Biomechanical analyses of whiplash injuries using an experimental model

FROM ABSTRACT

Neck pain and headaches are the two most common symptoms of whiplash. The working hypothesis is that pain originates from excessive motions in the upper and lower cervical segments.

The research design used an intact human cadaver head-neck complex as an experimental model. The intact head-neck preparation was fixed at the thoracic end with the head unconstrained. Retroreflective targets were placed on the mastoid process, anterior regions of the vertebral bodies, and lateral masses at every spinal level. Whiplash loading was delivered using a mini-sled pendulum device. A six-axis load cell and an accelerometer were attached to the inferior fixation of the specimen. High-speed video cameras were used to obtain the kinematics.

During the initial stages of loading, a transient decoupling of the head occurs with respect to the neck exhibiting a lag of the cranium.

The upper cervical spine-head undergoes local flexion concomitant with a lag of the head while the lower column is in local extension.

This establishes a reverse curvature to the head-neck complex. With continuing application of whiplash loading, the inertia of the head catches up with the neck.

Later, the entire head-neck complex is under an extension mode with a single extension curvature.

The lower cervical facet joint kinematics demonstrates varying local compression and sliding.

While the anterior- and posterior-most regions of the facet joint slide, the posterior-most region of the joint compresses more than the anterior-most region.

These varying kinematics at the two ends of the facet joint result in a pinching mechanism.

Excessive flexion of the posterior upper cervical regions can be correlated to headaches.
The pinching mechanism of the facet joints can be correlated to neck pain.

The kinematics of the soft tissue-related structures explain the mechanism of these common whiplash associated disorders.

THESE AUTHORS ALSO NOTE:

Whiplash associated disorders (WAD) depend upon the following variables:

(1) Vehicular factors
(2) Occupant positioning
(3) Collision variables
(4) Individual human tolerance

“Rear-end crashes account for about 85% of all WAD.”

25% of whiplash patients become chronic.

10% of whiplash patients suffer serious pain.

More than 50% of all traffic injuries with long term consequences involve the neck.

“This study further indicates that WAD leads to long term problems in 10% of the cases.”

The liability claims in the US due to rear-end crashes are more than $10 billion per year, and the cost in the UK is about 2.5 billion pounds.

Human volunteer studies have been conducted at sub-injury levels.

This study used intact human cadaver specimens, free of pre-existing trauma.

“Excessive compressive and/or sliding kinematics in the lower cervical spine facet joints during the initial stages of loading induce structural alterations which are responsible for neck pain.”

“Excessive angular flexion in the upper neck motion segments during the initial stages of loading induces stretching, which is responsible for suboccipital headaches.”

“Headache and neck pain are the two most common complaints in WAD.”

Whiplash loading was applied at a velocity of 2.2 m/s.

\[
\frac{(2.2 \text{ m/s}) \times (3.281 \text{ feet/meter}) \times 1 \text{ mile/5280 feet}}{\text{miles/sec}} = 0.001367 \text{ miles/sec} \\
\frac{(0.001367 \text{ miles/sec}) \times (3600 \text{ sec/hour})}{\text{miles/hour}} = 4.9212 \text{ miles/hour} \\
\textbf{[Therefore, these are 5 mph collisions].}
\]
The test was photographed using a high-speed video camera operating at 4500 full frames per second.

The observed motions were divided into:
(1) upper head-neck, occiput-C2
(2) middle neck, C2-C5
(3) lower neck, C5-T1

The facet joint local compression and sliding motions at its anterior and posterior regions were computed using targets placed on them.

RESULTS

During the initial phases of loading, the upper cervical spine-head undergoes local flexion while the lower cervical spinal column is in local extension.

This is followed by the entire head-neck complex extension.

The lower cervical spine facet joint kinematics demonstrates local compression and sliding.

“While both the anterior- and posterior-most regions of the facet joint slide, the posterior-most region of the joint compresses more than the anterior-most region.”

“These varying kinematics at the two ends of the facet joint result in a pinching mechanism.”

“The upper and the middle regions of the head-neck complex initially went into flexion followed by extension while the lower region of the structure sustained local extension throughout the loading phase.”

Significant rotation, sliding, and compression was documented.

“The macroscopic and radiographic evaluations indicated that the specimens were intact after the test.”

DISCUSSION

To obtain greatest accuracy, these authors used the entire intact head-neck complex, which includes the ligamentous column, musculature, skin, and cranium.

Since these authors used a human cadaver, the effects of active musculature are not included.

However, “for dynamic loading conditions, it is generally acknowledged that muscle contraction occurs late in the dynamic event.”
Electromyography evidence from neck musculature during volunteer rear-impact vehicular collisions “indicate that initial muscle activation does not occur until 100 ms after events start, and full muscle contraction does not occur until 150-170 ms after event onset.” At this time, the head-neck is already in extension.

Other studies show that the time to develop muscle force is about 200 ms.

Therefore, initial injury occurs before this time and, therefore, “active muscle contraction is not a primary determinant of whiplash injury.”

“This premise is more directly applicable to occupants unaware of impending rear impact.”

INJURY MECHANICS

“The two most common WAD complaints are headache and neck pain.”

“It is widely known that these complaints are soft tissue related.”

“These patients do not demonstrate radiographic damage, and computed tomography and magnetic resonance images are also normal considering the age of the patient.”

“The temporal local flexion of the occipito-atlanto-axial complex distracts the posterior structures with a concomitant compression of the anterior structures of the upper cervical spine. This local distraction may overstretch the dorsal region, which includes the upper cervical musculature and ligament complexes. The stretching of these innervated soft tissue structures may induce pain to connective regions; in this case the posterior-suboccipital region of the cranium. It is reasonable to hypothesize that localized tensile loading/stretching of the posterior upper cervical-cranium structures, which occurs during the early stages of the rear crash pulse, may be responsible for the resulting headaches.” [IMPORTANT]

“The facet joints are replete with pain sensitive structures that can be a source of pain.”

“The facet joint kinematic information obtained from the present study indicated a pinching mechanism; varying compression and sliding motions occurred.”

“Excessive motion in the components of the facet joint (fluid, membrane, cartilage, capsular ligament) may disrupt its integrity.”

“The pinching action as demonstrated by the sliding motion and compressive action of the joint represented by the accentuated motions in the posterior-most regions (compared with the anterior region), may compromise the integrity of the synovium, thus eliciting neck pain.”
SUMMARY

During the initial stages of whiplash loading, the upper cervical spine goes into flexion with lower cervical spine in extension, resulting in an S-curve.

The upper cervical flexion causes stretching of the posterior head-neck complex.

The lower spine facet joints undergo compression.

“This compression combined with an anteroposterior sliding of the facet joint results in a pinching mechanism.”

“Excessive stretching of the posterior upper cervical complex and the pinching mechanism due to compression and sliding of the facet joint may explain the presence of suboccipital headache and neck pain, respectively, in patients with whiplash associated disorders.”

KEY POINTS FROM DAN MURPHY

(1) Neck pain and headaches are the two most common symptoms of whiplash.

(2) During the initial phase of whiplash, the upper cervical spine-head undergo flexion.

(3) This excessive flexion of the posterior upper cervical is correlated with headaches.

(4) At the same time, the lower cervical joints extend.

(5) This extension of the lower cervical joints is coupled with compression and sliding, and a pinching mechanism.

(6) This compression, sliding, and pinching mechanism of the facet joints is correlated with neck pain.

(7) Rear-end crashes account for about 85% of whiplash injury and pain.

(8) 25% of whiplash patients become chronic and for 10% the pain is serious.

(9) The initial injury in whiplash occurs before the muscle reflexes activate to protect the joints.

(10) X-rays, CT, and MRI are non-revealing for most patients with whiplash injury.