Development of a Realistic Thoracic Impact Test for PTW-to-Vehicle Crashes

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I. INTRODUCTION

Powered two-wheeler (PTW) riders remain among the most vulnerable road users worldwide [1]. Despite overall improvements in road safety, fatality trends for PTW riders have not improved at the same rate as those for passenger vehicle occupants, and in some regions have worsened [2–3]. A common crash configuration involves the front of a PTW impacting the side of another vehicle [4–6]. These crashes frequently result in serious thoracic injuries, highlighting the thorax as a critical region for injury mitigation [7–10]. Protective systems such as inflatable airbag jackets have been developed to reduce thoracic injury risk in PTW crashes. However, evaluating the effectiveness of these systems remains challenging due to the limited biomechanical data available to validate anthropometric test devices (ATDs) and finite element (FE) human body models (HBMs) under PTW-specific loading conditions (i.e. in PTW crashes). Without appropriate experimental data, it is difficult to determine whether these models accurately reproduce the thoracic loading conditions experienced during PTW crashes. Previous full-scale post-mortem human subject (PMHS) tests investigating PTW-to-passenger vehicle impacts revealed complex thoracic loading conditions and distinct injury patterns [11–12]. These included posterior rib fractures that are not typically reproduced in conventional thoracic component-level impactor tests. While full-scale tests provide valuable insight into injury mechanisms, they are both costly and technically challenging. Therefore, there is a need to develop a simplified experimental method that reproduces the thoracic loading conditions observed in PTW crashes. The objective of this study was to develop and evaluate a thorax-specific test configuration with realistic boundary conditions to reproduce thoracic loading and injury patterns observed in previously conducted full-scale impacts. This work specifically investigates how body support and posture influence thoracic loading and resulting injury patterns.

II. METHODS

Five PMHS were selected to match the anthropometry of the three 50th percentile male PMHS used in the full-scale tests (Table I). Female subjects had breast tissue removed to minimize its influence on thoracic response. PMHS were instrumented with strain gages (Micro-measurements, Wendell USA) and six-degree-of-freedom (6DOF) (DTS, Seal Beach USA) sensors: rosettes on the manubrium and bilaterally on anterior ribs 2–5 and posterior ribs 3–5; uniaxial gages bilaterally on anterior ribs 6–10, lateral ribs 3–6, and posterior ribs 6–9; and 6DOF sensors mounted at C4, sternum, T4, T8, T12, S1, and bilateral iliac.

PMHS were secured in a harness attached to a 5.26 m long steel cable–chain pendulum system to reproduce the inertial loading conditions hypothesized to drive the distinct thoracic injury patterns observed in full-scale tests (Fig. 1). The PMHS impacted aluminum tubes mounted to a rigid structure oriented at a 35° offset to replicate the boundary conditions of the full-scale configuration [11–12]. The impact structure consisted of three slightly separated 102 mm OD 6061-T6 aluminum tubes (1.6 mm wall), selected using FE simulations to reproduce the deformation characteristics of the full-scale vehicle roof rail [11–12]. The tubes were separated to prevent cross-talk between the three-axis load cells (Humanetics, Farmington Hills USA) mounted behind each tube. PMHS were positioned such that the upper sternum and adjacent upper thoracic ribs served as the primary impact location, and tests were conducted at a target impact speed of 5.4 m/s.

The first two PMHS (Tests 4–5) were positioned using a DBI-SALA Delta Bosun Chair harness (3M, St. Paul USA), resulting in a more upright or seated posture (Fig. 2). This configuration did not reproduce the rib fracture

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patterns observed in the full-scale impacts and, in comparison, exhibited reduced spinal extension and a more upright orientation. The chair harness was therefore replaced with an F*Lite 2 paragliding harness (Ozone, Livingston UK), which was used for the last three PMHS (Test 6–8) to achieve a more extended and forward-oriented thoracic posture (Fig. 3).

TABLE I

PMHS ANTHROPOMETRY MEASUREMENTS

Test #	**Config.**	**Sex**	**Age** (yr)	**Height** (cm)	**Weight** (kg)
1	FS	M	82	177.8	72.8
2	FS	M	68	180.3	68.7
3	FS	M	75	186.7	72.8
4	CH	F	66	165.1	72.3
5	CH	M	68	166.4	64.0
6	PH	M	58	181.6	69.6
7	PH	M	75	176.5	66.0
8	PH	F	63	168.9	68.9

Note: FS = full-scale, CH = chair harness, PH = paragliding harness

Fig. 1. Full-Scale Impact.

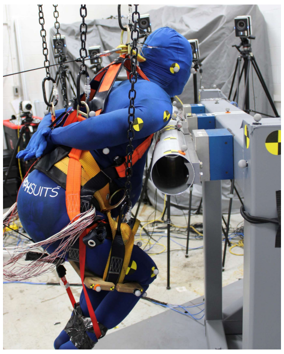

Fig. 2. Chair Harness.

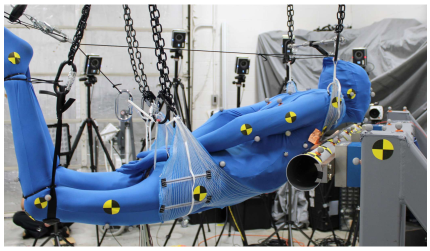

Fig. 3. Paragliding Harness.

III. INITIAL FINDINGS

The two chair harness tests (Tests 4–5) produced 14–15 total rib fractures but did not result in posterior rib fractures, despite an average peak resultant impact force of 6330 N measured at the tube interface. This finding suggests that inertial loading conditions alone were insufficient to reproduce the thoracic injury patterns observed in the full-scale tests. In contrast, PMHS tested in the paragliding harness (Tests 6–8) exhibited both anterior and posterior rib fractures across all tests, with 6–29 total rib fractures. These tests had a lower average peak resultant impact force of 3299 N. Despite the reduced force, the modified PMHS posture more closely replicates the injury patterns observed in the full-scale configuration.

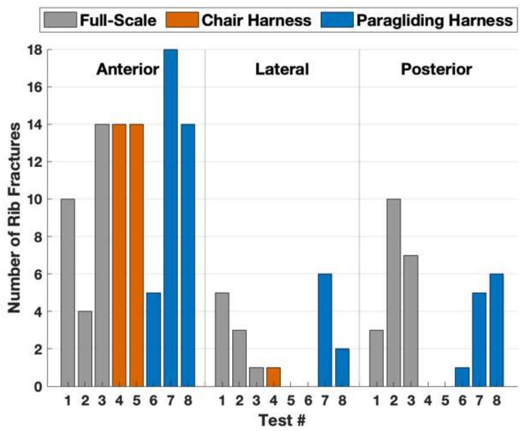

Fig. 4. Rib Fractures per Test by Location.

IV. DISCUSSION

These findings indicate that thoracic injury patterns in this test condition depend on whole-body inertial loading as well as subject posture and support conditions produced by the harness configuration. Although inertial loading was preserved in both configurations, posterior rib fractures were only reproduced in the paragliding harness tests, suggesting that inertial loading alone was insufficient to generate those injuries. The difference in fracture outcome occurred despite a lower average peak resultant impact force in the paragliding harness configuration, indicating that peak resultant impact force alone does not explain the injury responses. Instead, the more horizontal posture appeared to better reproduce the thoracic extension and inertial spine loading observed in the full-scale tests, which may be necessary to generate realistic posterior rib fracture patterns. Ongoing analysis of thoracic spinal kinematics and rib strain, including principal strain and its direction, will provide further insight into the injury mechanisms. Overall, these findings support the development of thorax-specific test methods that reproduce the posture, constraint, and inertial loading conditions observed in full-scale impacts. Such methods can enhance the biofidelity and injury predictive capabilities of ATDs and HBMs and support the evaluation of thoracic protection systems.

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