Quantitative evaluation of subaxial cervical facet deflection, strain and failure load during simulated flexion and shear loading

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INTRODUCTION

Traumatic cervical facet dislocation (CFD) is often associated with devastating spinal cord injury.[1] The injury mechanisms leading to traumatic CFD are complex and have not been replicated in biomechanical testing;[2] however, anterior shear and flexion loading modes are likely associated with dislocation.[3] Facet fracture is commonly observed with CFD,[4] yet facet strain, stiffness and failure load have not been reported for the cervical spine. A better understanding of the mechanical behaviour of the facets during cervical trauma is important for validating finite element models and anthropometric test devices, and developing preventative measures. The aim of this study was to determine the mechanical response of the facets when loaded in directions thought to be associated with traumatic CFD.

METHODS

Sixteen functional spinal units (FSUs; 4×C2/3, 3×C3/4, 3×C4/5, 3×C5/6, 3×C6/7) were prepared from seven fresh-frozen cadaver spines (mean age 68 years, range 48-92, four male). The vertebral bodies of each FSU were embedded such that a rectangular block of polymethylmethacrylate (PMMA) protruded approximately 50 mm from the superior endplate of the superior vertebra. The specimen-PMMA assembly was fixed to the base of a materials testing machine (Instron 8874) via a custom apparatus attached to a rotary table. Using the rotary table, the inferior articular facet surfaces of the inferior vertebrae were positioned, relative to the actuator, to simulate *in-vivo* 1) flexion, and 2) anterior shear loading. Three cycles of sub-failure loading (10-100 N) were applied bilaterally at 1 mm/s using 6 mm diameter hemispherical loading pins, in each loading direction; the last cycle was used for analysis. Each specimen was failed in a randomly assigned direction at 10 mm/s. Applied loads/moments were quantified using a 6-axis load cell (±4.4 kN, AMTI), and facet deflection was measured using a motion capture system (Optotrak Certus, Northern Digital). Rosette strain gauges (TML) were used to calculate peak principal strains at the base of the bilateral articular pillars. Apparent facet stiffness was determined from the linear region of load-displacement data, and peak failure load was determined. Paired and independent t-tests were used for comparisons ($\alpha=0.05$). For this analysis FSUs from different vertebral levels were grouped together.

RESULTS AND DISCUSSION

Apparent facet stiffness and peak failure load were greater in flexion than in anterior shear (Figure 1). There was no significant difference in facet deflection at 100 N (0.35 vs 0.29 mm, $p=0.085$) or in maximum principal strains (Left facet: 94.6 vs 180.6 μstrain, $p=0.061$; Right: 172.1 vs 128.5 μstrain, $p=0.095$) for the two loading directions. Failure occurred through the facet tip in anterior shear, while failure through the pedicles was most common for flexion loading. A further 14 specimens will be tested and linear mixed effects models will be used to account for vertebral level and specimen age.

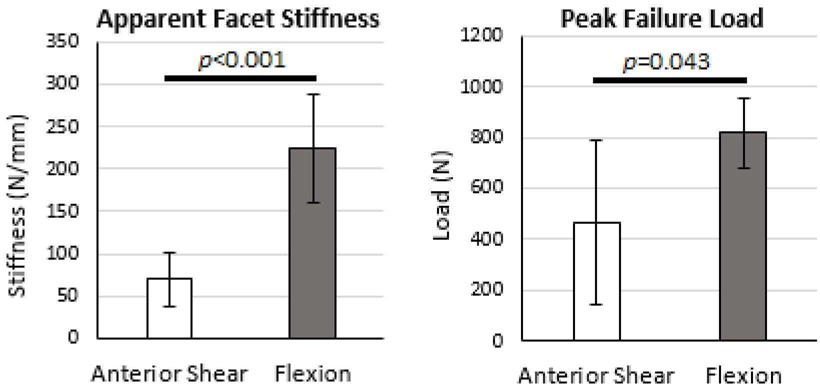

Figure 1: Mean (±1SD) facet stiffness (left) and failure load (right) for anterior shear vs flexion loading directions.

CONCLUSIONS

Cervical facets tended to be stiffer, and have a higher failure load, when loaded in flexion compared to anterior shear, and failure location was dependent on loading mode.

REFERENCES

1. Hadley MN, et al., Neurosurgery. 5:661-6, 1992.
2. Foster BJ, et al., IRCOBI Conference. 2012.
3. Panjabi MM, et al., Eur Spine J. 16:1680-8, 2007.
4. Piccirilli M, et al., J Spinal Disord Tech. 6:261-5, 2013.