Cervical Disc Spine Injury in Low Speed Collisions

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Cervical Disc Injury Thresholds

Cervical Injury Mechanisms

- Bending
- Compression
- Shear
- Combinations

Load Rate & Duration
Cervical Disc Injury Thresholds

Average Peak Head Accelerations

Frontal & Lateral
- Up to 2X average vehicle G

Rear
- Up to 3X average vehicle G

Absolute peaks are frequently slightly higher.
Non-Physiologic Motion

Ono et al \[^1\] found that C5-C6 had the highest rotational angle in low speed collisions. The motions of the cervical vertebrae are beyond the normal physiological motions.

The rotational angle of the cervical vertebrae during impact is particularly high between the fifth and sixth vertebral facets that are quite different from that in normal condition. The lower vertebral center of rotation moves upward on impact forcing articular facets collision. [pp 351-352, and 354]

In rear end collisions, abnormal motion occurs in collisions with delta V as low as 2.5 mph.

In rear end impact simulations using cadavers, Yoganandan et al. found AIS 2-3 injuries, including cervical disc herniations, at upper cervical bending moments between 194 in-lb and 412 in-lb.

194 in-lb at the upper cervical spine corresponds to a moment of about 291 in-lb to 340 in-lb in the lower cervical spine.

412 in-lb at the upper cervical spine corresponds to a moment of about 618 in–lb to 721 in-lb relative to the lower cervical spine. The respective axial forces range was 82 lb to 203 lb, and the shear force range was 58 lb to 125.

Yoganandan et al. also identified an AIS 3 neck bending moment injury threshold value of 274 in-lb for the 5% female (like A 5% female) and 690 in-lb for the 95% male.[pp 195, 196, 199] Taking into account neck geometry, this proposed moment threshold would be about 411 in-lb in 5% females, and 1207 in-lb in 95% males in the lower cervical spine.

Nightingale et al.\textsuperscript{[i]} [pp 729, table 3] reported that disc rupture occurred in lower cervical spine segments under bending moments. He did not report which of these specimens had disc rupture in this article.

However, the highest two bending moments reported were 301 in-lb (flexion) and 367 in-lb (extension). Since disc injury typically occurs at higher values than ligamentous injury, the higher two values most likely represented the spines with disc injury. Range for bending moment injuries of all types in the lower cervical segments was 80 in-lb to 367 in-lb.

\textsuperscript{[i]} Nightingale RW, Winkelstein BA, Knaub KE, Richardson WJ, Luck JF, Myers BS. Comparative strengths and structural properties of the upper and lower cervical spine in flexion and extension. \textit{J Biomech} 2002 Jun;35(6):725-32
Cappon et al.[i] compared selected crash dummy, volunteer and cadaver loads in the upper neck [pp5]. Bending moments in low speed rear end collisions can exceed the injury thresholds for the 5% female.

Proportionality of Mechanical Characteristics in the Spinal Discs

Forces and moments causing disc injury increase progressively down the vertebral column.

Yamada et al[1], Sances et al and Burton et al (and others) found that cervical discs fail at mean loads and moments about 1/5 to 1/3 of lumbar disc values [Yamada tables 89, 90 & 91].

Since injury thresholds are reduced by up to 1/3 for degenerated discs, the values the 1/5 proportion most likely reflects some degree of disc degeneration.

Proportionality for Disc vs. Spinal Structure

Cervical discs are about 1/3 the strength of lumbar discs. Osavander et al. recorded a mean lumbar disc bending moment injury at moderate impact load pulses as found in a low speed collisions (26 J of energy). Disc failure occurred at a mean of 1239 in-lb or 103 ft-lb (min 1062 in-lb or 88.5 ft-lb) [pp 1231].

Using the higher 1/3 proportional value, the mean bending moment injury threshold for cervical discs in a low speed collision is about 413 in-lb, and the corresponding minimal threshold value is about 354 in-lb.

- Mean at 1/3 proportion is 248 in-lb
- Min at 1/5 proportion is 210 in-lb

At more a severe load rate found in higher velocity collisions (44 J of energy) disc failure occurred at a mean bending moment of 1638 in-lb, and min of 1327 in-lb. [pp 1231]

Using the higher 1/3 proportional value, the mean bending moment injury threshold for the cervical region for a somewhat higher speed collision is about 546 in-lb, and the corresponding minimal threshold value is about 442 in-lb. (Mean and min at 1/5 proportion is 328 in-lb and 265 in-lb)

These values agree with the values reported by Nightingale et al as highlighted before.

Cervical Injury Thresholds

Taking into account impulses and load rates in a low speed collision, and a minimum potential contribution of about 15 in-lb to about 54 in-lb to overcome of flexor muscle activation\[i, [iii], [iii], [iv]\], we have calculated that the injury threshold for cervical disc injury in low speed collisions in the range of about 301 in-lb to 421 in-lb of external moment. (Range takes into account recommendations by Yoganandan [v] whose experimental work includes the effect of the local muscle/bone and ligament structure, and Nightingale et al[vi] who tested necks without muscle effect.)

5% female threshold (or flexible spine with prior degeneration)....

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\begin{align*}
248 \text{ in-lb} + 15 \text{ in-lb (muscle resisting moment)} & = 263 \text{ in-lb external moment.} \\
248 \text{ in-lb} + 54 \text{ in-lb (muscle resisting moment)} & = 302 \text{ in-lb external moment.} \\
274 \text{ in-lb} + 15 \text{ in-lb (muscle resisting moment)} & = 289 \text{ in-lb external moment.} \\
274 \text{ in-lb} + 54 \text{ in-lb (muscle resisting moment)} & = 328 \text{ in-lb external moment.} \\
354 \text{ in-lb} + 15 \text{ in-lb (muscle resisting moment)} & = 369 \text{ in-lb external moment.} \\
354 \text{ in-lb} + 54 \text{ in-lb (muscle resisting moment)} & = 408 \text{ in-lb external moment.} \\
367 \text{ in-lb} + 54 \text{ in-lb (muscle resisting moment)} & = 421 \text{ in-lb external moment.}
\end{align*}
\]

In an 5% female in a 5 mph delta V rear end collision, average peak external moments can be up to a range of 336 and 403 in-lb. Moments in this range are sufficient to cause disc herniation.

The threshold for larger females and males can be up to double depending on neck strength and disc health.


Can we draw a line in the sand for cervical DISC injury thresholds in bending?

Male?

Female?

Stemper et al [i] have new work which we will be reviewing shortly.

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Reflexive muscle contraction alters segmental angulations by less than 10% and facet joint capsular ligament distractions by less than 16% during the time of maximum S-curvature, slightly changing spinal kinematics in unaware occupants subjected to whiplash loading.

Whiplash injury likely occurs during the non-physiologic S-curvature phase of spinal kinematics, present during the first 100 msec after the initiation of T1 acceleration.

This work involves modeling of dynamic neck motions and forces with passive, proprioceptive and active muscle effects is similar to the work of Van Horst et al. Also presented at IRCOBI this fall.

Pure flexion, and combined flexion and compression produced similar patterns of injuries. The disc was the most commonly injured structure, with annular injuries noted in 8 of the 12 specimens, and with anterior herniation of the nucleus occurring in two specimens. Wedge fractures and posterior ligament injuries were noted in both specimen groups and with both modes of loading.

Ray [pp 11] noted that MAIS level 3 injuries (disc tears) begin to appear at delta V of 5 mph.\[ii\]
Thank You!

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