Effects of abnormal posture on capsular ligament elongations in a computational model subjected to whiplash loading

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FROM ABSTRACT:

Although considerable biomechanical investigations have been conducted to understand the response of the cervical spine under whiplash (rear impact-induced postero-anterior loading to the thorax), studies delineating the effects of initial spinal curvature are limited.

This study advanced the hypothesis that abnormal curvatures (straight or kyphotic) of the cervical column affect spinal kinematics during whiplash loading.

Specifically, compared to the normal lordotic curvature, abnormal curvatures altered facet joint ligament elongations.

The quantifications of these elongations were accomplished using a validated mathematical model of the human head–neck complex that simulated three curvatures. The model was validated using companion experiments conducted in our laboratory that provided facet joint kinematics as a function of cervical spinal level. Regional facet joint ligament elongations were investigated as a function of whiplash loading in the four local anatomic regions of each joint.

Under the normal posture, greatest elongations occurred in the dorsal anatomic region at the C2–C3 level and in the lateral anatomic region from C3–C4 to C6–C7 levels.

Abnormal postures increased elongation magnitudes in these regions by up to 70%. Excessive ligament elongations induce laxity to the facet joint, particularly at the local regions of the anatomy in the abnormal kyphotic posture.

Increased laxity may predispose the cervical spine to accelerated degenerative changes over time and lead to instability.

Results from the present study, while providing quantified level- and region-specific kinematic data, concur with clinical findings that abnormal spinal curvatures enhance the likelihood of whiplash injury and may have long-term clinical and biomechanical implications.
THESE AUTHORS ALSO NOTE:

“While lordosis is the normal curvature of the cervical spine, certain conditions such as aging, degeneration, trauma, and surgical procedures may result in a loss of this curvature.”

Decreased lordosis is associated with narrowing of the intervertebral disc space in the elderly population.

“Spinal degeneration can decrease intervertebral disc height until uncovertebral joints come into contact and form osteophytes.”

Disc degeneration affects the anterior of the disc more than the posterior, “resulting in the loss of lordotic curvature (straightening) and eventually the formation of reverse curvature (kyphosis).”

Loss of cervical lordosis results from major and minor traumatic injuries.

“Because curvature influences the load-carrying capacity of the cervical spinal column, abnormalities in curvature can affect injury mechanisms and lead to acute or chronic disorders.”

“Experimental investigations have demonstrated that the severity of injury, injury mechanisms, and fracture classification are dependent upon cervical posture at the time of loading.”

Pre-impact alignment of the cervical spine significantly affects injury mechanisms and severity of injury.

“Clinical investigations have documented increased morbidity and whiplash injury severity for patients with pre-existing abnormal cervical postures.”

“During inertially applied (non-contact) dynamic loading, it was reported that whiplash injury severity significantly depends upon the cervical curvature; patients with pre-existing abnormal curvatures demonstrate greater injury severity with higher levels of morbidity.”

“Chronic illness is also reported to be associated with spinal posture. Five years after sustaining whiplash injury, patients with abnormal cervical curvature at the time of injury demonstrated higher incidence of degenerative changes in the spine.”

In whiplash loading, the cervical spine undergoes three distinct kinematic phases:
1) S-curvature resulting from the head lagging behind the thorax.
2) C-curvature characterized by overall extension of the head–neck complex.
3) Rebound that occurs after the head makes contact with the head restraint.
“The first phase (S-curvature) is a non-physiologic curvature characterized by flexion in upper and extension in lower cervical segments. This abnormal curvature places non-physiologic loads on spinal soft tissues and is the likely time at which the whiplash injury occurs.” [Important]

These authors hypothesize that abnormal spinal curvature alters kinematics during whiplash by increasing facet joint ligament elongations during the time of non-physiologic S-curvature.

Because motion and injury are related, increased capsular ligament elongations because of abnormal spinal postures would indicate that spinal posture plays a role in whiplash injury.

The models in these experiments were subjected to a rear impact velocity of 2.6 m/s [5.8 miles/hour], resulting in an acceleration of 2.3 g. 

\[2.6 \text{ m/s} \times 3.281 \text{ feet/meter} \times \frac{1 \text{ mile}}{5280 \text{ feet}} = 0.0016 \text{ miles/sec}\]

\[0.0016 \text{ miles/sec} \times 3600 \text{ sec/hour} = 5.8 \text{ miles/hour}\]

RESULTS

“Upon the initiation of rear impact acceleration, the cervical spinal column sustained non-physiologic S-curvature, characterized by upper cervical flexion and lower cervical extension.”

“As the thorax was displaced in the posterior to anterior direction, the head remained initially stationary due to inertia.”

“In order to compensate for this differential motion between the head and thorax (T1), the cervical spinal column moved into S-curvature, which lasted for 113 ms for the normal posture.”

“The S-curvature lasted 110 ms (straight) and 119 ms (kyphosis) for the two abnormal postures.”

“After the period of S-curvature, the head and entire cervical spine demonstrated extension at all levels (C-curvature).”

During these experiments, kyphotic posture showed the largest increase (22% over the normal posture) in posterior ligament elongation. The largest increase in ligament elongation occurred at the C5–C6 level with the kyphotic posture (73%).

DISCUSSION

“Initial cervical posture is of particular relevance in both impact- and inertially induced whiplash loading and injury because the biomechanical response of the
spine depends on the interactions of various segmental components of the cervical column.”

Many studies using models ranging from intact human cadavers, human volunteers, and isolated cervical ligamentous columns subjected to injurious and subinjurious loading, have shown that the “non-physiologic cervical S-curvature plays a pivotal role in whiplash injury mechanisms.”

During the non-physiologic S-curvature, the cervical facet joints are injured due to stretch of the capsular ligaments.

Maximum facet joint capsular ligament elongation in the present study approached 2.0 mm in the normal posture and 3.3 mm in the kyphotic posture. This magnitude of stretch would cause subcatastrophic capsular ligament failure. These subcatastrophic injuries can initiate a noxious (pain) response.

Pre accident abnormal kyphotic posture increases likelihood of reaching the subcatastrophic threshold for injury.

The results of this study show that “abnormal spinal curvature negatively influences whiplash kinematics and injury.”

“In a follow-up study investigating 146 patients 5 years after sustaining soft tissue injuries in automotive collisions (60–74% in rear impacts), occupants with reversal of spinal curvature (kyphosis) and no other degenerative changes at the time of injury had a significantly higher incidence of disc degeneration in the lower cervical spine (C5–C6) than occupants with normal curvatures at the time of injury.” [IMPORTANT]

Disc degeneration at a single level alters segmental loading patterns which may “influence degenerative changes at adjacent levels, result in osteophyte formation, accelerate progressive changes in spinal curvature, and lead to spinal instability”

Cervical spondylosis at one level pre-disposes the levels above “to early instability and decreased load carrying capacity.”

“These clinical findings, coupled with the results of the present investigation, demonstrate that the abnormal spinal curvature may not only influence ligament elongations but also the long term affects of the injury to the cervical spinal column under whiplash trauma.” [Very IMPORTANT]

It is “unlikely that resting [muscle] contraction magnitudes are sufficient to significantly affect cervical spine kinematics in whiplash.”
“Although head restraints were mandated by the United States federal government in 1969 for all passenger cars to decrease the risk of neck injuries in rear impacts (NHTSA, 1969), their effectiveness has been limited.”

“Governmental research reported that head restraints decreased the overall risk of neck injury by only 5–20%. These studies imply that the whiplash injury occurs prior to head restraint contact, i.e., during the retraction (S-curvature) phase.”

There are mechanoreceptors and nociceptors in the facet joint capsule, capsular ligament, and synovial fold, all capable of generating a noxious response with excessive joint excursion.

The presence of facet capsule pain receptors, coupled with excess joint excursions in patients with abnormal initial cervical spinal postures, cause the “ligament elongations sustained by the cervical facet joints during whiplash loading to result in a noxious response.”

“Results of the present investigation demonstrated that compared to the normal lordotic posture facet joint ligament elongations increase up to 70% with abnormal spinal posture, indicating that the kyphotic posture is at a higher risk for whiplash injury than normal or straight postures.”

“Because motion and injury are related, greater ligament elongation magnitudes lead to a concomitant increase in the likelihood of subcatastrophic regional tissue failure that may add laxity to the surrounding intervertebral facet joint.”

“Particularly in kyphotic postures, this change in segmental kinematics may also lead to spinal degeneration over time.”

“The present results, while providing quantified level- and region-specific kinematic data, concur with clinical findings that abnormal spinal curvatures enhance the likelihood of whiplash injury.”

KEY POINTS FROM DAN MURPHY

1) This study showed that pre-whiplash accident straight or kyphotic curvatures of the cervical spine increase injury to the facet joint ligaments.

2) Specifically, straight or kyphotic curvatures of the cervical spine increased cervical facet capsular ligament stretch by up to 70%.

3) Increased capsular ligament stretch induces laxity to the facet joint, particularly at regions of kyphotic posture.
4) Increased laxity predisposes the cervical spine to accelerated degenerative changes over time and leads to instability. [Very Important]

5) Straight cervical spines and cervical kyphosis affect injury mechanisms and lead to increased acute and chronic disorders.

6) Pre-whiplash impact alignment of the cervical spine significantly affects injury mechanisms and severity of injury.

7) There is increased whiplash injury severity for patients with pre-existing abnormal cervical postures.

8) Chronic illness is associated with abnormal spinal posture. [Important]

9) The first phase of whiplash injury is a non-physiologic S-curvature characterized by flexion in upper and extension in lower cervical segments, and this is when the primary whiplash injury occurs.

10) During the initial whiplash non-physiologic S-curvature phase, the cervical facet joints are injured due to the stretch of the capsular ligaments.

11) Subcatastrophic facet capsular injuries can initiate a pain response.

12) Pre-accident abnormal kyphotic posture increases likelihood of reaching the subcatastrophic threshold for injury.

13) In a 5-year study of 146 patients, those with cervical kyphosis but with no degenerative changes after whiplash injury had a significantly higher incidence of disc degeneration in the lower cervical spine (C5–C6) than those with normal curvatures at the time of injury.

14) Disc degeneration at a single level alters segmental loading patterns, which accelerate degenerative changes at adjacent levels.

15) Cervical spondylosis at one level pre-disposes the levels above to early instability and decreased load carrying capacity.

16) Straight or kyphotic curvatures of the cervical spine influence ligament elongations during whiplash trauma, and also influence the long-term prognosis of the injury.

17) Head restraints have limited (5–20%) ability to decrease neck injuries in rear impacts because greatest ligament stretch occurs during the S-curvature, before the head contacts the head restraint.

18) Capsular ligament stretch from whiplash, particularly in kyphotic postures, leads to motor unit laxity and to spinal degeneration over time.