Investigating the Effect of Forward Lap-belt Anchor Positions and Steeper Belt Angle on Pelvis Fracture Tolerance in Frontal Collisions

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I. INTRODUCTION

The automobile industry predicts forward-facing postures with reclined seatbacks will be desired by occupants of future vehicles [1-2]. Reclined occupants in frontal crashes tend to exhibit high pelvis excursion and, as a result, are subjected to substantial lap-belt forces if no knee bolster is present. Previous studies investigating occupant protection in frontal crashes using post-mortem human subjects (PMHS), both upright and reclined, resulted in fractures in the pelvic wing between the anterior superior iliac spine (ASIS) and the anterior inferior iliac spine (AIIS) [3-6]. The fractures did not threaten the integrity of the pelvic ring structure, but they affected the integrity of the pelvic wing, created small sharp bone fragments near fragile organs, and disrupted the insertions of the tensor fascia latae and rectus femoris muscles. These types of injury impact normal function and ambulation.

This study investigated pelvis fracture tolerance and evaluated a lap-belt loading orientation that would occur with forward positioned belt anchors, causing a smaller belt-to-pelvis (Nyquist) angle (Fig. 1). We hypothesise that this orientation may mitigate the risk of pelvis wing fracture caused by lap-belt loading. Several studies in the literature have presented experiments in which PMHS sustained pelvis fractures from belt loading [3-6], but we are unaware of any studies that investigated belt loading to the pelvis in this orientation. The objective was to evaluate whether the pelvis could sustain higher forces when loaded with this lap-belt orientation.

II. METHODS

Two seated, male PMHS (Subject 1: 70 years, 56.7 kg, 177.8 cm; Subject 2: 75 years, 71.7 kg, 175.3 cm) were subjected to lap-belt tensioning experiments and pelvis fracture tolerance was compared to values identified in a previous study [7]. The lap belt was pulled to a displacement of 12 cm at a rate of 1.5 m/s using a pneumatically powered, hydraulically controlled system (Fig. 1). A force limiting rig ensured maximum lap-belt tension of 10 kN. The lap belt was placed across the anterior pelvis and the belt anchors were moved until the desired belt-to-Nyquist angle was achieved (89° and 80°) (Fig. 2). Fracture timing was identified by examining sudden signal changes provided by acoustic sensors on the bilateral femurs, and strain gauges on the bilateral iliac wings and femurs. Belt tension gauges measured input force and loadcells in the seatback and in the seat pan measured reaction forces. All tissue donation, testing, and handling procedures followed ethical guidelines approved by a Biological Protocol Committee at the Center for Applied Biomechanics and the University of Virginia Institutional Review Board – Human Surrogate Use Committee.

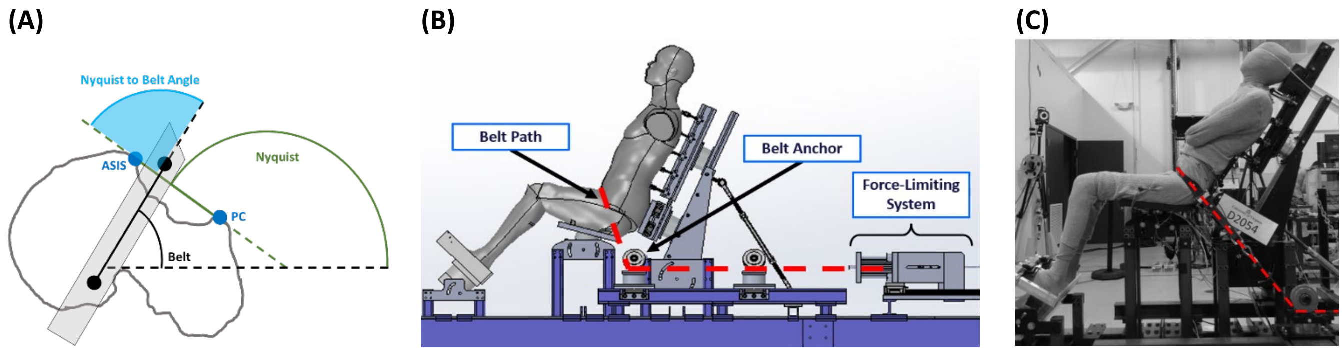

Fig. 1. (A) Belt-Nyquist angle. (B) CAD model of lap-belt tensioning experiment setup. (C) PMHS 1 with 500 N belt pre-tension.

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III. INITIAL FINDINGS

Left and right lap-belt tension forces at time of fracture were identified for both subjects. The subjects sustained fractures at varying belt forces, locations, and severities. Fracture initiation for Subject 1 (89° Belt-Nyquist angle) occurred at 6.8 cm displacement with a belt force of ~6.5 kN (Fig. 2A). The maximum belt force was ~7.9 kN, which resulted in additional injuries. Subject 1 sustained bilateral comminuted wing fractures (Fig. 3A) and the fracture pattern was likely related to the fixed rear boundary condition—a rigid seatback—that is not typically present in real-world frontal crashes. Fracture initiation for Subject 2 (80° Belt-Nyquist angle) happened at 10.4 cm with a belt force of ~7.4 kN (Fig. 2B). However, Subject 2 withstood a peak force of over 8.7 kN and only sustained an AIS2 oblique fracture of the superior pubic ramus (Fig. 3B) (no iliac wing fracture). Bone quality may affect fracture tolerance; however, Subject 2, who had a higher fracture tolerance and smaller belt-to-Nyquist angle, had lower bone mineral density (0.884 g/cm^3 vs. 0.668 g/cm^3; Young Adult T-score: -1.5 vs. -3.0).

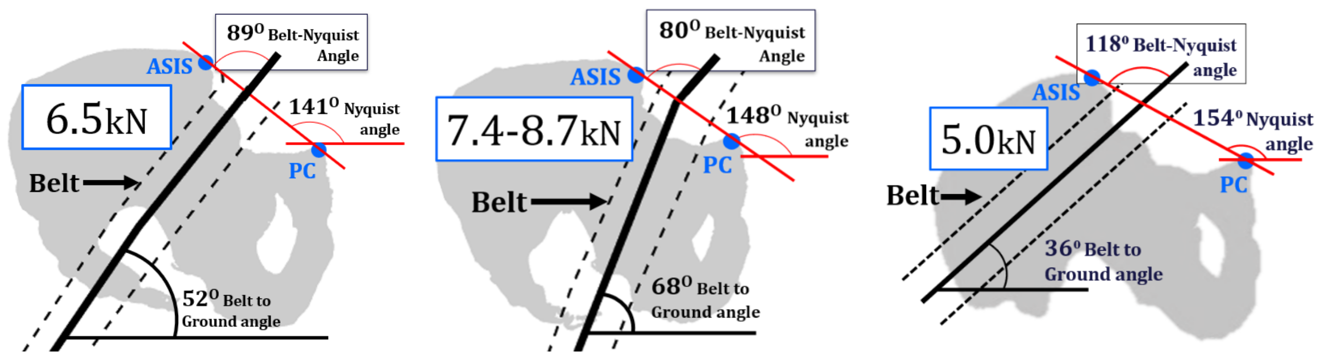

Fig. 2. Pelvis and lap-belt orientation, with fracture force, for (A) Subject 1, (B) Subject 2, and (C) previous experiment [7].

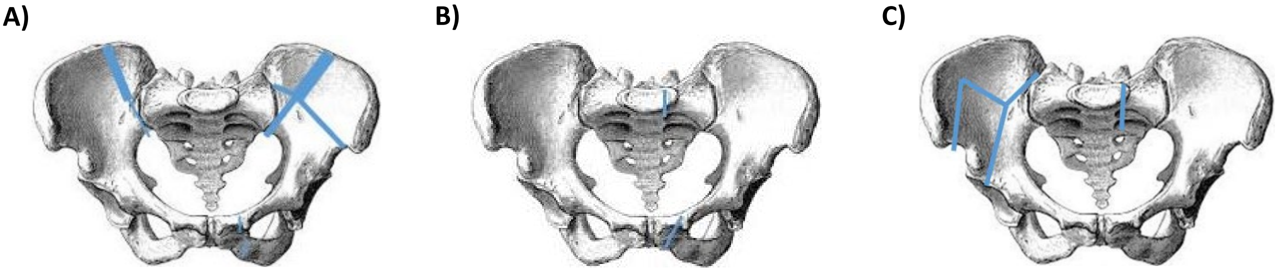

Fig. 3. Pelvis injury for (A) Subject 1, (B) Subject 2, and (C) previous experiment [7].

IV. DISCUSSION

Sled testing without a knee bolster has previously resulted in iliac wing fractures due to high lap-belt loads [4-6]. A previous lap-belt tensioning experiment [7] recreated this iliac wing fracture, which was located between the ASIS and AIIS. Compared to that experiment, we observed higher tolerances to fracture (6.5-8.7 kN vs. 5.0 kN) when belt anchors were moved forward to achieve a smaller belt-to-Nyquist angle.

We were able to achieve a lap-belt loading scenario that represents the type of loading that could happen if manufacturers move the belt anchors forward. Forward anchor positions that reduce belt-to-Nyquist angles and minimise loading to the ASIS could allow for substantial lap-belt loading while minimising the risk of severe injury. This loading orientation has the potential to also reduce the risk of submarining, because it places the lap belt lower on the pelvis. This loading mode should be evaluated in sled tests to further explore its effect on overall occupant kinematics and protection.

V. REFERENCES

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