Defining a Non-injurious Load Case for Small Female ATDs Based on PMHS Tests

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I. INTRODUCTION

Although seat belt pretensioners have been used in vehicles for over 50 years, there is little documentation of injuries directly attributed to their use. A recent study examined low-severity crashes, found that only one out of 395 occupants with an activated seat belt pretensioner sustained an AIS2+ thoracic injury, indicating a 0.3% risk. The authors suggested that a simple pretensioner test could serve as a "lower bound for a thoracic injury risk function" [1]. As new safety tools are developed, particularly those representing small females, it is crucial that they do not predict AIS2+ thoracic injuries from belt pretensioning alone, given the minimal risk reported in recent literature. This research aimed to analyse three different small, elderly PMHS test series to evaluate anterior-posterior thoracic displacements, seat belt tension shoulder loads, and the potential for rib fractures caused solely by pretensioner loading.

II. METHODS

This study integrated data from two separate experimental studies utilising 5th percentile, elderly female Post-Mortem Human Subjects (PMHSs). The first was a series of 10 PMHS side impact sled tests based on a moving deformable barrier (MDB) near-side test conducted at 50 kph. The realistic boundary conditions of these tests included a modern mass-production driver's seat equipped with a side airbag and a standard three-point restraint with pretensioner. In addition, a production door liner was fitted across four independently controlled pneumatic rams, with each representing a quadrant of an intruding door in accordance with recorded lateral door intrusions as part of the Advanced Side Impact System (ASIS) (DSD, Linz, AU). The testing included two different airbags, with five tests using a production side impact airbag and five tests using an experimental *c-shape* side airbag intended to concentrate loading to the shoulder and pelvis of the occupant. All methods used for these tests including instrumentation and data analysis are detailed here [2].

The second study involved three 5th percentile female PMHSs tested in the lab with a static deployment of the same production seatbelt pretensioner used in the previous sled series. Three PMHSs, ethically acquired from The Ohio State University Body Donation Program, were utilised. Subject inclusion criteria included females, aged 60 or older determined to be osteopenic with bone mineral density (aBMD) corresponding to -2.5 – -1 T-score and -1 – +1 Z-score [3]. Height (136-166 cm) and weight (42-56 kg) closely matched the SID-IIs ATD. These criteria constituted female subjects that were small, fragile, and elderly. Demographics for all 13 PMHSs used in these studies are shown in Table 1. It is important to note that all breast tissue was removed from ESIL01 and ESIL02 to facilitate chestband placement.

TABLE 1
SUBJECT INFORMATION

		Phase I Tests					Phase II Tests					Phase III Lab Tests		
Test ID	Target (female)	ESI 01	ESI 02	ESI 03	ESI 04	ESI 05	ESI 06	ESI 07	ESI 08	ESI 09	ESI 10	ESI L01	ESI L02	ESI L03
Age (yrs)	60+	61	83	81	67	69	62	67	94	83	80	64	80	68
Height (cm)	136-167	167	155	160	155	165	147	159	152	163	158	164	156	175
Weight (kg)	42-56	56	44	52	55	56	56	51	55	50	40	43	41	41
aBMD (t-score)	-2.5< x <-1	-2.4	-1.6	-1.4	-1.5	-2.2	-1.0	-2.1	-2.2	-1.4	-1.7	-0.9	-0.4	-1.2

The lab test setup was intended to mimic the sled test conditions [2]. A custom seatbelt and pretensioner mounting fixture was constructed to match the functional design of the B-pillar, and the same production driver's seat and three-point seat belt with pretensioner from the sled series were used in the lab tests. The seatbelt was mounted to the custom fixture and the system was tuned by comparing seat belt loads between the static test with the previous sled series using a SID-IIs. The seat belts were equipped with four seat belt tension load cells. Exemplar test set-ups from both the sled series and the lab static test are shown in Figure 1.

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Fig. 1. Pre-test photos from Phase I sled (left), Phase II sled (middle), and Phase III lab (right) tests.

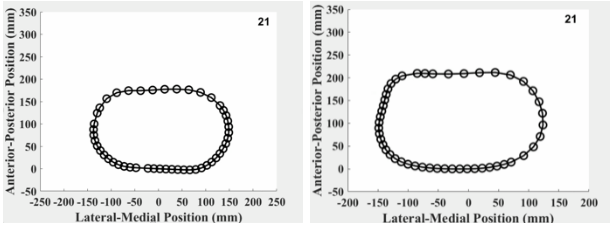

Fig. 2. Chestband shape for pretensioner only loading (left) & for combined loading (right).

Two chestbands (Humanetics Innovative Solutions) were used in both test series to measure chest deflection at the axillary and xiphoid process levels of the thorax (only axillary data will be discussed here). Chestband data were processed using CrashStar 2.8 (NHTSA), to calculate anterior-posterior (A/P) thoracic deflection throughout the pretensioner event. Twenty-eight strain gauges (Model C4A-13-060SL-350-39P; Micro-Measurements) at multiple locations were used to determine rib strain and identify fracture timing [4]. All data were collected at 20,000 Hz using a combination of SlicePro and G5 (Diversified Technical Systems, Inc.; Seal Beach, CA) data acquisition.

All subjects were seated in the production seat, restrained with a standard 3-point seatbelt, and positioned to match the position of the PMHSs in the sled series [2]. The hips were situated against the seat bite, while the upper body was partially extended away from the seatback to mimic a natural driving position. The head and arms were suspended, and the head was positioned so the Frankfort plane was ±5 degrees relative to the ground.

III. Results

Data from both series were analysed to calculate axillary A/P thoracic deflection, shoulder belt tension, and rib fractures due to pretensioner loading, Table 2. A critical finding of the sled series was the timing of the seatbelt pretensioner loading versus lateral contact to the thorax from the side airbag [2]. Four of five Phase I PMHSs experienced combined loading as the airbag began loading the lateral thorax as the seat belt reached maximum A/P deflection due to the pretensioner. Figure 2 compares two chestband contours at 21 msec into the event; one showing only A/P deflection, while the other reveals combined loading. The *c-shaped* airbag used in Phase II sled tests resulted in only thoracic loading due to the pretensioner. Ultimately, 9 of 13 tests resulted in singular, A/P loading due to the pretensioner, and no rib fractures were documented in any tests. In the combined loading tests, all four resulted in rib fractures at the time the airbag contacted the lateral thorax during pretensioner loading. A/P deflection across all 13 tests ranged from 14-23 mm with an average of only 18±4 mm. Shoulder belt tension loads were similar across all 13 tests, with a range of 880–1390 N and average of 1020±150N (Table 2).

TABLE 2
ANTERIOR-POSTERIOR DISPLACEMENT OF THE THORAX AND SEAT BELT TENSION FORCES FOR ALL TESTS

	Phase I Tests					Phase II Tests					Phase III Lab Tests			
Test ID	ESI 01	ESI 02	ESI 03	ESI 04	ESI 05	ESI 06	ESI 07	ESI 08	ESI 09	ESI 10	ESI L01	ESI L02	ESI L03	Avg ± St. Dev
A/P Displ (mm)	16	16	16	15	14	19	21	27	17	20	18	14	23	18 ± 4
Shoulder Belt Loads (N)	1050	880	920	930	NA	1050	1390	1180	890	930	880	990	1150	1020 ± 150
Combined Fxs?	-	Y	Y	Y	Y	-	-	-	-	-	-	-	-	-

IV. DISCUSSION

All three PMHS test series involved pretensioner loading on small, frail females. In nine out of 13 tests, the pretensioner did not cause rib fractures, providing valuable thoracic deflection data for non-injurious load cases. In the four tests involving combined thoracic loading, rib fractures resulted from airbag interaction rather than the pretensioner itself. Excluding these four cases, the peak average deflection is 19±4 mm. Including breasts in these tests might alter peak deflection, but unlikely to increase the risk of rib fracture. It is recommended that these data be incorporated into future calculations of thoracic injury criteria for small female safety tools to ensure they do not predict thoracic injuries from pretensioner loading alone.

V. REFERENCES

[1] Östling M et al., IRCOBI, 2024.
[2] Bolte J et al., TIP(S1-ESV), 2023.
[3] Kanis J et al., JBMR, 1994.
[4] Kemper A et al.,ABME 2011.