Implementation of Lap Belt Load-Limiters in Reclined Frontal Impact Sled Tests with PMHS

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I. INTRODUCTION

Advancements in autonomous vehicle technology have prompted increased research interest in the response of occupants seated in a reclined posture. As a result, frontal impact sled tests have been conducted on reclined post mortem human subjects (PMHS) at various institutions, ranging in degree of recline, anthropometry, sex, and impact severity [1-6]. Previous studies have utilised common contemporary restraint components such as pretensioners (PTs) and load-limiters (LLs), but the LLs has primarily been limited to the shoulder belt [1-6]. One study [2] investigated the impact of a lap belt LL system on reclined occupant response but used a lap belt independent to the shoulder belt. This study aimed to investigate the effect of a lap belt LL in a fully integrated 3-point belt system on occupant kinetics and injuries in reclined frontal impacts.

II. METHODS

Frontal impact sled tests were conducted on two adult PMHS (one mid-size male and one mid-size female) using a reverse acceleration sled system (1.4 MN ServoSled®, Seattle Safety, Auburn, WA, USA). PMHS testing procedures followed the ethical guidelines established by the National Highway Traffic Safety Administration (NHTSA) and were reviewed and approved by the Biological Protocol Committee at the Center for Applied Biomechanics (CAB) as well as the University of Virginia Institutional Review Board – Human Surrogate Use (IRB-HSU) Committee. The tests replicated prior studies of reclined PMHS subjected to frontal impacts [1][5-6] (Fig. 1). A 35 g, 50 km/h sled pulse was used in conjunction with a 3-point prototype seatbelt system including dual lap belt PTs, a crash-locking tongue, a shoulder belt PT, and a shoulder belt LL. The seatbelt system also included an outboard lap belt retractor LL and a buckle LL consisting of a buckle sewn onto the webbing of a retractor, allowing the entire lap belt to be load-limited [7].

Positioning and orientation targets established from prior tests [1][6] were utilised for the subsequent lap belt load-limiting tests in this test series. Torso angle, defined as the angle between the vertical and the line connecting the H-point to the acromion [1][6] (mean ± SD: 46 ± 1 deg) was used as a primary positioning target.

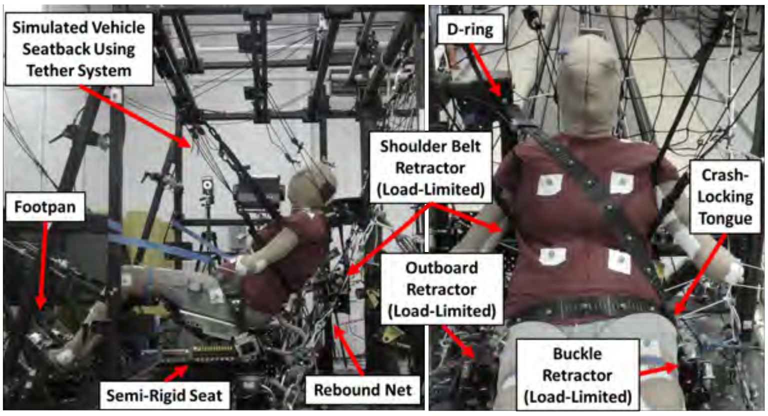

Fig. 1. Test environment. Further details can be found in prior studies [1][5-6].

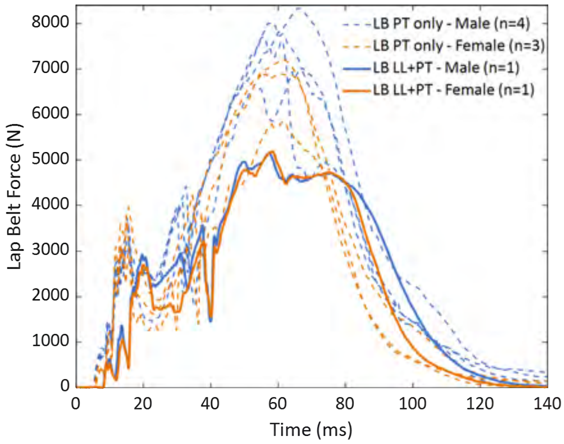

Fig. 2. Lap belt force time-history (CFC 600). Dashed lines indicate tests without lap belt LL and solid lines indicate tests with lap belt LL.

III. INITIAL FINDINGS

The outboard and inboard retractors worked together to successfully limit lap belt forces to approximately 5 kN (Fig. 2). Submarining was not observed in either female or male test; however, both the female and male PMHS sustained multiple injuries (Table I). The female sustained a vertebral compression fracture at L1 (Fig. 3),

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a sacrum fracture at S4, a sternum fracture, and 11 rib fractures. Pressure transducer signals determined timing of the lumbar fracture to be at 67 ms [6]. The male sustained anterior vertebral compression fractures with minimal anterior height loss at L3 and L5, a left iliac wing fracture near the anterior superior iliac spine (ASIS) (Fig. 3), a sacrum fracture at S4, a sternum fracture, and 5 rib fractures. Strain gauge signals determined timing of the iliac wing fracture to be at 74 ms, at which time the lap belt force was approximately 4.7 kN.

TABLE I
OBSERVED INJURIES

Test	Subject	Spine Fracture	Pelvis Fracture	Sacrum Fracture	Sternum Fracture	Rib Fracture (#)
S0846	0982F/F4	✓ (L1)	–	✓ (S4)	✓	11
S0847	1044M/M5	✓ (L3 + L5)	✓ (L)	✓ (S4)	✓	5

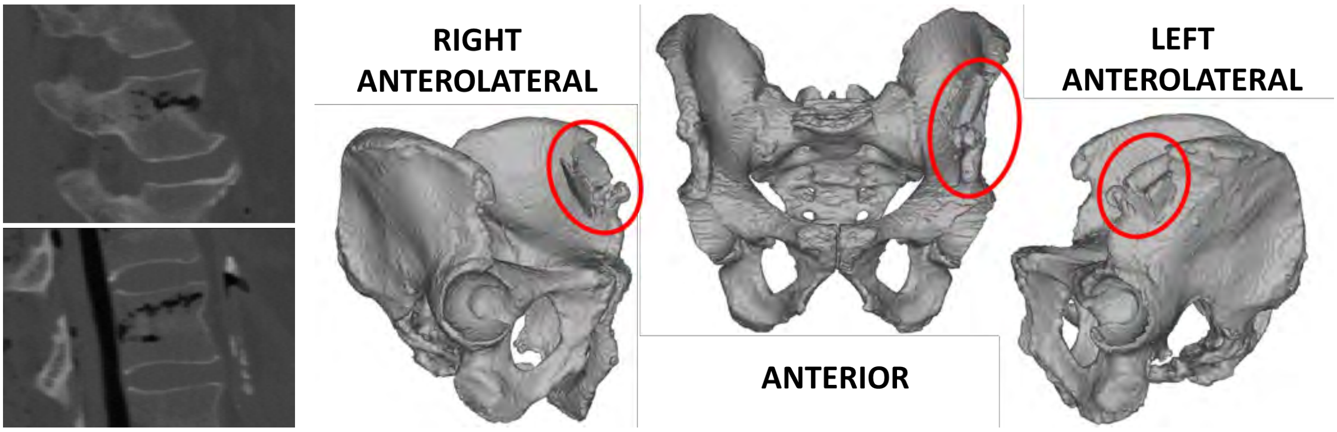

Fig. 3. Post-test sagittal view CT images of the L1 vertebral compression fracture observed in the female (**left**) and the left iliac wing fracture observed in the male (**right**).

IV. DISCUSSION

Even with a lap belt LL, submarining was not observed, similar to all but one previous test in replicate conditions [1][5-6]. Furthermore, lap belt force was lower than in previous tests without a lap belt LL (Fig. 2), signaling that the outboard and buckle-side retractors were effective in load-limiting the lap belt. Despite load-limiting of the lap belt, an iliac wing fracture with a comparable degree of comminution to prior tests was observed in the male subject (Fig. 3) [1][5]. The fracture force of 4.7 kN corresponds to an approximately 53% risk of injury observed in a prior study investigating iliac wing fracture tolerance [8]. Injury patterns were generally consistent between the lap belt LL+PT tests and the lap belt PT only tests, with one notable difference being the left-sided iliac wing fracture in the current study (as opposed to right-sided in prior studies) [1][5-6]. Injury patterns were less consistent between this study and a prior study that also utilized lap belt load-limiting on PMHS [2], despite some shared boundary conditions (i.e. semi-rigid seat, reclined posture, feet constrained to footpan). This may be due to the lower force limit implemented in the prior study (3.5 kN), as well as the use of an independent shoulder belt and lap belt, which may impact occupant kinematics and load transfer from the occupant to its environment.

The findings of this study suggest the need for deeper investigation into the injury tolerance of the pelvis, especially involving the ASIS region, as it may provide better insight into the development of more robust restraint design and more effective management of load distribution across various body regions. As mentioned in prior studies utilising a semi-rigid seat, a boundary condition limitation is the lack of a seat cushion. As such, future work should involve quantifying the effect of using a production-style seat with cushions in reclined tests in an effort to better encapsulate real-world conditions.

V. REFERENCES

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