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Spine and Pelvis Fractures in Axial Z-Acceleration

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ABSTRACT

Axial compressive spine loading may occur through impact with the pelvis in multiple scenarios. A previous study demonstrated out of 122 CIREN cases, 52 occupants had fractures at the T12 or L1 vertebrae. The literature documenting fracture levels from military events include reports that indicate ejection seat events produced more trauma at the lower thoracic levels, helicopter crashes produced more fractures at the thoracolumbar junction, and underbody blast events produced more trauma at the mid to lower lumbar levels. The goals of the present study were to understand the effect of pulse differences on injury outcome and understand the differences between pelvis and spine trauma with an input acceleration to the seat bottom in the inferior-to-superior direction. Five PMHS were run in 15 tests on a Seattle Safety systems acceleration thrust sled. Additional Hybrid-III fiftieth male dummy tests were also conducted. Triangular pulses were used initially and varied from 1 G/msec, to 5 G/msec, to 10 G/msec and pulse durations of 40, 20, and 10 msec. In latter tests a sigmoid-shaped pulse with pulse durations on the order of 50 to 60 msec were used. The triangular pulses at 5 and 10 G/msec produced pelvic fractures but no spine fractures. The sigmoid-shaped pulse with 60 msec duration produced no pelvic fractures but did produce an L1 burst fracture. The Hybrid-III with the straight lumbar spine demonstrated higher Z-axis lumbar spine loads in the matched-pair test condition that induced an L1 burst fracture than the dummy with a curved spine.

INTRODUCTION

The motivation for conducting the study was applications to axial loading of the spinal column through the pelvis including: military underbody vehicle blast, military helicopter crashes, falls (to the backside), and vehicle-related trauma. Previous studies have indicated that axial compressive spine loading through impact with the pelvis can occur in multiple scenarios. Munjin, et al (2011), examined a series of thoracolumbar fractures in patients that had endured a speed hump riding in the back of a bus. The vast majority of the cases (34 out of 46) were fractures at either T12 or L1 vertebrae. They postulated that the fracture occurred either when the person was launched up from the seat during the speed hump crossing or when the person fell back down into the seat after being launched. The Medical College of Wisconsin (Pintar, et al, 2012) conducted an investigation into thoracolumbar fractures that occurred during frontal impacts. Out of 122 CIREN cases, they found that 52 occupants had fractures at the T12 or L1 vertebrae. They postulated that the nature of the crash pulse and the occupant interaction with the seat and restraint system were contributors to the injury. The literature documenting fracture levels from military events include reports that indicate ejection seat events produced more trauma at the lower thoracic levels, helicopter crashes produced more fractures at the thoracolumbar junction, and underbody blast produced more trauma at the mid to lower lumbar levels (Ragel et al, 2009). This may indicate that spinal fractures at different levels have preference toward input acceleration pulse. The goals of the present study were to understand the effect of pulse differences on injury outcome and understand the differences between pelvis and spine trauma with an input acceleration to the seat bottom in the inferior-to-superior direction.

METHODS

Five PMHS were run in 15 tests on a Seattle Safety systems acceleration thrust sled. Additional Hybrid-III fiftieth male dummy tests were also conducted. The standard forward (kyphotic) curvature lumbar spine and also the straight column lumbar spine in the dummy were evaluated. The Seattle Safety sled has the capability to respond to a digitally input acceleration pulse. Sled pulses were varied in shape and velocity including pulse duration and maximum acceleration levels. Triangular pulses were used initially and varied from 1 G/msec, to 5 G/msec, to 10 G/msec and pulse durations of 40, 20, and 10 msec. In latter tests a sigmoid-shaped pulse with pulse durations on the order of 50 to 60 msec were used.

A unique sled buck was designed to place the dummy or PMHS in a posture with the occupant lying on its back with lower extremities such that the hips, knees, and ankles were all at 90-degree angles (Figure). The seat back angle was adjustable such that different spine postures (pre-flexed or pre-extended) were possible. The seat pan and foot plate were instrumented with load cells. The occupants were belt restrained in essentially a four-point system with belts crisscrossing the chest and another belt restraining the pelvis. Instrumentation included head, T1, T12, and sacrum acceleration measures in the PMHS and standard acceleration measures in the dummy with the addition of lower spine and lumbar loads.

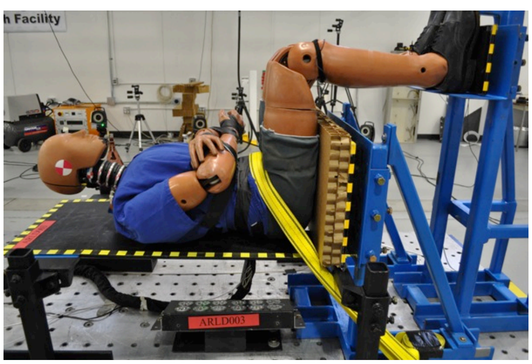

Figure 1: Hybrid-III dummy on sled buck system. Note complete belt system is not shown.

RESULTS

Initial low level tests were completed to ensure adequate instrumentation measures were recorded and to document low-level response. After each low-level test palpation was done and x-rays were taken to provide confidence that no noticeable injuries occurred. The test series was designed such that the last test was expected to produce some type of fractures. The triangular pulses at 5 and 10 G/msec produced pelvic fractures but no spine fractures. The triangular pulse with a 40 msec pulse duration did not produce any pelvis or spine fractures. The sigmoid-shaped pulse with 50 msec duration produced sacral fracture and a minor T12 compression fracture. The sigmoid-shaped pulse with 60 msec duration produced no pelvic fractures but did produce an L1 burst fracture. Accelerations at the sacrum and T12 indicated that high magnitudes of sacrum Z-axis acceleration occurred early for the two tests that produced pelvic bone fractures; T12 acceleration peaked earlier than sacrum acceleration when a spine fracture occurred and a pelvic bone fracture did not occur. Sigmoidal-shaped accelerations perhaps allow sufficient time for the pelvis mass to be accelerated without fracture but leaving the spine at risk for injury.

The Hybrid-III with the straight lumbar spine demonstrated higher Z-axis lumbar spine loads in the matched-pair test condition that induced an L1 burst fracture than the dummy with a curved spine. The accelerations at the sacrum and thorax of the straight spine dummy were also more appropriate than for those from the curved spine dummy.

CONCLUSIONS

The human thoracolumbar spine may fracture due Z-axis (inferior-to-superior) accelerations applied to the buttocks of a seated occupant. These fractures may occur in automotive environments, falls, and military events including pilot ejection from high-performance aircraft, helicopter crashes, and underbody blast to a vehicle. The pelvis may fracture if the acceleration event allows for a very fast loading rate; at slower rates, it appears the thoracolumbar spine is at risk. The dummy with a straight spine may be a better model in this mode of loading.

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