

## Influence of Pelvis Acceleration on Spinal Fracture in High-Rate Vertical Loading

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### I. INTRODUCTION

Fracture to the thoracolumbar spine is a known consequence of high-rate vertical loading to seated occupants in vehicles exposed to under-body blast (UBB) [1-3]. The boundary condition created by the seat, combined with the anatomic alignment of the centre of mass of the torso over the pelvis, allows for compression and flexion of the spine, leading to spinal fracture [3]. Energy-absorbing seat systems act to reduce the acceleration of the pelvis and thereby influence the rate and magnitude of force transfer to the body, mitigating injury to the pelvis and spine. The current study utilised high-rate loading of whole-body post-mortem human subjects (PMHS) in seated postures to compare thoracolumbar fracture patterns to pelvis and thoracic accelerations.

### II. METHODS

Thirty whole-body male PMHS were tested on three rigs custom-built for generation of high-rate vertical loading: pneumatic-driven, drop tower, and blast-driven (Table I). Subjects were mounted to a seat, with varying seat-pan boundary conditions, and accelerated to specified peak seat velocities (peak-V) and seat time-to-peak velocities (TTP-V). All PMHS donned Tyvek suits and army combat boots. Military personal protective equipment, including a combat helmet and tactical vest, was donned for select tests. Accelerometers, angular rate sensors and strain gauges were implanted at strategic anatomic locations to capture the kinematic response of the PMHS throughout each test. In particular, a six degree-of-freedom suite of accelerometers and angular rate sensors was implanted at the posterior-superior sacrum and posterior twelfth thoracic (T12) vertebra. For this analysis, accelerometer data were filtered with a low-pass Butterworth filter with a 300 Hz cut-off to establish acceleration profiles that characterise the interaction of the pelvis with the thoracolumbar spine. High-speed video captured motion of the test fixtures and specimen. Pre-test and post-test x-rays and/or Computed Tomography (CT) images, in conjunction with autopsy, were utilised to evaluate the presence and pattern of fractures created.

TABLE I

WHOLE-BODY TESTS PERFORMED WITH ASSOCIATED SEAT-PAN CONDITION, PEAK VELOCITY, AND TIME-TO-PEAK VELOCITY.

Rig Type	No. of PMHS	PPE	Seat Pan Condition	Seat Peak-V (m/s)	Seat TTP-V (ms)
Pneumatic	4	None	Rigid	4.0	5.0
Drop Tower	4	Medium	Rigid	4.0	5.0
Pneumatic	3	None	Rigid	4.0	10.0
Pneumatic	3	Medium	Rigid	4.0	10.0
Drop Tower	3	Medium	Rigid	4.0	40.0
Pneumatic	3	Medium	Rigid	4.0	30.0
Blast	4	None	Rigid	5.0	4.0
Drop Tower	3	Medium	Foam	5.0	10.0
Pneumatic	3	Medium	OEM Seat	3.0	8.0

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### III. INITIAL FINDINGS

Fourteen PMHS sustained thoracolumbar spine vertebral body fractures: eight isolated to the lumbar spine, five isolated to the thoracic spine, and one with both thoracic and lumbar fractures. Sixteen PMHS did not sustain thoracolumbar vertebral body fracture, one of which sustained fracture to the sacroiliac joint. Peak vertical pelvis acceleration (PV-AZ) was calculated through a process of transforming accelerations and rotations measured at the posterior-superior sacrum to the centre of rotation of the pelvis. Peak vertical thoracic acceleration (T12-AZ) was measured from the T12 z-axis accelerometer. The difference between peak vertical thoracic acceleration and peak vertical pelvis acceleration (DIFF) was also calculated. An analysis of variance (ANOVA) of these three measures was performed for three injury groups: non-injury (NON), isolated lumbar injury (LUM), and isolated thoracic injury (THOR) (Fig. 1). The tests resulting in SI joint fracture and both lumbar and thoracic fracture were excluded from the analysis. PV-AZ was found to be significantly different between injury groups ( $p=0.004$ ), while T12-AZ and DIFF were not ( $p=0.079$  and  $p=0.821$ , respectively). Post-hoc analysis using Tukey's honest statistical difference test found that PV-AZ was significantly greater for the lumbar injury group than the non-injury and thoracic injury group. PV-AZ was not different between the non-injury and thoracic injury groups.

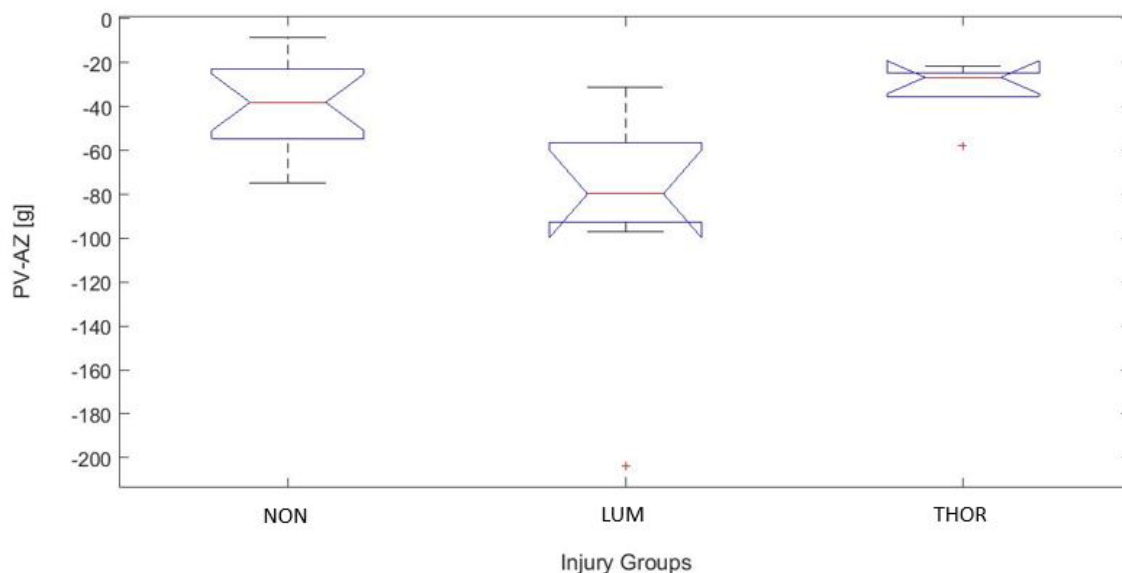


Fig. 1. Box plots resulting from the ANOVA of PV-AZ between non-injury (NON), isolated lumbar injury (LUM) and isolated thoracic injury (THOR) groups.

### IV. DISCUSSION

High-rate vertical loading to whole-body PMHS created fracture to the thoracolumbar spine. A majority of these were vertebral body compression fractures isolated to either the lumbar or thoracic spine. Lumbar fracture occurred more often than thoracic fracture. Fracture type and distribution were consistent with an evaluation of thoracolumbar spine injury to Warfighters in mounted UBB attacks [3]. Peak vertical acceleration of the pelvis was found to be significantly greater in magnitude during tests resulting in lumbar spine fracture when compared to tests resulting in thoracic fracture or non-injury. The results of this study suggest that reducing pelvis acceleration during high-rate vertical loading events, such as UBB, may be effective in mitigating lumbar spine injury to seated occupants. However, reduction in pelvis acceleration may not mitigate injury to the thoracic spine. Consequently, injury mitigation strategies unique to the thoracic spine may be necessary to effectively reduce the occurrence of thoracolumbar fracture in high-rate vertical loading.

### V. REFERENCES

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