Injuries due to Lower Spine Blunt Force Impacts Associated with the Planetary Suit Body Seal Closure (BSC)

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I. INTRODUCTION

In an attempt to increase trunk mobility of astronauts in the Orion space capsule upon re-entry and landing on Earth, the National Aeronautics and Space Administration (NASA) designed a planetary suit body seal closure (BSC). This BSC is a stainless steel, interlocking ring, that would be surrounding the torso of Orion occupants and allow for compartmentalization of the planetary suit. As designed, the BSC attached the upper and bottom halves of the suit at the level of the lumbar spine or sacrum depending on the occupant's height. In addition, the Orion capsule was designed for *splash-down* landings in water, with astronauts laying supine. This position meant that the astronauts would be laying on the BSC during the landing, which may result in posterior forces from the BSC into the lumbar spine.

While people are often injured due to posterior blunt impacts from falls, pedestrian collisions and motorcycle collisions; very few research studies have focused on injury thresholds of the spine due to blunt impacts [1]. Viano *et al.* [2] impacted eight post-mortem human subjects PMHS' with a 23kg hub impactor centered at T1 and also T6 at both 4.4m/s and 6.6m/s [2]. While the tests did result in rib fractures, there were no reported spine fractures. Recently, Forman *et al*. [1] conducted a series of 97.5kg hub impacts on four PMHS centered on T8 at speeds up to 5.5m/s. These tests resulted in both rib fractures and multiple instances of costo-vertebral joint laxity along the spine. The majority of fractures occurred due to peak impactor forces of 6.9 to 10.5kN.

The objective of this study was to explore potential injuries that may result from the BSC in a posterior landing scenario. While a few previous studies examined hub style impacts to the mid-thoracic region, no studies to-date have investigated impacts to the lumbar and sacral regions.

II. METHODS

Three 50th percentile male PMHS, ethically acquired from The Ohio State University Body Donation Program (Columbus, OH, USA) were included in this study. Instrumentation included an array of three accelerometers mounted at each of the following locations: sternal body, posterior aspects of the 12th thoracic (T12), 4th lumbar (L4), and 3rd sacral (S3) vertebral levels.

A 5-point harness was used to secure each PMHS to a rigid seat (Fig. 1). The seat had a partially open back to allow for interaction of the BSC, but had cross braces for support at the head, upper and lower thoracic spine, and also included unidirectional wheels to allow natural movement of the PMHS away from the impactor. The 3.9kg impactor face was a partial stainless steel planetary suit BSC ring affixed to the front of a 21.3kg pneumatic ram (Fig. 1). Displacement of the ram was measured by a linear potentiometer. Impact forces and moments were recorded by a six axis load cell behind the ram face. An accelerometer on the ram was used to verify ram displacement as well as inertially compensate the impactor load cell.

Each PMHS was impacted posteriorly at either a lumbar (L2/L3) or superior sacrum (S1/S2) level according to the test matrix in Table I. The tests were conducted at two different energy levels: 15g or 20g (Table I). Bias was removed and data were filtered using SAEJ211 standard. Ring force was obtained from the inertially compensated load cell data. Resultant acceleration at each spinal location and the sternum was calculated from three accelerometers. Spinal displacement with respect to the chair was calculated to quantify lumbar spine deflection during the event, i.e., lumbar displacement – chair displacement.

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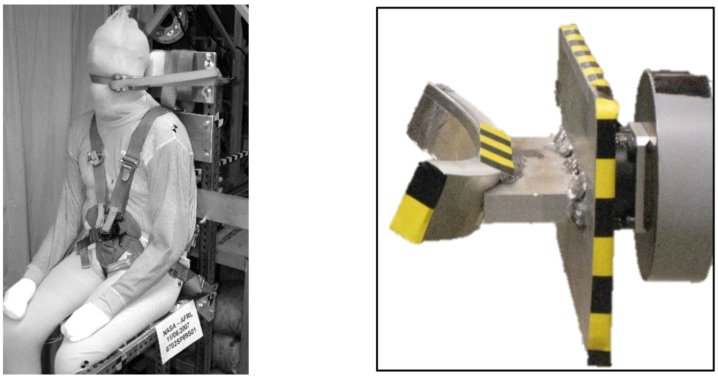

Fig. 1. Subject 0702 in seated position prior to testing (left), and the ram face impactor with partial ring (right).

TABLE I
TEST MATRIX

PMHS	Impact Location	Target Input
0701	Sacrum	10 g
	Sacrum	20 g
0702	Sacrum	10 g
	Lumbar	10 g
	Lumbar	20 g
	Sacrum	20 g
0703	Sacrum	10 g
	Lumbar	10 g

III. INITIAL FINDINGS

TABLE II
SUBJECT INFORMATION AND RESULTS

PMHS	0701		0702				0703	
Age	60		50				47	
Height (cm), Weight (kg)	172, 81		184, 86				175, 82	
aBMD t-score (L2-4)	+0.1		-2.5				-0.5	
Impact Location	Sacrum	Sacrum	Sacrum	Lumbar	Lumbar	Sacrum	Sacrum	Lumbar
Impact Force (N)	2669	3799	3496	3003	4350	5498	3225	3652
Sacrum acceleration (g)	19	76	50	26	53	99	31	11
Lumbar acceleration (g)	18	32	52	382	79	85	27	90
Peak ring X- Force (N)	2621	3805	3434	3008	4353	5535	3224	3653
Spinal displacement (mm)	44	59	69	100	119	96	69	117

Table II contains a summary of biomechanical results and subject information. All injuries and associated Abbreviated Injury Severity (AIS) codes (2005 with 2008 updates) are in Table III. Most notably, PMHS 0702 sustained multiple injuries including rib fractures at the anterolateral location of left and right ribs 1-7 (corresponds to harness strap locations) and a transverse fracture through the body of the first lumbar vertebra (L1). This catastrophic failure to L1 occurred during the 3rd impact to this subject (20g lumbar) along with failure of both transverse processes (Fig. 2).

TABLE III
INJURY SUMMARY

PMHS	Description	AIS code
	Rib Fractures	
0701	none	*
0702	L & R, 1-7	450203.3
0703	11 & 12	450202.2
	Vertebral Fractures	
0701	none	*
0702	Body (L1) Trans. Process (L1) Trans. process (L2)	650634.3 650617.2 650620.2
0703	none	*

*MAIS: 0701=0, 0702=3, 0703=2

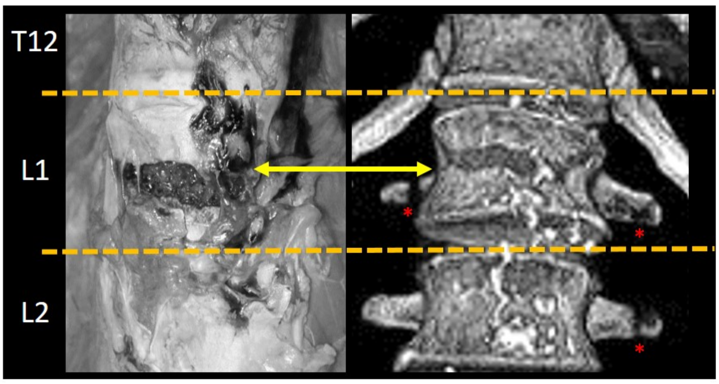

Fig. 2. PMHS-0702 L1 fracture (yellow arrow) shown from gross image (left) and in 3D CT image (right). Red asterisks indicate locations of transverse process fractures.

IV. DISCUSSION

The BSC impacts to the three PMHS resulted in AIS3 level injuries to both the thorax and lumbar spine. The impactor forces related to the injuries were between 3.0 to 4.3kN. The rib fractures documented were similar to previous posterior impact studies, but the L1 body fracture in this study was unique to the BSC impact scenario.

V. REFERENCES

[1] Forman J et al., J.Biomech, 2015.
[2] Viano et al., J.CrashPrev.Inj.Control, 2001.