The prognostic significance of traumatic brainstem injury detected on T2-weighted MRI

Clinical article

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Object. Magnetic resonance imaging is frequently used to evaluate patients with traumatic brain injury in the acute and subacute setting, and it can detect injuries to the brainstem, which are often associated with poor outcomes. This study was undertaken to determine which MRI and clinical factors provide prognostic information in patients with traumatic brainstem injuries.

Methods. The authors performed a retrospective analysis of cases involving patients admitted to a Level I trauma center who were identified in a prospective database as having suffered traumatic brainstem injury identified on MRI. Patient outcomes were dichotomized to dead/vegetative versus functional groups. Standard demographic data, admission Glasgow Coma Scale (GCS) scores, results of the motor component of the GCS examination at admission and 24 hours later, CT scan findings, and peak intracranial pressure were collected from medical records. Volumetric analysis of each patient’s injuries was performed with T2-weighted and gradient echo sequences. The T2-weighted MRI sequence for each patient was reviewed to determine the anatomical location of injury within the brainstem and whether the injury crossed the midline.

Results. Thirty-six patients who met the study inclusion criteria were identified. At 6-month follow-up, 53% of these patients had poor outcomes and 47% had recovered. Patients with injuries to the medulla or deep bilateral injuries to thepons did not recover. The T2 volumes were found superior to gradient echo sequences in regard to predicting survival (ROC/AUC 0.67, p = 0.07 vs 0.60, p = 0.29, respectively), but neither reached statistical significance. The timing of MR image acquisition did not influence the findings. The time from admission to MRI did not differ significantly between the recovered group and the poor-outcome group (p = 0.52, Mann-Whitney test), and lesion size as measured by T2 volume did not vary with time to scan (R² = 0.03, p = 0.3, linear regression). Performing a stepwise logistic regression with all the variables yielded the following factors related to recovery: crossing midline, p = 0.0156, OR 0.075; and 24-hour GCS motor score, p = 0.0045, OR = 2.25, c-statistic 0.913. Further examination of these 2 factors disclosed the following: none of 15 patients with midline-crossing lesions and a 24-hour GCS motor score of 4 or less recovered; conversely, 12 of 13 patients with lesions that did not cross midline recovered, regardless of GCS motor score.

Conclusions. Bilateral injury to the pons and medulla as detected on T2-weighted MRI sequences was associated with poor outcome in patients with brainstem injuries; T2 volumes were found superior to gradient echo sequences in regard to predicting survival, but neither reached statistical significance. When MRI findings were coupled with clinical examination findings, a strong correlation existed between poor outcome and the combination of bilateral brainstem injury and a motor GCS score of 4 or less 24 hours after admission.

Key Words • trauma • brainstem injury • MRI • volumetric analysis • outcome • traumatic brain injury

One of the most important tools in the initial evaluation of patients with TBI continues to be the CT scanner, particularly in those who present with a low GCS score. The CT scanner has become nearly ubiquitous in emergency departments and allows for the rapid acquisition of readily available and easily interpretable images. Early detection of diffuse cerebral edema and lesions causing mass effects, such as epidural hematomas, subdural hematomas, and contusions, can lead to immediate and potentially lifesaving neurosurgical intervention.

Computed tomography, however, is not without limitations. The resolution of the CT scan is often not sufficient to adequately identify injury to the structures of the posterior fossa, specifically brainstem injury. In the supratentorial compartment, CT frequently fails to identify insults that may lead to severe cortical dysfunction, such as diffuse axonal injury. Injuries to the brainstem and/or diffuse axonal injury are often suspected in those TBI patients who have profoundly abnormal findings on neurological examination or who remain comatose in spite of a CT scan that fails to account for such deficits.
Traumatic brainstem injury and MRI

Increasingly, MRI has been used in the evaluation of the stabilized TBI patient in the acute setting. This imaging modality provides superior visualization of the brainstem and allows for delineation of areas of edema, ischemia, hemorrhage, and infarction. While such injuries are often ominous signs, outcomes can range from complete recovery to severe disability or death. Although MRI may help clarify the anatomical extent of neurological injury and account for abnormal findings on neurological examination, the role of MRI as a prognostic tool in traumatic brainstem injury has not been clearly defined. A greater understanding of these radiological abnormalities and the relationship to outcomes of TBI is needed if MRI is to be used effectively in the evaluation of patients with these injuries.

Methods

Patient Characteristics and Injury-Related Data

In this retrospective study, patients were identified from a prospectively maintained database at a Level I trauma center. The database was searched using the broad term “head injury” to ensure that all possible patients were identified. Only those patients who underwent MRI of the brain following the initial admission after suffering a TBI and who had abnormalities detected on either T2-weighted images and/or gradient echo sequences in the midbrain, pons, or medulla, as determined by a fellowship-trained neuroradiologist, were included in the study population.

Those patients who had mechanisms of injury consistent with trauma were included. Patients who had incomplete medical records, excessive artifacts on MRI, or signal abnormalities attributable to another cause (microvascular disease, central pontine myelinolysis, cerebrovascular accident) were excluded.

All patient demographic data and injury-related information were obtained from the medical records. Demographic data included age and sex. Injury-related data included mechanism of injury, total GCS score at admission and 24 hours after admission, and the motor component of the GCS examination at admission and 24 hours after admission. The type and number of neurosurgical operative procedures and indications, the placement of ICP monitors, and the highest ICP for each patient, when applicable, were documented.

Imaging

All patients underwent cranial CT scans as part of the initial admission evaluation. Magnetic resonance imaging was performed with a 1.5-T Siemens Symphony or a 1.5-T Siemens Vision (Siemens AG) utilizing 5-mm slices. The MRI sequences consisted of transverse spin echo T1-weighted images, T2-weighted spin echo images, T2-weighted FLAIR, T2*-weighted gradient echo sequences, diffusion-weighted images, and apparent diffusion coefficient.

The time between admission and the MRI study was determined by the attending physician. The primary indication for each patient undergoing MRI of the brain was an abnormal finding on a neurological examination. For those patients who had multiple MRI studies of the brain during the course of their admission, only the first MRI study was utilized in this study.

Image Analysis

For each patient axial MR images were digitally copied and then transferred to a laptop computer for image analysis (Apple MacBook Pro, Apple, Inc.). Ten slices of the brainstem were selected from a standard brain MRI atlas (https://msu.edu/~brains/brains/human/index.html) as reference images. To ensure precise anatomical localization of the injury within the brainstem, patient T2-weighted fast spin echo images and gradient echo sequences were aligned with the reference image utilizing the GNU Image Manipulation Program (http://www.gimp.org). Each patient’s MRI study was reviewed to determine the number and anatomical location of signal abnormalities within the brainstem (midbrain, pons, medulla) and whether there was a contiguous midline-crossing injury (Fig. 1). Volume analysis was performed by manually tracing the signal abnormality, and volume was calculated as a function of the imaging system software package (Carestream Vue PACS, Carestream Health Inc.)

Each patient’s initial CT scan was evaluated to determine the presence of subdural or epidural hematoma, subarachnoid hemorrhage, contusions, or intraventricular hemorrhage. Brainstem injuries and findings consistent with diffuse axonal injury were also documented.

Outcomes

Outcomes were dichotomized as nonrecovered (GOS score 1 or 2) or recovered (GOS score 3–5) at the 6-month follow-up point. Outcomes were determined through medical records, clinic charts, or telephone phone calls conducted as part of routine follow-up care. Patients were determined to be vegetative if they did not have any meaningful interaction with their environment. Those patients who died within 6 months of discharge and who did not have a functional neurological recovery at the time of discharge were considered to have succumbed to their injury.

The following factors were evaluated in relation to outcome: age, admission GCS score, the motor component of the GCS examination at admission and at 24 hours postadmission, peak ICP, total volume of brainstem injury based on T2-weighted and gradient echo MRI sequences, presence of bilateral brainstem injuries, presence of diffuse axonal injury in the brainstem and the supratentorial compartment (including the cortex, basal ganglia, and corpus callosum) on both CT and MRI, cerebral contusions, subarachnoid hemorrhage, epidural hematoma, subdural hematoma, and intraventricular hemorrhage.

Statistical Analysis

Statistical analysis was performed with MedCalc 11.6.1 (MedCalc Software). Relevant statistical tests are contained within figures and the body of the text. Where appropriate, the c-statistic (concordance statistic) was uti-
lized in the ROC analysis. The c-statistic compares the predictive value of the logistic regression result versus what actually occurred in the context of a logistic regression analysis.

Informed Consent and Disclosure

The Allegheny General Hospital institutional review board approved the study. Informed consent was waived.

Results

Between July 2004 and July 2010 there were 8922 admissions for head injury to the neurosurgical or trauma surgical service of Allegheny General Hospital. In 616 of these admissions, the patients underwent MRI of the brain, and in 48 patients abnormalities of the brainstem were identified on MR images. Seven of these 48 patients were determined to have findings not consistent with trauma and 5 had excessive motion or metal artifact, leaving 36 cases available for study.

The mean age of the 36 patients identified for this study was 45.5 years (range 17–90 years), and 69% of the patients were male. The mean GCS score at admission was 6 (range 3–15), with 24 patients (67%) comatose (GCS score ≤ 8) at presentation. At 6 months postadmission, 19 patients (53%) had poor outcomes, including 17 (47%) deaths and 2 (6%) patients in a vegetative state, and 17 patients (47%) had functional outcomes (Table 1).

The most common abnormality detected on the initial CT scan was subarachnoid hemorrhage, occurring in 47% of patients; the second most common was subdural hematoma, occurring in 44%. Epidural hematomas were identified in 5 patients (14%) and contusions in 10 patients (28%). Ten patients (28%) had findings consistent with diffuse axonal injury on CT, and another 11 patients had evidence of brainstem injuries detected on CT (31%).

Eight (22%) patients had no acute abnormalities identified on initial CT scan.

Eleven (31%) patients underwent operative neurosurgical procedures with 6 (17%) patients undergoing evacuation of subdural or epidural hematoma. Unilateral decompressive craniectomy in combination with either subdural or epidural clot evacuation was performed in 4 (11%) patients, and 1 (3%) patient underwent bilateral decompressive craniectomy due to elevated ICP refractory to conservative management. ICP monitoring, either by external ventricle drain or fiber optic intraparenchymal

<table>
<thead>
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<th>Variable</th>
<th>Recovered</th>
<th>Nonrecovered</th>
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<td>no. of patients (%)</td>
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<td>19 (52.8)</td>
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<td>0.53</td>
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* Values are numbers of patients unless otherwise indicated. Recovery status is based on assessment 6 months after admission, with recovery defined for purposes of this study as a GOS score of 3–5. Abbreviations: DAI = diffuse axonal injury; EDH = epidural hematoma; GE = gradient echo; IVH = intraventricular hemorrhage; SAH= subarachnoid hemorrhage; SDH = subdural hematoma.
† Student t-test.
‡ Mann-Whitney test.
§ Chi-square test.
Traumatic brainstem injury and MRI

pressure monitor was used in 15 (42%) patients. The ICP ranged from 2 to 79 mm Hg. There was no statistical difference in outcomes based on highest ICP recorded (stepwise logistic regression).

The majority of brainstem lesions involved the midbrain, with 22 (61%) injuries occurring at that level and subsequently decreasing caudally with 17 (47%) injuries occurring in the pons and 2 (6%) injuries occurring in the medulla. Of these brainstem injuries 11 (31%) had contiguous involvement of the midbrain and pons, 5 of which crossed the midline. The proportion of brainstem injuries that crossed the midline increased in a rostral to caudal progression, with 55% of midbrain injuries, 70% of pons, and 100% of medulla injuries crossing the midline.

Based on anatomical location within the brainstem, the poorest outcomes occurred with injury to the medulla—with a 100% mortality rate. Poor outcomes were also associated with any injury to the pons. Eleven patients (31%) had isolated pontine injuries, and 8 of these patients (73%) did not recover. There were 9 patients with isolated midline-crossing injuries to the pons; 7 (78%) had poor outcomes, and 2 (22%) had functional outcomes. Isolated midbrain injuries were detected in 11 patients (31%); 5 had unilateral injuries, and in 6 the injuries crossed the midline. Of this group, 4 patients (36%) had poor outcomes—one with a unilateral midbrain injury and 3 with a bilateral midbrain injury. Of the patients who had injuries spanning multiple brainstem levels, 5 had midline-crossing injuries extending from the midbrain into the pons, and none of these patients survived; in contrast, the 6 patients who had injuries that were similar but did not cross the midline had functional outcomes. When taking into account any injury that crossed the midline in the pons, whether in isolation or in conjunction with an injury at another level, 11 (85%) of 13 patients had poor outcomes.

There was a significant correlation among brainstem injuries that crossed the midline, the motor component of the GCS examination performed 24 hours after admission, and outcome (Table 2). Of the 15 patients with a 24-hour postadmission GCS motor score of 4 or less who had a midline crossing injury, no patient recovered, whereas 5 of the 6 patients with comparable examination results and injuries that did not cross the midline had functional outcomes. When taking into account any injury that crossed the midline in the pons, whether in isolation or in conjunction with an injury at another level, 11 (85%) of 13 patients had poor outcomes.

Performing a stepwise logistic regression with all the variables yielded the following factors related to recovery: crossing midline (p = 0.0156, OR 0.075) and 24-hour GCS motor score (p = 0.0045, OR 2.25, c-statistic 0.913). Further examination of these 2 factors disclosed the following: none of 15 patients with midline-crossing lesions and a 24-hour GCS motor score of 4 or less recovered; conversely, 12 (92%) of 13 patients with lesions that did not cross the midline recovered, regardless of 24-hour GCS motor score.

### Discussion

Magnetic resonance imaging appears to have the greatest potential to predict patient-specific outcomes following traumatic head injury. It can identify hemorrhage, ischemia, infarction, and shear injury with a high degree of clarity within specific anatomical structures throughout the entire intracranial compartment. Although MRI has been available for more than 30 years and has been indispensable as a diagnostic tool, as a prognostic instrument its potential has yet to be fully realized.

Injury to the brainstem may be the most consistent...
pathological finding on MRI that portends a poor outcome following head trauma.\textsuperscript{3,4,11,20,21} Even in the context of diffuse axonal injury, an entity often associated with severe neurological injury and prolonged coma, involvement of the brainstem appears to be the only factor that ultimately determines poor long-term outcomes.\textsuperscript{1,20}

With the increased utilization of MRI in the evaluation of the TBI patient, it has become apparent that the incidence of traumatic brainstem injury is more common than previously thought.\textsuperscript{3,22} Furthermore, it is now evident that not all patients with brainstem injuries suffer permanent neurological consequences.

More than 25 years ago, Wilberger et al.\textsuperscript{23} published one of the first reports describing the MRI findings in a population of patients with TBIs and a persistent GCS score of 7 or less. Their case series involved 24 patients with minimal CT scan findings and normal ICP who remained comatose. These patients were found to have either white matter shear injury, diffuse injuries, or injuries to the brainstem. Of the 5 patients who were found to have brainstem injuries, one patient died and the rest remained in a persistent vegetative state.

Firsching and colleagues\textsuperscript{8} examined outcomes in 61 patients with brainstem injuries detected on T2-weighted MRI in relation to outcomes in patients who had only supratentorial abnormalities. In a subsequent series of 102 patients who presented comatose they devised a 4-tier grading system based on the presence of supratentorial lesions only (Type I), unilateral lesions at any brainstem level (Type II), bilateral lesions of the mesencephalon (Type III), and bilateral pontine lesions (Type IV).\textsuperscript{4} Those patients who had a brainstem injury had an overall significant increase in morbidity and mortality compared with those without brainstem injuries. Unilateral lesions at any level and bilateral injuries to the midbrain were associated with prolonged duration of coma. Bilateral injuries to the pons (Type IV) were found to be uniformly fatal, a finding that has been replicated in other studies.\textsuperscript{3,22}

Schaefer and colleagues\textsuperscript{17} correlated outcomes with total volume of injury in 26 patients with diffuse axonal injury. In their study, volumes were measured throughout the entire intracranial compartment utilizing T2-weighted fast spin echo sequences, T2*-gradient echo sequences, DWI, and FLAIR and were correlated with outcomes utilizing the modified Rankin score. The strongest correlation with outcomes occurred with total volume of injury as measured by DWI with T2-weighted fast spin echo and FLAIR sequences, which also reached statistical significance. In contrast to other studies, this study did not show any significant correlation between the presence of brainstem injuries and worse outcomes.

In our retrospective study, we found that brainstem injury resulting from traumatic mechanisms resulted in a high degree of morbidity and mortality. More than half of the patients either died or were left in a persistent vegetative state. Patients with injury to the midbrain had the highest percentage of functional recovery, while injuries to the pons or medulla were associated with poor outcomes. Bilateral pontine injuries were associated with poor outcomes in this study. However, we did not find that midline-crossing pontine lesions were necessarily a uniformly fatal injury, contrary to findings in other studies,\textsuperscript{3,4,11} as 2 patients with midline-crossing lesions located in the ventral aspect of the pons made functional recoveries.

The outcome in these 2 cases suggests that ventral pons lesions have a more favorable outcome than more deep-seated pontine injuries regardless of whether the injury crosses the midline. Shibata et al.\textsuperscript{19} identified 17 patients with traumatic brainstem injuries detected on MRI and found that those who had superficial or more ventrally located abnormalities of the brainstem, even when located in the pons, had a good recovery while those with more deep-seated injuries, both in the midbrain and pons, ultimately were left with a severe disability. However, they did not describe whether these injuries crossed the midline.

Firsching et al.,\textsuperscript{3,4} Kampfl et al.,\textsuperscript{8} and Mannion et al.,\textsuperscript{11} documented consistent fatal outcomes after bilateral pontine injury, but they did not describe whether injuries in these patients were in the deep dorsal pons or were more ventrally located. The discrepancy between their data and our findings of 2 survivors with bilateral injuries to the pons is likely due to selection criteria, as all of their patients selected were comatose. In contrast our study population was selected based solely on the presence of MRI detected brainstem abnormalities and not on level of consciousness.

Bilateral injury to deep dorsal aspects of the pons is a recurring finding that correlates with poor outcomes in the patient with traumatic brainstem injury. However, unilateral injuries at any level and bilateral injuries of the midbrain have greater variability in outcomes, with some patients making full recovery and others not gaining any meaningful level of consciousness. It would appear that factors other than location of the injury within the brainstem may influence outcomes, and it would seem logical that total extent of injury might be such a factor.

In this study, we performed volumetric analysis of T2-weighted and gradient echo sequences as an in vivo marker to determine the extent of brainstem injury. We used T2-weighted sequences for several reasons. First, T2 signal hyperintensity has been the most widely studied MRI abnormality in conjunction with brainstem injuries. Second, the hyperintense signal of T2 is the last to diminish following TBI compared with other conventional MRI sequences. Finally, T2-weighted imaging is the single imaging sequence that allows for detection of the greatest range of pathology. Gradient echo sequences were used, as they allow for the detection of both frank hemorrhage and microhemorrhages associated with diffuse axonal injury.\textsuperscript{3} Ultimately, we did not find that volume of brainstem injury correlated with outcome. It appears that location of injury is a stronger factor in outcomes than extent of injury as determined by volumetric analysis. Clearly, the most profoundly predictive variables that correlated with patient outcomes were the variables of midline-crossing injuries and the 24-hour motor component of the GCS examination when analyzed in combination. In the logistic regression model this combination was associated with a c-statistic of 0.913, suggesting that over 90% of the variability in outcome is explained by those 2 factors.

Uniformly poor outcomes occurred in patients who had a GCS motor score of 4 or less at 24 hours after admis-
sion and bilateral brainstem injuries, regardless of injury location within the brainstem, but this correlation disappeared in patients with a GCS motor score greater than 4 even if the injury crossed the midline. The 8 patients who had a 24-hour postadmission GCS motor score of 5 or greater and had a midline crossing injury recovered regardless of the anatomical location of their lesions within the brainstem.

We examined outcomes in this patient population using admission GCS scores and scores on the motor component of the GCS examination obtained at admission and 24 hours after admission. There has been inconsistency in the literature regarding the correlation between admission GCS scores and outcomes. It is our supposition (as well as that of other authors) that the GCS score is often falsely low based on the initial admission examination and therefore is not an accurate depiction of a patient’s true neurological status. This disparity may occur due to the sedative medications and the paralytic agents used for intubation, as well as hypoxia, hypotension, injuries to other major organ systems, alcohol and/or drug intoxication, other metabolic derangements, and incomplete resuscitation. However, the motor component of the GCS has been shown to be a more reliable prognostic indicator following severe TBI. We found in this study that the 24-hour postadmission motor GCS score was a more reliable predictor of outcome while the motor component of the admission GCS examination was not, most likely due to the factors previously mentioned.

Due of the retrospective nature of this study, we could not control for the timing of when each patient underwent an MRI. This variability may result in differences in T2 signal intensity between patients, as T2 signal changes over time. Such variations may have altered interpretation of the MRI studies and therefore may have influenced the results. Those patients who did not recover underwent MRI much sooner after admission than those who did recover, although this difference was not statistically significant. In addition, there was no statistically significant difference when comparing outcomes and the single variable of time to MRI postadmission or when comparing outcomes in combination with the 2 variables of T2 volumes and time to MRI postadmission.

Our patient population differs from that of other studies in that we have focused on the outcome of all patients identified with traumatic brainstem injuries detected on MRI, regardless of initial examination findings at presentation, whereas previous studies have focused on patients who were comatose. By selecting our patient population in this manner we were able to determine the overall significance of MRI-detected brainstem injuries in the TBI population and which MRI abnormalities in combination with clinical examination findings differentiated those who had a functional recovery from those who succumbed to their injury. Our findings suggest that the traditional determinants of head injury such as age, surgical lesions, and ICP did not pertain to this particular group of patients and that MRI findings supersede factors used to predict outcome among TBI patients as a whole.

Limitations

This study was limited by the small patient popula-

tion, such that the confidence intervals of any prediction are going to be very wide. Moreover, it is retrospective in nature, and thus we could not control for variables such as time to MRI, variations in patient management, and overall patient selection. In order for any clear determination to be made about the significance and prognosis of brainstem injuries detected by MRI, larger prospective studies that yield more robust data need to be undertaken.

Furthermore there are no clear guidelines or consensus as to which MRI sequences are the most appropriate for evaluating brainstem injuries. We elected to use T2-weighted and gradient echo sequences as this allowed for the greatest detection of pathology, but other MRI sequences may yield better predictive information, particularly in the context of volumetric analysis of brainstem injury.

Conclusions

We analyzed outcomes for all patients admitted to a tertiary trauma center who had injury to the brainstem as detected by T2-weighted MRI. We established that although these lesions constitute an ominous sign (53% poor outcomes), poor outcomes were consistently seen only in those with bilateral brainstem injuries and poor results on 24-hour postadmission GCS motor examination. Conversely we found that unilateral brainstem injuries, regardless of examination findings, resulted in functional recovery more than 80% of the time. In our patient population, age, increased ICP, the detection of epidural hematoma, subdural hematoma, subarachnoid hemorrhage, contusions, and diffuse axonal injury based on CT scan, the presence of diffuse axonal injury in the supratentorial compartment, and total volume of brainstem injury did not correlate with outcomes.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Chew, Quigley. Acquisition of data: Chew, Spearman, Quigley. Drafting the article: Chew. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Chew. Statistical analysis: Quigley. Administrative/technical/material support: Wilberger. Study supervision: Quigley, Wilberger.

References


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