without PHI. A favorable neurological outcome was defined as a good recovery or moderate disability.

**Statistical Analysis**

A multivariate logistic regression analysis was performed to determine the predictors of PHI. The outcome variable was dichotomized as PHI positive or negative. The data were analyzed using Excel and SPSS software (Microsoft Corp., Redmond, WA, and SPSS, Inc., Chicago, IL). Predictors were defined as being significant (p < 0.05) after all predictors were added to the model. The Poisson regression for repeated measures was used to determine the effects of PHI, especially on ICP. Chi-square statistics were calculated for categorical comparisons. Values for the continuous parameters are given as the mean ± SD.

**Illustrative Case**

This 57-year-old woman fell 12 ft (4 m) from a balcony. On arrival in the emergency room she was hemodynamically stable, with an initial GCS score of 6. Her ethanol level on arrival was 217 mg/dl. Initial coagulation parameters were normal (platelets 219,000, PTT 27.3 seconds, PT 10.6 seconds). The initial CT scan (Fig. 1 left) obtained approximately 30 minutes postinjury demonstrated multiple small contusions in the left frontal, temporal, and right temporal lobes and a thin left convexity SDH; basilar cisterns were open. The second CT scan (Fig. 1 right) obtained 5 hours and 40 minutes postinjury revealed hemorrhagic progression in the left frontotemporal areas with progressive shift and swelling; her ICP had also begun to increase above 20 mm Hg. She underwent emergency craniotomy for evacu-
ation of the SDH and contusions in the left frontotemporal lobes.

Results

Rates of PHI by Patient Group and Lesion Type

A total of 142 patients (mean age 34 ± 14 years, male/female ratio 4.3:1, median admission GCS score of 8) were included in this study. The mean time from the injury to the first CT scan was 2 ± 1.6 hours, and the mean time between the first and second CT scan was 6.9 ± 3.6 hours. Progressive hemorrhagic injury was present in 60 patients (42.3%). Of 107 patients in whom a first CT scan was performed within 2 hours of injury, 48.6% demonstrated PHI on their second CT scan, accounting for 87% of all patients in whom PHI was diagnosed (Fig. 2).

As shown in Table 2, the highest rates of PHI were in patients with intraparenchymal hemorrhages (51%), whereas enlargement of EDH, SAH, and SDH was seen in 22%, 17%, and 11% of patients, respectively. Progressive hemorrhage of more than one lesion type was seen in 16 patients (in 11% of all 142 patients and in 27% of 60 patients with PHI). Of the 60 patients with PHI, enlargement was observed in lesions categorized as IPCH, SAH, EDH, and SDH in 80, 23, 13, and 9% of patients, respectively (Fig. 3). Of all enlarging IPCHs, 85% were in the frontal, orbitofrontal, or temporal lobes.

Indices of mass effect were associated with PHI; in the 60 patients with this syndrome, 52% had abnormal cisterns seen on their CT scans, compared with 33% of the 82 patients without PHI (p = 0.03). Similarly, progressive brain shift and swelling was present in 23% of patients with PHI but in only 4% of patients without PHI (p = 0.003). The second CT scan was performed earlier in patients with progressive brain shift and swelling than in patients without this finding (6.4 ± 4.2 hours postinjury compared with 9.3 ± 3.9 hours postinjury; p < 0.01). Of the 17 patients with progressive shift and swelling, eight underwent craniotomy for evacuation of an EDH (two patients), SDH (one patient), or IPCH (five patients) after the second CT scan.

Predictors of PHI

Of 14 potential factors, a logistic regression model of six predictors was identified (Table 3). This model allowed us to predict PHI correctly approximately two thirds of the time by providing a balanced sensitivity and specificity of 65%. In Table 3 the results of this analysis demonstrate that patient age, sex, the timing of CT scans relative to time of injury, the PTT, and arterial BP during the initial injury phase were the strongest predictors.

Older patients were more likely to have PHI than younger patients (p = 0.01, adjusted p value from logistic regression analysis). For example, of the 21 patients older than 50 years, 57% developed PHI compared with 40% of 121 patients who were younger than 50 years. Regarding patients’ sex, 48% of men developed PHI compared with 18% of women (p = 0.01 adjusted from logistic regression analysis). The time interval between injury and the first CT scan was also strongly predictive of PHI. The earlier the

TABLE 2

Rate of hemorrhagic lesions in all 142 patients and rate of PHI by lesion type

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>No. of Patients (%)</th>
<th>Rate of PHI by Lesion Type (%)</th>
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</thead>
<tbody>
<tr>
<td>EDH</td>
<td>36 (25)</td>
<td>8 of 36 (22)</td>
</tr>
<tr>
<td>SDH</td>
<td>52 (37)</td>
<td>6 of 52 (11)</td>
</tr>
<tr>
<td>IPCH</td>
<td>94 (66)</td>
<td>48 of 94 (51)</td>
</tr>
<tr>
<td>SAH</td>
<td>83 (58)</td>
<td>14 of 83 (17)</td>
</tr>
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Fig. 1. Left: Initial CT scans obtained 30 minutes postinjury, demonstrating multiple small contusions. Right: Second CT scans obtained 5 hours and 40 minutes postinjury, revealing hemorrhagic progression. (Note that the gantry angles for the first and second CT scans are not parallel.)

Fig. 2. Bar graph showing the relationship between PHI and the time from injury to the first CT scan. Of the entire cohort, in 75% (107 patients) the initial CT scan was performed within the first 2 hours of injury. Of these patients, 48.6% had PHI (dark stippling). In only six patients was the initial scan performed more than 6 hours postinjury and in no patient was an initial CT scan performed more than 10 hours postinjury. Absence of PHI is indicated by light stippling.
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In 27% of these patients, PHI occurred in multiple lesion types. ICH/Cx = IPCH.

Effects of PHI—Surgery

The classification of lesions removed surgically after the first or second CT scan is shown in Table 4. Of the 142 patients, 96 (68%) did not require a craniotomy for hematoma evacuation, and of these patients, 36% had PHI. Of the 23% of patients (32 individuals) who underwent craniotomy after the first CT scan, 47% had PHI. In 14 of these 15 patients with PHI after the initial craniotomy, the enlarging lesion seen on the second (postoperative) CT scan was an IPCH in a location remote from the surgical site. One patient rebled at the surgical site after evacuation of an SDH and IPCH.

Of the 11% of patients (15 individuals) who underwent craniotomy after the second CT scan, surgery was prompted in four patients by enlargement of the hematoma alone, in seven patients by enlargement of the hematoma in combination with progressive brain shift and swelling, and in four patients by elevated ICP alone. Categorized by evacuated hematoma type, these 15 patients accounted for 29, 21, 56, and 29% of all evacuated EDH, SDH, IPCH, and combination hematoma lesions, respectively. The 11 patients with PHI noted on the second CT scan accounted for 24% of all craniotomies performed for hematoma in the cohort. Of the factors shown in Table 1, two were predictive of surgery for hematoma evacuation after the second CT scan. As shown in Table 5, those patients with longer PTT and lower maximum body temperatures were more likely to require late surgery (p = 0.01).

Effects of PHI—ICP and CPP

Monitoring of ICP was conducted in 76% of patients. On average, patients with PHI tended to undergo ICP monitoring for a longer time than patients without PHI (3.8 ± 4 days compared with 2.7 ± 3.6 days, p = 0.08). Additionally, as seen in Fig. 4, starting on postinjury Day 1, in patients with PHI there were more hours per day when ICP was higher than 20 mm Hg and CPP was lower than 70 mm Hg than in patients without PHI (p = 0.01).

Outcome and PHI

Outcomes were classified at discharge and 6 months postinjury. Six-month follow-up data were obtained in only 51% of patients. At discharge, 17% of patients with PHI had a favorable outcome and 28% of patients without PHI had a good outcome (p = 0.13). At 6 months postinjury, a favorable neurological outcome was seen in 60% of patients with and in 70% of those without PHI, respectively (p = 0.34).

Discussion

Overview of Findings

In a population of 142 head-injured patients (who on average underwent their first CT scan within 2 hours of injury), progressive hemorrhage was observed on the second CT scan in 42% of all patients and in 49% of patients who underwent their first CT scan within 2 hours of injury. The rates of hemorrhagic progression for IPCH, EDH, SDH, and SAH were 51%, 22%, 11%, and 17%, respectively. Intraparenchymal lesions in the frontal, orbitofrontal, and temporal regions accounted for 85% of all enlarging parenchymal lesions. Of all craniotomies performed for

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Timing of hematoma evacuations</th>
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<tr>
<td>Stone</td>
<td>100.0</td>
</tr>
<tr>
<td>After</td>
<td>146.0</td>
</tr>
<tr>
<td>1st CT</td>
<td>60.0</td>
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<tr>
<td>2nd CT</td>
<td>40.0</td>
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* Combined lesions consisted of the following: one EDH with IPCH, three SDHs with IPCH, and one EDH with SDH.
† Two IPCHs with SDH, including one that rebled after the initial operation.
‡ Of these 15 craniotomies, 11 were prompted by PHI (including seven patients with PHI and progressive brain shift and swelling).
hematoma evacuation, 24% were done after the second CT scan because of PHI. The strongest predictors of PHI were older age, male sex, short time interval between injury and the first CT scan, a long initial PTT, and the absence of hypotension postinjury. On average, patients with PHI had longer periods of intracranial hypertension and reduced CPP over the first 10 days postinjury than did patients without PHI. Neurological outcome at discharge and 6 months postinjury was similar in patients with and without PHI, although 6-month outcome data were not available in almost half the patients.

Methodological Issues

The definition of PHI as an unambiguous increase in lesion size between the first and second CT scans was thought to represent a reproducible threshold. Although adequate methods for more precise volumetric analysis of changes in hemorrhage volume are currently available, such methods were not easily implemented at the time this analysis began in 1996. The effect of orally or intravenously administered contrast agents given between the first and second CT scans for the purposes of diagnosing intestinal or vascular injuries is also potentially problematic. When these materials are administered the size of cerebral contusions and the presence of SAH may be seen to increase. In analyzing patients as having or not having PHI, however, an effort was made to account for contrast administration by analyzing CT scans obtained subsequent to the second one to see if such enlarging hematomas or SAH actually grew more.

The administration of fresh-frozen plasma to improve intraoperative hemostasis during hematoma removal after the first CT scan is also problematic. Because both craniotomy for hematoma evacuation and administration of clotting factors are intended to halt bleeding and restore hemostasis, in patients who might otherwise have had significant hemorrhagic progression this process was likely diminished to some degree by these interventions.

Previous Studies of Progressive or Delayed IPCH

The focus of our study was on acute ICH in evolution. Originally, progression of ICH was often recognized in a delayed fashion. In 1891, Otto Bollinger first described secondary intracranial hematomas after head injury. After his first report, the term “Bollingerische Spätapoplexie” was used. Bollinger found intracranial hematomas during autopsies performed in head-injured patients who had shown symptoms of a stroke after a symptom-free interval. Subsequently, in 1938, Doughty introduced the term “delayed intracranial hemorrhage,” which became more popular with the advent of CT technology in the 1970s. The time period for detection of a delayed hemorrhage ranged from 6 hours to 30 days postinjury. Mertol, et al., noted that delayed ICH had been observed in previous reports in 0.6 to 7.4% of head-injured patients.

Based on the timing of the initial CT scan after injury, Frowein, et al., concluded that the 2nd and 3rd hour post-injury are particularly important for the detection of hemorrhagic lesions. This study, however, did not address findings on subsequent CT scans. Over recent decades, with the increasing availability of CT technology, sequential scans are frequently performed and the time interval between scans has diminished. In more recent studies of PHI, 23 to 47.5% of patients have demonstrated progressive enlargement of an ICH if two consecutive CT scans are performed within 24 to 72 hours of injury. In the present study we suggest that almost 50% of patients will show significant hemorrhagic progression if the first CT scan is performed within 2 hours of injury.

Factors Associated With PHI

In this study, the predictors of PHI were older age, male sex, a shorter time interval between injury and the first CT scan, a longer initial PTT, and the absence of hypotension in the first 24 hours postinjury. The timing of the first CT scan is clearly an important factor. It is not surprising that the sooner after injury the first scan is performed, the greater likelihood there is of subsequent hemorrhagic progression on later CT scans. A similar finding was reported by Kazui, et al., in patients with spontaneous intracerebral hematomas. In their study of 204 patients, hematoma enlargement occurred in 36% of those who underwent CT scanning within 3 hours of symptom onset, compared with only 6% of patients who underwent their initial CT study within 12 to 24 hours of symptom onset.

The finding that older age is also associated with PHI may be related to increased vascular rigidity and fragility. Hypertension, diabetes mellitus, and amyloidosis are also associated with blood vessel fragility, are more common in older patients, and are important in the development of hemorrhagic stroke. Whether these factors are relevant in PHI occurring after head trauma is unclear.

The fact that male sex was so strongly associated with PHI was somewhat surprising. It is possible that the putative neuroprotective effects of estrogen and progesterone in women reduce their likelihood of PHI; estrogen effects include diminished lipid peroxidation and cell membrane breakdown, decreased platelet aggregation and apoptosis, and increased cerebral blood flow. Progesterone’s neuroprotective effects are mainly due to membrane stabilization, glutamate receptor inhibition, and γ-aminobutyric acid receptor potentiation. In a rat model of head injury,
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male animals developed more pericontusional brain edema than did females.  

Regarding coagulopathy, in this study only the initial PTT value postinjury correlated with PHI and the need for surgery after the second CT scan. The three parameters used to define coagulopathy in this study (PT, PTT, and platelet count) are available in most hospitals, yet their reliability in predicting PHI is controversial. Studies by Stein and colleagues showed that an increase in PT and PTT, and a decrease in platelets, were predictive for PHI. Others, however, have not observed a correlation of these three factors with PHI. Other studies indicate that progressive hemorrhage after head injury is associated with diffuse intravascular coagulation as defined by increased concentration of fibrin degradation products and low fibrinogen concentration. These parameters may be more reliable markers of coagulopathy than PT, PTT, and platelet counts. Interestingly, patients who experienced an episode of hypotension were less likely to have PHI. This finding indicates that patients with systemic hypertension are more likely to have PHI. Nevertheless, an analysis of the highest and lowest recorded BPs prior to the second CT scan did not show such a direct correlation of PHI with BP. Other factors, including initial body temperature, ethanol level, and hypoxia were not predictive of PHI in this study. Lower body temperature, however, was associated with late surgery. Although hypothermia is a known cause of coagulopathy after trauma, it is usually associated with large drops in core temperature. No patient in this study had a recorded body temperature below 32°C, which is often cited as a critical threshold below which coagulopathy is likely. Ethanol intoxication has also been shown in several studies to impair platelet aggregation, prolong bleeding time, and to potentiate hypothermia and coagulopathy. The lack of correlation between the presence of ethanol or the level of ethanol with PHI in this study may be related to the fact that high levels of ethanol intoxication can also cause systemic hypotension, which in this study was predictive of the absence of PHI. The lack of correlation between hypoxia and PHI may be related to the fact that hypoxia itself is strongly associated with diffuse brain swelling. This hypoxia-induced brain swelling may limit PHI because of the mass effect associated with swelling.

Clinical Impact of Progressive Hemorrhage

Patients with PHI had a higher rate of compressed cisterns on CT scans, and, on average, had longer periods of elevated ICP and reduced CPP than those without PHI. In contrast, the neurological outcome did not appear to be affected by the presence of PHI. Nevertheless, the low rate of follow up at 6 months postinjury precludes definitive conclusions regarding PHI and outcome. Probably the most important clinical point of this analysis is that patients who sustain moderate or severe head injury have rapidly evolving intracranial injuries that warrant early reimaging and intensive monitoring. The fact that almost one quarter of all craniotomies performed in this series were prompted by PHI observed on the second CT scan emphasizes this point. Although surgical evacuation of intracerebral contusions and hematomas remains controversial, results of the present study reaffirm that these lesions have the greatest tendency to progress early after injury, often in dramatic and rapid fashion. We strongly agree with the recent recommendation by the European Brain Injury Consortium that early follow-up CT scans are warranted in patients whose initial CT scan demonstrates evidence of a diffuse injury as defined by the Traumatic Coma Data Bank.

Conclusions

Early after moderate or severe head injury, the initial CT scan does not reveal the full extent of hemorrhagic injury in almost 45% of patients. For patients undergoing scanning within 2 hours of injury, the rate of PHI approaches 50%. Parenchymal lesions in the frontal and temporal lobes are the most likely to progress. Male sex, older age, time from injury to first CT scan, and PTT appear to be key determinants of PHI. Patients with PHI have a greater degree of subsequent ICP elevations, and account for almost 25% of patients who require craniotomy for hematoma removal. Based on these findings, it is recommended that in moderately and severely head injured patients in whom a first CT scan is performed within 4 hours of injury and demonstrates ICH, a repeated CT scan should be performed within 4 to 6 hours of the first one.

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References


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