Lower Neck Injury Criteria from Post-Mortem Human Subject Tests using an Injury Mechanism Approach

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I. INTRODUCTION

Neck injury criteria in the current United States Federal Motor Vehicle Safety Standards are obtained from experiments with piglets, human cadavers and computational models [1]. Animal tests conducted in the late 1970s and early 1980s form the primary basis for the criteria [2-3]. Injuries sustained by piglets exposed to mechanical loading (airbag) were matched with upper neck forces and bending moments in the Hybrid III child dummy exposed to similar insults, in order to develop the interaction response between the two metrics [3]. Data were scaled to adult anthropometry using the equal stress equal velocity approach [4-5]. The present neck injury criterion, N_{ij}, is applicable to the upper neck loads/head-neck junction in the Hybrid III dummy family [1].

Recent epidemiological and descriptive studies in the USA (e.g., National Automotive Sampling System and Crash Injury Research and Engineering Network) and elsewhere have shown that lower regions of the cervical spinal column sustain injuries more often than the head-neck junction/upper cervical spine [6-8]. Consequently, new studies have focused on designing tests to obtain lower neck injury metrics and criteria [9-10]. These include loading in frontal and rear impact modalities. Although some authors have suggested lower neck injury criteria, analysis based on statistical measures is very sparse [11-12]. The intention of this short communication is, therefore, to present a survival analysis-based methodology using the conventional and mechanistic approaches, and also to examine the efficacy of the location where the biomechanical metric is derived within the lower cervical spinal column using survival analysis.

II. METHODS

Isolated post-mortem human subject (PMHS) head-neck complex tests published elsewhere were used [13]. Briefly, specimens were fixed at the distal end and a six-axis load cell was attached. The preparation was attached to the platform of an electrohydraulic piston device and axial forces were applied to the head at velocities ranging from 2.5 to 8.0 m/s. The cervico-thoracic joint was unconstrained. Load cell-recorded forces and moments were transformed to two locations: the centre of the cervico-thoracic disc; and posterior longitudinal ligament level at the tip of the superior vertebral body. The Society of Automotive Engineers' recommendations were used to filter the signals: Class 1000 for forces and Class 600 for moments [14].

The statistical approach was based on the recommendation of the working group of the International Standards Organization (ISO/TC22/SC12/WG6) to obtain injury risk curves from the 19 retrospective PMHS tests. Parametric survival analysis was used. Results are presented for the Weibull model. All injury data were treated as uncensored in order to demonstrate the methodology and to compare the efficacy of the location or the origin of the metric as well as the approach. Age was included as a covariate in the survival analysis. The mean age of 64 years was used if it was significant at the 0.05 level; otherwise, risk curves were assumed to be age independent. Isolated risk curves were constructed based on the peak axial force and peak bending moment. The critical intercept was defined at the 90% risk level. Using these intercepts, lower neck injury criteria were computed based on the conventional N_{ij} approach, termed CLNij, and based on the mechanism of injury, termed MLN_{ij}, referred to as the mechanistic approach. The former was independent of the time of occurrence of the interaction metrics, while the latter was constrained to the specific injury mechanism and time: compression-flexion, compression-extension, and pure compression. Both criteria were obtained at two locations: disc centre and posterior longitudinal ligament level, as described earlier.

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III. INITIAL FINDINGS

Early findings included the derivation of injury risk curves for the peak axial force, peak flexion bending moment and peak extension bending moment. Age was found to be a significant covariate for the peak force and flexion moment. Critical intercepts were 4.5 kN for the lower neck peak axial force, 220 Nm for the flexion bending moment and 120 Nm for the extension bending moment. Figure 1 shows the risk curves computed using the conventional and mechanistic methods and at the two locations in the lower intervertebral joint anatomy.

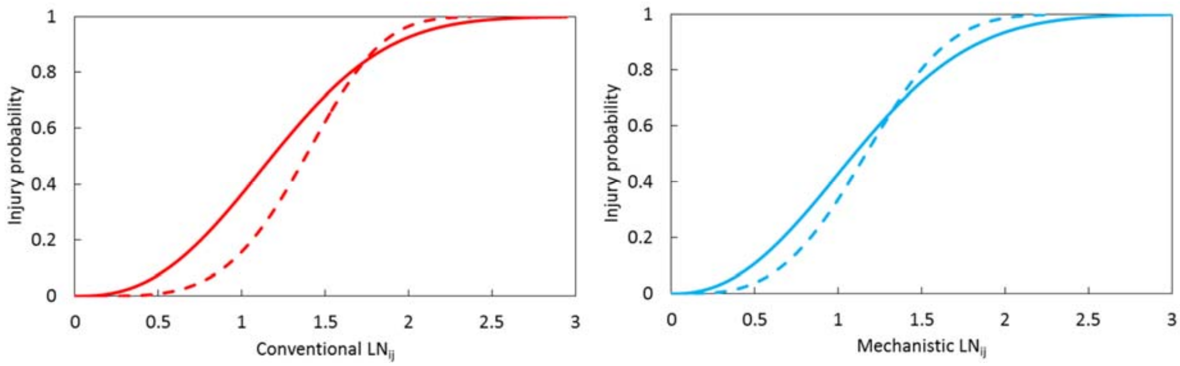

Fig. 1. Risk curves based on the two approaches: *dashed curves* correspond to the centre of the disc; *solid curves* correspond to the posterior longitudinal ligament level.

IV. DISCUSSION

A unique aspect of the study is that it explores differences between the conventional approach of calculating the index and the new mechanistic-based approach where only pertinent metrics and times are used to derive lower neck injury criteria. Yet another novelty of the study is that it explores the sensitivity of the anatomical location of the metric to injury criteria. Albeit brief, it appears that the level of the posterior longitudinal ligament at the tip of the superior vertebral body is less sensitive, and hence better suited, to characterise/quantify lower spine injuries in automotive environments. A more complete study is needed with the addition of sample sizes and other loading vectors to verify these early findings.

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VI. REFERENCES

[1] FMVSS-208, Code of Federal Regulations, 2001.
[2] Mertz, H.J. *et al*., Experimental Safety Vehicles Conference, 1978.
[3] Prasad, P. and Daniel, R., Stapp Car Crash Conference, 1984.
[4] Eppinger *et al*., Experimental Safety Vehicles, 1976.
[5] Kleinberger *et al*., National Highway Traffic Safety Administration, 1998.
[6] Claytor, B. *et al*., *Spine*, 2004.
[7] Wang, M. *et al*., *Journal of Neurosurgery Spine*, 2009.
[8] Yoganandan *et al*., Stapp Car Crash Conference, 1989.
[9] Pintar, F.A. *et al*., Stapp Car Crash Conference, 2010.
[10] Yoganandan *et al*., Stapp Car Crash Conference, 2000.
[11] Schmitt, K. *et al*., Experimental Safety Vehicles Conference, 2001.
[12] Munoz *et al*., Experimental Safety Vehicles Conference, 2005.
[13] Pintar *et al*., *Spine,* 1998.