Biomechanics of the cervical spine Part 3: minor injuries.

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FROM ABSTRACT:

Minor injuries of the cervical spine are essentially defined as injuries that do not involve a fracture.

Archetypical of minor cervical injury is the whiplash injury.

Among other reasons, neck pain after whiplash has been controversial because critics do not credit that an injury to the neck can occur in a whiplash accident.

In pursuit of the injury mechanism, bioengineers have used mathematical modelling, cadaver studies, and human volunteers to study the kinematics of the neck under the conditions of whiplash.

Particularly illuminating have been cinemophotographic and cineradiographic studies of cadavers and of normal volunteers.

They demonstrate that externally, the head and neck do not exceed normal physiological limits.

However, the cervical spine undergoes a sigmoid deformation very early after impact.

During this deformation, lower cervical segments undergo posterior rotation around an abnormally high axis of rotation, resulting in abnormal separation of the anterior elements of the cervical spine, and impaction of the zygapophysial joints.

The demonstration of a mechanism for injury of the zygapophysial joints complements postmortem studies that reveal lesions in these joints, and clinical studies that have demonstrated that zygapophysial joint pain is the single most common basis for chronic neck pain after injury.

THESE AUTHORS ALSO NOTE:

“There is no universally accepted definition of what distinguishes major from minor injuries to the cervical spine.”
Consequently, the distinction is whether or not there has been a fracture or a dislocation.

Fractures of the vertebral body, the pedicles, the odontoid process, and the ring of the atlas, and dislocations are considered to be major injuries, as they threaten the stability of the cervical spine its neural contents.

Fractures in an articular process or across the anterior edge of a vertebral body can be minor because they do not threaten spinal stability.

Minor injuries of the cervical spine are usually classified as “soft-tissue injuries”, implying no bone injury, but rather injury to muscles or ligaments.

X-rays cannot demonstrate these soft tissues.

Computerised tomography (CT) and magnetic resonance imaging (MRI) also do not help in demonstrating these soft tissue injuries.

“CT may be used to better define fractures already evident on plain films, or to search for occult fractures, but it does not resolve soft-tissue injuries.”

“MRI has the capacity to resolve certain soft-tissues, but no correlations have been established between neck pain and any feature evident on MRI.”

Several factors render neck soft-tissue injuries controversial:

(1) They are not demonstrated on X-rays.

(2) Soft-tissue injuries in the limbs, often (but not always), heal rapidly, in days or weeks.

(3) Soft-tissue neck injuries are often associated with insurance claims. Compensation and monetary gain confounds the clinical picture.

(4) A proportion of these patients develop chronic symptoms that last well beyond the expected period in which soft-tissue injuries should have healed.

“However, the more that whiplash has been studied, the more has scientific inquiry dispelled incorrect notions that caused this controversy.”

“The literature is replete with studies that have shown small injuries to intervertebral, discs, zygapophysial joints, and uncovertebral clefts, both in collagenous tissues and in cartilage and bones, that are plainly invisible on plain radiographs. Radiography simply lacks the sensitivity to detect these injuries,
and therefore, cannot be used to exclude or refute them. Normal radiographs do not mean that there has been no injury.”

“Extrapolation from the limbs about the nature of soft-tissue injuries and their period of healing is both inappropriate and false.”

Muscle injury is not an acceptable model for the healing of ligaments, capsules, joints, and intervertebral discs.

Although most sprained ankles recover within weeks, some do not, and many patients are left with chronic symptoms even though compensation is not involved.

Knee meniscus injuries often do not resolve and cause chronic pain and disability.

Small articular fractures can cause chronic disability.

“Intervertebral discs, like the menisci of the knee, are unlikely to heal spontaneously after injury, probably because of their relatively meager blood supply.”

“Clinical experience abounds with examples of soft tissue injuries to the limbs that do not summarily heal.”

“Correctly used, therefore, extrapolation would predict that at least some injuries of the cervical spine would not heal.”

“Whereas muscle sprains should resolve rapidly, injuries to joints and discs may remain sources of chronic pain.”

Formal studies refute that patients with neck pain exaggerate or perpetuate their symptoms for the purpose of financial gain, and their symptoms often persist after settlement of compensation claims.

Biomechanical research over the last 40 years has provided insights into how and where whiplash injuries occur.

MODES OF INVESTIGATION

Effort to determine the biomechanics of whiplash injuries include mathematical models, finite-element models, physical models, animal models, experiments using human cadavers, and the use of human volunteers.
Human cadaver studies have limitations because cadaver muscles “impose an artificial stiffness to the neck, for they are not relaxed. In addition, their inability to contract eliminates a possibly protective effect.”

“Cadavers with muscles removed provide an experimental model that provides valuable, prima facie, evidence of how the cervical spine behaves.”

The most daring method of studying whiplash is using human volunteers, but there are two limitations:

(1) Apprehension; “it can be argued that volunteers expecting an insult might brace themselves to a greater extent than victims of natural motor vehicle collisions.”

(2) Ethics; “Human volunteers can be subjected to only minimal impacts, for fear of seriously injuring them.”

These limitations bias experiments towards conservative findings.

“A braced neck subjected to low impact is unlikely to be injured to the same extent as a relaxed neck.”

“What occurs in human volunteer studies is the very least that might occur in natural injuries.”

A 1972 study using 21 embalmed human cadavers, rear-ended impacts at 25 kph [25 kph X .62 = 15.5 mph], with and without head rests. Subsequent dissection revealed:

90% had injuries to intervertebral discs.

80% had tears of the anterior longitudinal ligament.

40% had tears of the zygapophysial joint capsules.

30% had fractures of the posterior vertebral body or a spinous process.

“No injuries were found in the group protected by head rests.”

MODERN STUDIES

Current studies of the biomechanics of whiplash use high-speed photography and high-speed cineradiography to determine the kinematics of the cervical
spine as a whole and of individual segments, using both cadavers and human volunteers. The results of these various studies show remarkable consistency.

Studies in 1995, 1997, and 1998 show that during whiplash, a pinching at the zygapophysial joints results in neck pain, and a posterior stretch at the upper head-neck region resulted in headaches.

WHIPLASH BIOMECHANICS REVIEWED

0 – 50 ms after impact, there is no response by the body

60 ms, the hips and low back are thrust upwards and forward

50 – 75 ms, the cervical spine undergoes a sigmoid [S-shape] deformation as it is compressed by the rising trunk. The lower neck undergoes extension while the upper neck flexes.

100 ms, the upper trunk continues to move upward and forward, which causes additional compression of the cervical spine, resulting in an upward acceleration of the neck of 1 – 1.5 g.

120 ms, the cervical spine extends into a C-shape.

“Although the cervical spine as a whole does not exceed physiological ranges of movement at any stage during its excursion, lower cervical segments consistently exceed physiological limits of posterior rotation.”

Moreover, this rotation occurs around an abnormal axis of rotation, resulting in pure posterior rotation without translation. This abnormal rotation causes the anterior ends of adjacent vertebral bodies to separate [disc injury], while the articular inferior articular processes of the zygapophysial joints chisel into the superior articular processes of the vertebra below.

“Muscles are recruited relatively late during the whiplash event. They start to be recruited by 100 - 125 ms, but may take a further 60 ms to develop tension. In the unbraced individual the delay may be 200 ms or even 250 ms.”

“By the time muscles are activated, compression of the cervical spine, and the abnormal intersegmental movements that seem critical to injury, have already occurred.”
DISCUSSION

The critical revision of whiplash injury brought about by modern research is that in less than 150 ms after impact, the cervical spine is compressed.

During this period of compression, the cervical spine buckles; upper cervical segments are flexed while lower segments extend around abnormally located axes of rotation, causing injury.

“The cause of the compression is the upward thrust of the trunk.”

“This has been attributed to the seatback extending the thoracic kyphosis, for compression occurs only when the subject sits in a stooped posture.”

The compression injury does not occur if the subject’s head is against the headrest. “Under those conditions, the torso and the head collapse backwards together as the seatback collapse, and no upward thrust is exerted on the neck.” This axial compression occurs rapidly after impact, before bending of the cervical spine occurs.

60% of those injured will recover within 6 months.

80% of those injured will recover within 16 months.

“Whether or not a victim sustains an injury is a function of multiple factors: the magnitude of the impact, their posture at the time, their anatomy, and the material strength of the components of their cervical spine.”

Human volunteer tests are designed not to produce injury, and they understate the magnitude of the displacements and forces that conceivably might occur in impacts of greater speed.

There is a convergence between biomechanics research, postmortem studies, and clinical research.

Human volunteer and cadaver research have demonstrated the biomechanical findings that lower cervical zygapophysial joints are impacted during the whiplash event.

Injuries might range from contusions of intra-articular meniscoids and intra-articular haemorrhage to impaction fractures of the articular cartilage or fractures of the articular processes.
These lesions are identified in postmortem studies of victims of motor vehicle accidents.

Clinical studies have established that zygapophysial joints are the single most common source of chronic neck pain after whiplash, accounting for at least 50% - 80% of cases.

Biomechanics also suggest that disruption of an intervertebral disc may occur as the vertebral bodies separate anteriorly, tearing the anulus fibrosus, or the disc may be avulsed from the vertebral body.

These lesions have been produced in experimental studies on cadavers and identified at postmortem.

CONCLUSION

“Most victims of whiplash probably escape substantial injury but for those who develop chronic pain, biomechanics research has revealed a plausible mechanism of injury.”

“As the cervical spine is compressed the lower cervical vertebrae undergoes rotation about an abnormally located axis.”

The anterior vertebral elements [disc] separate while the zygapophysial joints impact.

The intervertebral disc may be torn or avulsed, and zygapophyssial joints may be bruised or fractured.

“For the 10% or 20% of victims who develop chronic symptoms, the available data indicate that their condition is not imaginary or fictitious. The biomechanics data, the postmortem data, and the clinical data agree that injuries can, and do, occur.”
During whiplash movement, the IAR is displaced upwards and anterior into the moving body. As C5 rotates backwards about this axis, the tip of its inferior articular process chisels into the surface of the superior articular facet of C6.