Facet Joint Kinematics and Injury Mechanisms During Simulated Whiplash


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FROM ABSTRACT:

Study Design.
Facet joint kinematics and capsular ligament strains were evaluated during simulated whiplash of whole cervical spine specimens with muscle force replication.

Objectives.
To describe facet joint kinematics, including facet joint compression and facet joint sliding, and quantify peak capsular ligament strain during simulated whiplash.

Summary of Background Data.
Clinical studies have implicated the facet joint as a source of chronic neck pain in whiplash patients.

Prior in vivo and in vitro biomechanical studies have evaluated facet joint compression and excessive capsular ligament strain as potential injury mechanisms.

No study has comprehensively evaluated facet joint compression, facet joint sliding, and capsular ligament strain at all cervical levels during multiple whiplash simulation accelerations.

Methods.
The whole cervical spine specimens with muscle force replication model and a bench-top trauma sled were used in an incremental trauma protocol to simulate whiplash of increasing severity.

Peak facet joint compression (displacement of the upper facet surface towards the lower facet surface), facet joint sliding (displacement of the upper facet surface along the lower facet surface), and capsular ligament strains were calculated and compared to the physiologic limits determined during intact flexibility testing.

Results. Peak facet joint compression was greatest at C4–C5, reaching a maximum of 2.6 mm during the 5g simulation.

Increases over physiologic limits were initially observed during the 3.5g simulation. [Very Important]
In general, peak facet joint sliding and capsular ligament strains were largest in the lower cervical spine and increased with impact acceleration.

Capsular ligament strain reached a maximum of 39.9% at C6–C7 during the 8g simulation.

Conclusions. Facet joint components may be at risk for injury due to facet joint compression during rear-impact accelerations of 3.5g and above.

Capsular ligaments are at risk for injury at higher accelerations.

THESE AUTHORS ALSO NOTE:

“Clinical and pathologic investigations have targeted the facet joints (FJs) as possible sources of pain in whiplash patients.”

Clinical evidence of facet pain comes from studies that used nerve block and radiofrequency ablation of FJ afferents to successfully relieve pain.

Autopsy studies of subjects with soft tissue neck injuries have revealed FJ hemarthroses, articular cartilage damage, synovial fold displacement, and capsular ligament (CL) tears.

In a whiplash simulation using cadavers, FJ diastases and CL tears were found in specimens subjected to low-speed rear impacts.

“Thus, sufficient clinical and pathologic evidence exists to support the hypothesis of possible FJ injury during whiplash.”

Two distinct FJ injury mechanisms have been hypothesized:

1) Excessive compression of the FJ articulation.

“The C5–C6 intervertebral center of rotation was dynamically shifted superiorly during simulated whiplash impacts, implying that the facet articular surfaces were forcefully compressed during intervertebral extension.”

Facet joint compression has been demonstrated directly in cadaver studies.

“FJ compression could damage synovial folds that contain nociceptive nerve endings and potentially lead to facet pain.”

2) CL strain beyond the physiologic limit.

Biomechanical studies have identified excessive CL strain during whiplash as a potential injury mechanism.
This study used 6 human cadavers.

Specimens were subjected to horizontal T1 accelerations of 3.5, 5, 6.5, and 8g.

Facet joint compression, FJ sliding, and CL strain data were determined for each intervertebral level (C2−C3 to C6−C7) during the total intervertebral extension time period. [Note, they did not assess occiput-C1-C2]

RESULTS

“Maximum FJ compression occurred in the posterior region of the facet joint, whereas maximum CL strain was achieved in the anterior CL fiber.”

“Facet joint compression above the physiologic limit was first observed at C4−C5 during the 3.5g simulation.”

“Nonphysiological compression was also observed at C2−C3 during the 6.5g and 8g simulations.”

“Facet joint compression reached a maximum of 2.6 mm at C4−C5 during the 5g simulation.”

“Peak posterior FJ sliding tended to increase with impact severity and was greatest in the lower cervical spine region.”

“The peak CL strains were highest in the lower cervical spine and increased with acceleration.”

The lower cervical spine demonstrated the most consistent and dramatic kinematic changes.

“Peak FJ compression occurred first, followed by peak FJ sliding and then peak CL strain.”

DISCUSSION

No previous single study has comprehensively analyzed FJ compression, FJ sliding, and CL strain throughout the entire cervical spine at multiple impact accelerations.

“In the current whiplash simulation, the posterior region of the FJ was compressed, and the upper facet slid posteriorly along the lower facet during intervertebral extension.”

“Facet joint compression exceeded physiologic limits at C2−C3 and C4−C5, reaching a maximum of 2.6 mm at C4−C5 during the 5 g simulation.”
“Peak CL strain occurred due to the separation of the facets while the upper facet remained posterior to the lower facet.”

“Thus, both FJ sliding and FJ separation contributed to peak CL strain.”

“Facet joint compression exceeded physiologic limits at 3.5g and above, suggesting that compression injury may occur at low impact accelerations.” [IMPORTANT]

“Capsular ligament strain exceeded the physiologic values at 6.5g and above, validating it as a potential injury mechanism as well.”

Despite some limitations in this study, the authors “believe our results are clinically relevant.”

Others have demonstrated that the C5–C6 center of rotation was shifted superiorly during whiplash simulation and hypothesized that FJ impingement could injure the synovial fold. [Kaneoka K, Ono K, Inami S, et al. Motion analysis of cervical vertebrae during whiplash loading. Spine 1999;24:763–9].

“Their results provided implicit evidence of FJ compression, and the results of the current study confirmed this hypothesis.”

This study demonstrated that FJ compression in excess of physiologic limits occurs in both the lower cervical spine and the upper cervical spine as well.

“Facet joint compression that exceeds physiologic limits could potentially injure the facet articular cartilage.”

Other studies have demonstrated that acute loading of joints with loads above physiologic limits can lead to osteoarthritic changes in the cartilage. [IMPORTANT]

The upper facet can collide with the lower facet with sufficient force to cause irreversible damage to the cartilage, cartilage degeneration and osteoarthritis.

“Other authors have suggested that the synovial fold is at risk for injury during FJ compression, and the current study supports this hypothesis.”

It is the synovial folds that are present in the posterior region of the joint that is at greatest risk due to the FJ compression, neurovascular bleeding, pain and inflammation. [IMPORTANT]

Capsular ligament strains in the subfailure injury range were observed in this study, and could result in increased CL laxity. [This underscores the importance of stress radiography].
“The CL contains both mechanoreceptive and nociceptive nerve endings, and the facet capsule is lined with synovium. Excessive CL strain could potentially injure these structures and generate pain.”

“This study has identified facet articular cartilage, the synovial fold, and the facet capsule as structures at risk for injury during whiplash due to excessive FJ compression or CL strain.”

“Injury to the articular cartilage, synovial fold, or CL would likely result in inflammation, which could potentially sensitize peripheral and central nociceptive neurons.”

“This sensitization process could lead to the lowering of nociceptive firing thresholds, resulting in pain during normal motion.”

“Mechanoreceptors in the facet capsule or synovial fold could also be damaged during whiplash.” This disruption of proprioceptive transmission could lead to dysfunction of the spinal stabilizing system and the potential for spinal instability or uncoordinated, painful muscle contraction.

“It is reasonable to assume that excessive FJ compression or CL strain could lead to the chronic symptoms associated with whiplash injury.” [IMPORTANT]

**KEY POINTS FROM AUTHORS**

1) Peak facet joint compression and facet joint sliding exceeded the physiologic limits at 3.5 and 5g, respectively.

2) Capsular ligament strains exceeded the physiologic strains at 6.5g and were largest in the lower cervical spine.

3) Peak facet joint compression occurred at maximum intervertebral extension, whereas peak capsular ligament strain occurred after the maximum intervertebral extension had been reached as the facet joint was returning to its neutral position.

4) Facet joint components are at risk for injury during whiplash due to facet joint compression and excessive capsular ligament strain.

**KEY POINTS FROM DAN MURPHY**

1) This study shows whiplash causes two types of injury to the facet joints:
   A)) Compression injury to the posterior facet cartilage. This injury also results in trauma to the synovial folds, bleeding, inflammation, and pain.
   B)) Stretching injury to the facet capsular ligaments. This injury results in joint laxity and instability.
2) Injury was initially observed during the 3.5 g simulation, which is low impact.

3) Clinical and pathologic investigations have shown that the facet joints are the source of pain and injury in whiplash patients. These studies have revealed facet joint bleeding, articular cartilage damage, synovial fold displacement, and capsular ligament tears.

4) Facet joint compression in excess of physiologic limits occurs in both the lower and the upper cervical spines.

5) Facet joint cartilage injury can lead to osteoarthritic changes.

6) Capsular ligament injury alters the mechanoreceptive driven spinal stabilizing system resulting painful muscle spasm.

7) Injury to the articular cartilage, synovial fold, or capsular ligaments results in inflammation and peripheral and central nociceptive neuron sensitization.

8) This nociceptive sensitization lowers the nociceptive firing thresholds, resulting in pain during normal motion.

9) Excessive facet joint compression or capsular ligament strain can lead to the chronic symptoms associated with whiplash injury.

This is the cervical facet joint during whiplash extension motion:

A) Neutral, capsular ligaments are perpendicular to the facet joint.

B) The upper facet slides posterior on the lower facet, and there is lower facet joint compression.

C) Peak facet extension and compression is noted at about 50 ms.

D) The posterior facet separates, causing peak capsular ligament strain (70 ms).

E) Capsular ligaments are again perpendicular to the facet joint, though injured and separated.