Intracranial Diffuse Axonal Injury at Autopsy

JOHN R. PARKER, JOSEPH C. PARKER, JR., M.D., and JOHN C. OVERMAN, M.D.

Department of Pathology, Truman Medical Center, Kansas City, MO 64108

ABSTRACT

An illustrative case of diffuse axonal injury (DAI) emphasizes features that help to separate focal outer head trauma owing to blows and/or falls from angular acceleration head injuries associated with diffuse inner brain lesions. In the past, explaining significant neurological deficits and death as the result of diffuse closed head trauma received from high-speed automobile accidents has been difficult as well as confusing. The long-term consequences from such diffuse inner cerebral trauma are still poorly defined.

Head injuries sustained in automobile accidents have been associated with diffuse brain damage characterized by axonal injury at the moment of impact. The reported victim of a motor vehicle accident showed post-mortem findings for both inner cerebral trauma and focal outer cerebral damage. The diffuse degeneration of cerebral white matter is associated with sagittal and lateral acceleration with centroaxial trauma and has a different pathogenesis from outer focal head trauma, typified by subdural hematomas and coup injuries. Unlike outer cerebral injury, over 50 percent of victims with diffuse axonal injury die within two weeks. These individuals characteristically have no lucid interval and remain unconscious, vegetative, or severely disabled until death. Compared to head trauma victims without diffuse axonal injury, there is a lower incidence of skull fractures, subdural hemorrhages, or other intracranial mass effect as well as outer brain contusions. Primary brainstem injuries often demonstrated at autopsy are seen in the reported victim. Diffuse axonal injury is produced by various angles of acceleration with prolonged acceleration/deceleration usually accompanying traffic accidents. Less severe diffuse axonal injury causes concussion.

Introduction

While mechanisms for head injury are complex, the lesions can be classified as
either focal or diffuse. Focal head trauma, which typically occurs over the outer brain surfaces, includes cerebral contusions, subdural hemmorhages, and epidural hemmorhages, and may be associated with skull fractures. On the other hand, diffuse inner brain injuries are fundamentally different and are referred to as diffuse axonal injury (DAI). A victim of a motor vehicle accident will illustrate this phenomenon and is used to compare these two fundamental types of closed, blunt head trauma.

Diffuse axonal injury is demonstrated microscopically by damage to vast numbers of axons (neurites) throughout the inner brain and grossly by hemorrhagic lesions in the corpus callosum and dorsolateral quadrants of the rostral brainstem. The severity of neuropathological abnormalities, the duration of coma, and prognosis for recovery correspond with the direction of head movement at the initial insult. Primate studies have shown that sagittal acceleration produces the least amount of long-term injury, while lateral acceleration is the most devastating. More severe injuries tear many deep axons resulting in immediate coma.

From primate studies and case reports, it appears that diffuse axonal injury is caused by direct damage to axons at the moment of injury. This is the most common cause of traumatic coma in the absence of an intracranial expanding lesion and is illustrated herein by an automobile accident victim.

Case Report

R.K., a previously healthy 17-year-old white male, was a passenger in a half ton pick-up truck which struck a parked vehicle at an unknown rate of speed. The impact was sufficient to crush the front of the truck. R.K. presented at Truman Medical Center-West in Kansas City, MO., unconscious with dilated and fixed pupils. His extremities had numerous abrasions and were cyanotic. He did not respond to vasopressor agents, fluids, or other resuscitation efforts and died within hours of the accident.

The medical examiner’s autopsy revealed evidence of massive blunt head trauma. A large abrasion covered the right superior and lateral orbit, right temple, right cheek, right lower mandible, and right

Figure 1. Diffuse axonal injury manifested by petechial lesions in the corpus callosum.
neck. Reflection of the scalp revealed a scalp contu-
sion 4.5 cm in diameter over the right temple. The
dura was intact with diffuse subarachnoid hemor-
rhages over the right and left cerebral convexities.
No subdural hemorrhage was identified. There were
multiple skull fractures including a basilar fracture
involving the right middle fossa and another radiat-
ing from the right anterior fossa across the sella tur-
cica into the left middle fossa.

Other autopsy findings included multiple lung
contusions over the lateral and posterior aspects of
the upper and lower lobes of the left lung. The right
lung was atelectatic secondary to pneumothorax. No
traumatic injury of the heart or aorta was present. No
intra-abdominal trauma was identified.

The neuropathological examination revealed a
recent contusion over the inferior temporal lobes and
the inferior aspects of the frontal lobes. Diffuse sub-
arachnoid hemorrhage was present over the right
temporoparietal region. Diffuse edema was mani-
fested by flattened gyri and narrowed sulci. The brain,
coronally sectioned at 2.5 cm intervals, showed rotational and/or shearing injury manifested
by punctate hemorrhages in the corpus callosum and
basal ganglia (figure 1). Multiple brainstem hemor-
rhages were present (figure 2). Histological section-
ing revealed axonal spheroids in these hemorrhagic
areas (figure 3).

Discussion

Diffuse axonal injury, a term posed by
Adams,⁵ has many confusing synonyms,
including “intermediary coup” lesions,⁸
shearing or rotational injuries, diffuse
degeneration of cerebral white matter,¹⁰
inner cerebral trauma, and diffuse white
matter shearing injury.¹² Injuries severe
enough to produce diffuse axonal injury
are seen most commonly as a result of
automobile accidents.⁶ Unless an indi-
vidual falls from a considerable height,
falls do not produce diffuse axonal
injury.³ Studies⁴,⁹ have shown that
patients who suffer diffuse axonal injury
do not sustain skull fractures, cerebral
contusions, intracranial hematoma, or
sudden cerebral edema as often as those
who sustain only outer focal cerebral
damage (table 1). Subarachnoid hemor-

Figure 2. Diffuse axonal injury with small hemorrhages in the rostral brainstem.
Axonal injury has been detected in child abuse cases. In the study by Vowles, diffuse axonal injury was present in every case of contusional tearing. Shaking and blunt force injuries are the most common mechanisms of injury in infants.

This pattern of injury is in striking contrast to that associated with a low fall. The duration of acceleration is apparently much shorter than in automobile crashes. This shorter duration of acceleration combined with a lesser propensity for total frontal injury in low falls, results in a different pattern of injury characterized by focal lesions over the outer surface of the brain. Skull fractures, subdural hematomas, and brain contusions (classically of contracoup type) are common after low falls, while the instance of DAI is very low (table I). Nevertheless, many victims of closed head trauma, as seen in the reported case, experience varying combinations of both outer focal contusions and DAI. Clinical correlation with detailed descriptions of the injury are required to assess accurately these intracranial lesions.

<table>
<thead>
<tr>
<th>Clinical Circumstances</th>
<th>Outer (Focal)</th>
<th>Inner (Diffuse or DAI)</th>
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<tbody>
<tr>
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<td>2. Low</td>
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<tr>
<td>Blows</td>
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<td>1. Angular</td>
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<td>2. Linear</td>
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<td>Coma</td>
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<td>Early Death</td>
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*Legend: ++ = often present. + = not often present. 0 = not typical or absent.
In our case study, lesions in the corpus callosum and dorsolateral quadrants of the brainstem are indicative of diffuse axonal injury. Histologically, acute changes include diffuse damage to neurites with axonal retraction balls and varicosities. With time, reactive changes include microglial nodules throughout the white matter in the cerebrum, cerebellum and brainstem. Myelin may become distorted, and the axonal swellings may persist. After several months, Wallerian degeneration of the medial leminisci, pyramidal tracts, internal capsule, and cerebral white matter is seen. At autopsy, acute diffuse axonal injury manifests itself as hemorrhagic lesions (streaks, petechiae, or ball hemorrhages). Over months to years, the hemorrhagic lesions become lytic, cavitated, gliotic, and demyelinated.

Proper fixation is imperative for recognition of acute diffuse axonal injury. The characteristic lesions may be missed if the brain is cut without formalin fixation. The brain should be firm enough for a detailed and thorough macroscopic examination. Since some cases of diffuse axonal injury do not show characteristic macroscopic findings, microscopic sections from susceptible areas such as the corpus callosum, hypothalamus, and midbrain should be examined.

Acknowledgments

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References