Whiplash Injury Determination With Conventional Spine Imaging and Cryomicrotomy

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FROM ABSTRACT:

Study Design.
Soft tissue–related injuries to the cervical spine structures were produced by use of intact entire human cadavers undergoing rear-end impacts.

Radiography, computed tomography, and cryomicrotomy techniques were used to evaluate the injury.

Objectives.
To replicate soft tissue injuries resulting from single input of whiplash acceleration to whole human cadavers simulating vehicular rear impacts, and to assess the ability of different modes of imaging to visualize soft tissue cervical lesions.

Summary of Background Data.
Whiplash-associated disorders such as headache and neck pain are implicated with soft tissue abnormalities to structures of the cervical spine. To the authors’ best knowledge, no previous studies have been conducted to determine whether single cycle whiplash acceleration input to intact entire human cadavers can result in these soft tissue alterations.

There is also a scarcity of data on the efficacy of radiography and computed tomography in assessing these injuries.

Methods.
Four intact entire human cadavers underwent single whiplash acceleration (3.3g or 4.5g) loading by use of a whole-body sled.

Pretest and posttest radiographs, computed tomography images, and sequential anatomic sections using a cryomicrotome were obtained to determine the extent of trauma to the cervical spine structures.

Results.
Routine radiography identified the least number of lesions (one lesion in two specimens). Although computed tomography was more effective (three lesions in two specimens), trauma was not readily apparent to all soft tissues of the cervical spine.
Cryomicrotome sections identified structural alterations in all four specimens to lower cervical spine components that included stretch and tear of the ligamentum flavum, anulus disruption, anterior longitudinal ligament rupture, and zygapophysial joint compromise with tear of the capsular ligaments.

Conclusions.
These results clearly indicate that a single application of whiplash acceleration pulse can induce soft tissue–related and ligament-related alterations to cervical spine structures.

The pathologic changes identified in this study support previous observations from human volunteer observations with regard to the location of whiplash injury and may assist in the explanation of pain arising from this injury.

Although computed tomography is a better imaging modality than radiography, subtle but clinically relevant injuries may be left undiagnosed with this technique.

The cryomicrotome technique offers a unique procedure to understand and compare soft tissue–related injuries to the cervical anatomy caused by whiplash loading. Recognition of these injuries may advance the general knowledge of the whiplash disorder.

THESE AUTHORS ALSO NOTE:

Most whiplash-associated disorders (WAD) occur in rear-end vehicular crashes.

The estimated cost to treat WAD is $10 billion United States per year.

Whiplash injury is mainly an acceleration-induced phenomenon.

During whiplash, the neck-head structures respond with extension followed by flexion, without the head impacting any interior object within the vehicle.

“The injury of the head-neck complex belongs to the non-contact acceleration type, termed inertial loading.”

Usually “the severity of impact, as measured by the imparted acceleration, is considered to be of low magnitude.”

“Spine radiographs of whiplash-injured patients are routinely assessed to be normal for the specific age group.”

Cervical facet joints are replete with pain-sensitive structures that are mechanically damaged during single-impact rear-end acceleration input.
Percutaneous radiofrequency neurotomy is effective to relieve facet joint neck pain in whiplash patients.

This gives indirect validation of facet joint abnormality in whiplash patients.

However direct validation of facet joint injury is lacking.

MATERIALS AND METHODS:

Entire human cadavers were used. Trauma was not the cause of death in any of these cadavers. They were belted with lap and shoulder belts.

The specimens were tested at single rear-impact, mean acceleration levels of 3.3g or 4.5g by use of full-body sled equipment.

The change in velocity was 4.4 m/sec or 6.8 m/sec with a pulse duration of 137 msec or 154 msec.

“This level of acceleration pulse was chosen on the basis of published reports indicating that 75–90% of whiplash injuries occur at speeds less than 6.9 m/sec.”

Each subject was tested only once.

Radiographs of the head-neck were obtained after the impact.

Computed tomography scans were obtained also.

Cryomicrotomy was done on each subject. The use of cadavers made it possible to obtain sequential anatomic sections with the cryomicrotome. This method is “effective in documenting the post-test anatomy of the hard and soft tissue structures.”

“Injuries were identified in a blinded fashion by a team of clinicians from the neuroradiology, neurosurgery, and orthopedic surgery departments.”

RESULTS

“Peak head angular accelerations ranged from 590 to 1200 rad/sec/sec in these specimens.”

Bone fractures did not occur in any subject.

One specimen sustained a mild avulsion of the anterior-inferior tip of the fifth cervical vertebral body. “This injury was identified on plain radiographs, midsagittal computed tomography scans, and cryomicrotome images.”
“Cryomicrotomy revealed additional abnormalities, including the stretch of the anterior longitudinal ligament at the C5–C6 disc space at the distal body and diastasis of the right C5–C6 zygapophysial and atlantoaxial joints with associated capsular tears.”

“In another specimen, radiography and computed tomography revealed the distraction of the C5–C6 disc space.” This injury was also seen on cryomicrotomy. Radiography did not identify this injury.

“In all specimens, cryomicrotome sections identified structural alterations to midlower cervical spine components that included stretch and tear of the ligamentum flavum, disc anulus disruption, anterior longitudinal ligament rupture, and zygapophysial joint compromise with tear of the capsular ligaments.”

**DISCUSSION**

The authors note that there is a transient nonphysiologic “S” curve during the initial stages of acceleration and facet joint sliding kinematics in whiplash trauma.

“Human volunteer studies indicate that the thoracic spine straightens during rear-end impact, imparting motions to the neck and head.” This is why these authors used entire cadavers.

“The cryomicrotomy technique preserves the anatomic features of the spine in situ and facilitates the obtaining of sequential images of hard and soft tissue structures that parallel computed tomography scans.”

“Consequently, cryomicrotomy was used to determine the injuries and compared with other clinical methods.”

Because cadavers were used, passive musculature only was involved. However, studies have “demonstrated the time to develop muscle forces to be approximately 200 msec.”

“It has also been shown that the joints of the cervical spine undergo maximum deformation during the early part of whiplash acceleration wherein the muscle tone activations are minimal or absent.”

“Consequently, it can be concluded that the present intact cadaver model is appropriate to produce and compare injuries caused by whiplash loading.”

The cryomicrotome results were distinguished from old injuries because “pre-existing injuries in cadaver specimens would be identified with some scar tissue.”
In all cases, additional abnormalities were observed on cryomicrotome images than on routine radiography and computed tomography.

Computed tomography was more effective than radiography, but soft tissue trauma was still not readily apparent.

In fact, of computed tomography results were unremarkable in all but one case.

“All specimens showed abnormalities to the anterior and posterior columns on the cryomicrotome images.”

These injuries were confined to the lower spine.

“Anterior column abnormalities at C5–C6 were attributed to the extension injury.”

“Posterior column abnormalities consisted primarily of zygapophysial joint diastasis, attributed to the localized extension of the lower spine during the initial whiplash acceleration.”

“The anteroposterior sliding of the zygapophysial joint associated with pinching in the dorsal region and capsular strains may be responsible for the compromise in the joint integrity.”

“This can lead to pain because this component is reported to be rich in nociceceptor structures, which could undergo excitation by motions exceeding physiologic limits.”

“This study has shown documentary evidence for the potential onset of neck pain secondary to abnormal motions in these soft tissues.”

“Hematoma in the joint secondary to the compromise of the capsular soft tissue anatomy may also elicit pain.”

“The lack of objective radiographic findings in whiplash-associated injuries has often led to the dismissal of patients’ symptoms.”

“The present study has clearly shown that structural alterations occur to the head-neck complex as a result of whiplash injury and furthermore that these alterations do not completely lend themselves to identification by routine spine radiographs and computed tomography.” [WOW!]

“The predominant structural pathoanatomic changes noted in this study relate to potential apophyseal joint injury, especially the mid-lower facets of the cervical spine, which may serve as the secondary effect of the ‘pinching’ mechanism (anteroposterior
shear associated with axial motions of the capsule) in the facets during the whiplash phenomenon.”

The facet joint injuries demonstrated are the potential source of cervical pain.

It is reasonable to consider facet arthropathy in patients with severe posterior cervical pain after whiplash injury.

The decoupling mechanism during the whiplash may place adverse stresses on upper cervical structures, including the musculature and the C2 neural complex.

KEY POINTS:

(1) “This study verifies the production of soft tissue injuries to the cervical spine resulting from single whiplash acceleration to intact human cadavers,” and the region of primary injury is the lower cervical spine.

(2) Computed tomography is a better imaging modality than radiography, but still misses injuries.

KEY POINTS FROM DAN MURPHY:

(1) Most whiplash-associated disorder occurs in rear-end vehicular crashes.

(2) Therefore the injury is a non-contact acceleration inertial type.

(3) The impact severity is usually low magnitude.

(4) Spine radiographs of whiplash patients are usually normal for the age group.

(5) This study documents whiplash injuries to:
The vertebral body.
The anterior longitudinal ligament.
The zygapophysial joints.
The atlantoaxial joints with capsular tears.
Distraction injury to the C5–C6 disc.
Stretch and tear of the ligamentum flavum.
Disc anulus disruption.
Anterior longitudinal ligament rupture.
Zygapophysial joint compromise with tear of the capsular ligaments.

(6) Findings using human cadavers are applicable to the live human population because muscle reflex protection of joints takes a minimum of 200 msec, which is after the peak injurious forces have been reached.
Old injuries leave identifiable “scar tissue.” [The Fibrosis Of Repair].

The most common injuries are to the facets of the lower cervical spine.

Upper cervical spine soft tissue and neural stress is also probable.

This study proves that structural alterations occur to the neck from whiplash injury and that these alterations are not completely well identified by routine spine radiographs and computed tomography.

### Table 1. Radiologic, Computed Tomography, and Cryomicrotome Findings

<table>
<thead>
<tr>
<th>Patient</th>
<th>Radiology</th>
<th>Computed Tomography</th>
<th>Cryomicrotome</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>None</td>
<td>None</td>
<td>Anterior anulus tear at C5–C6, anterior longitudinal ligament, disruption at C5–C6, separation of C6–C7 ligamentum flavum at the superior level of the lamina with anterior displacement into the spinal canal</td>
</tr>
<tr>
<td>B3</td>
<td>None</td>
<td>None</td>
<td>Diastasis of the C5–C6 zygapophysial joint with tear in the joint capsular ligament in the ventral and dorsal regions on the right side; C6–C7 ligamentum flavum separated from the C7 superior lamina with associated hematoma</td>
</tr>
<tr>
<td>C4</td>
<td>C5–C6 disc distraction without body fracture</td>
<td>C5–C6 intervertebral disc distraction without bony fracture, C5–C6 zygapophysial joint distraction on the right side</td>
<td>Anterior longitudinal ligament rupture at C5–C6 interspace with disc disruption extending to the level of the posterior longitudinal ligament; stretch associated with mild tear of the ligamentum flavum at C5–C6; zygapophysial joint capsule stretch and tear at the C5–C6 ventral and dorsal regions on the right; diastasis of the C4–C5 zygapophysial joint on the left without tear of the capsular ligament at this level</td>
</tr>
<tr>
<td>D5</td>
<td>Mild avulsion of anterior–inferior C5 body</td>
<td>Mild avulsion of anterior–inferior C5 vertebral body</td>
<td>Diastasis and hematoma in the right C5–C6 zygapophysial joint with joint capsular ligament tear in the ventral region and right atlantoaxial joint with hematoma in the dorsal aspect of the joint with tear of the ligament in this region; C5 vertebral body anterior–inferior avulsion associated with anterior longitudinal ligament tear at the distal vertebral body level</td>
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**COMMENT FROM DAN MURPHY:**

This is a very important article because it proves that occult (hidden) injuries occur from traditional whiplash accelerations, and that these injuries are not imaged by radiographs or computed tomography imaging.