Comparative Frontal Crash Performance of a Prototype and Standard Hybrid III-5%F Lumbar Spine in Out-of-position Postures

Bianca Albanese, Byron Panos, Julie Brown, Lynne Bilston

I. INTRODUCTION

Out-of-position postures are commonly observed in naturalistic driving studies [1-2] and can increase the risk of abdominal and lumbar spine injury due to submarining [3]. Older children and small adults are at higher risk of these injuries due to poor fit in the rear seat [4-5]. At present, researchers cannot accurately study submarining and abdominal injury risk in small occupants because the lumbar spine of the Hybrid III-5%F anthropometric test device (ATD) is too stiff [6]. Our previous work developed a more biofidelic prototype lumbar spine designed to replicate the flexion response of a small female post-mortem human subject (PMHS) spine [7]. This study compares ATD kinematics and sensor outputs between a more biofidelic prototype lumbar spine and the standard HIII-5%F lumbar spine in common out-of-position postures during frontal impact.

II. METHODS

Forty-four frontal sled tests (Δv=49km/h, peak acceleration=27g) were conducted on a deceleration sled fitted with a standardised contoured bench seat and a three-point lap-sash seat belt representing a common sedan rear seat (Mazda 3). A Hybrid III-5%F ATD was tested in an upright (baseline) seated posture and four out-of-position postures: forward leaning (head 100mm forward), slouch (pelvis 100mm forward), inboard leaning (head 100mm left), slouch and inboard leaning. Each posture was tested twice with the prototype and standard lumbar spine. High speed video was recorded at 1000 frame/second from the side and overhead positions to visually assess submarining and markers were used for measuring head and femur excursions. Head, chest and pelvis acceleration, seat belt force, neck and lumbar spine forces and moments were measured using standard onboard sensors, with data acquisition performed according to SAE J211. These were used to calculate peak 3ms values. Due to equipment availability, neck and lumbar spine forces and moments were measured only in one replicate test each. The effect of posture on each outcome was compared between the two lumbar spines using repeated measures ANOVA (Graphpad Prism v 10.4).

Upright (reference)	Forward Leaning	Slouch	Inboard Leaning	Slouch + Leaning

Fig. 1. Test setup for each seated posture.

III. INITIAL FINDINGS

Submarining occurred in all tests where the ATD was initially slouched (slouched, slouched + inward lean) with both lumbar spine elements. Submarining also occurred during one of the two replicate tests with the prototype spine where the ATD was positioned inboard leaning without slouch, but not with the standard spine in the same test condition. Key results are plotted in Figure 2, below. Tests where submarining occurred are shaded in grey.

When submarining occurred, it was associated with (2-way ANOVA, RM where replicate data available): higher femur excursion ($P<0.0001$), lower head excursion ($P=0.0049$), a greater difference between femur and head excursion ($P<0.0001$), higher lumbar flexion moments ($P=0.0002$) and compressive forces ($P<0.0001$), and lower sash belt forces ($P=0.0005$).

In most test conditions, the prototype lumbar spine element performed similarly to the standard lumbar spine, but the increased flexibility of the prototype resulted in significantly (2-way RM-ANOVA) lower head accelerations

Dr. Bianca Albanese is a Postdoctoral Fellow, Byron Panos is a Crash Test Engineer, Prof. Julie Brown is a Conjoint Senior Principal Research Scientist and Prof. Lynne Bilston is Senior Principal Research Scientist in the Transurban Road Safety Centre at Neuroscience Research Australia. Lynne Bilston is Prof. in the Graduate School of Biomedical Engineering at the University of New South Wales and Julie Brown is Head of the Injury Division at the George Institute for Global Health. This research was supported by a partnership with Transurban Pty Ltd.

(P=0.0351) and excursions (P=0.0287), and a greater difference between femur and head excursion (P=0.035).

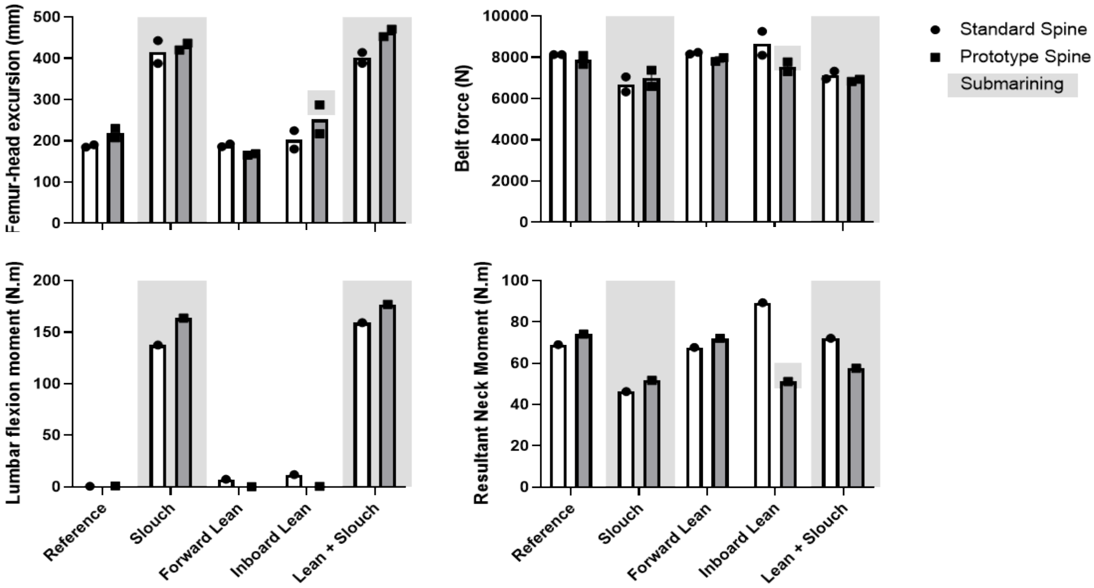

Fig. 2. Variation in excursion, sash belt force, lumbar flexion moments and neck moments in different seated postures with each lumbar spine.

IV. DISCUSSION

These results confirm previous research showing that submarining risk can be substantially increased by a slouched seated posture. The data also shows that lateral leaning may pose a higher risk of submarining, but this requires confirmation. In seated postures where submarining was *expected*, such as when the dummy was positioned in an initially slouched position, the dummy equipped with either lumbar spine element underwent submarining. In the standard upright seated position and in the forward leaning position, submarining did not occur with either lumbar spine element. There was only one test where the prototype spine submarined when the standard spine did not, when the dummy was upright, but inboard leaning. This occurred in one test but not the replicate, despite rigorous setup and positioning protocols, suggesting this is an *edge case* where even small differences in setup can result in different outcomes. Despite these broadly similar responses, the more flexible prototype spine resulted in modest reductions in head kinematics and accelerations, and a greater difference between head and femur excursion. The latter has been previously associated with submarining [8]. This is likely because the greater flexibility of the prototype lumbar spine allows more bending, so that the torso, head and pelvis are less tightly coupled, and thus they rotate and move less as the pelvis moves forward.

Limitations of this study include that we had only one spine load cell available, so one test was done in each condition with the load cell in either the neck or lumbar spine, limiting statistical power for those analyses. The pelvis on the Hybrid III ATD is also known to have limited biofidelity for replicating belt-pelvis-hip interactions due to its moulded shape. This may influence the accuracy of submarining risk prediction. Future research would benefit from a more realistic seating environment that includes both seat pan structure and advanced restraint systems, and comparison to real world crash data where submarining occurred is also required.

These results suggest that the prototype lumbar spine may be able to identify submarining risk in some non-standard seated positions that the standard lumbar spine does not, but more research is needed to assess whether the prototype spine can reliably differentiate submarining risk in different seating postures, vehicle seat and belt geometries that accurately replicate the vehicle fleet and real-world injury risk.

V. REFERENCES

[5] Greingor et al., Accid. Anal Prev., 1994.
[4] Brown et al., ESV Conference, 2007.
[6] Couturier et al., ESV Conference, 2007.
[1] Jakobsson et al., IRCOBI Conference, 2011.
[3] Beck et al., Traffic Inj. Prev., 2013.
[8] Visvikis et al., IRCOBI, 2018.
[2] Reed et al., Traffic Inj. Prev., 2022.
[7] Hatami et al., Crash Tech 2024 & AAAM 2023.