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Investigating Combined Thoracic Loading Using the Elderly Female Dummy (EFD)

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ABSTRACT – The Elderly Female Dummy (EFD) is an omni-directional ATD developed to represent a vulnerable population. The EFD it is able to be 3D printed and quickly altered to meet design requirements. A recent side impact sled test series suggested that small, elderly females may be at risk of thoracic injuries in side impact crashes due to combined loading from the belt pre-tensioner and side airbag. The EFD was altered to add four IR-TRACCs to the thoracic region to allow both x-axis and y-axis displacement to be evaluated in a similar test. While the IR-TRACCs did record the displacement due to combined loading, the rate of displacement and timing of the peak displacements did not match external chestband outputs. The next step for the EFD is to revise the locations of IRTRACCs in the thorax and begin component testing in lateral and frontal directions to improve thoracic biofidelity.

INTRODUCTION

The Elderly Female ATD (EFD), as described in Beebe *et al*. (2017), was introduced as an omni-directional ATD representing a 70-year-old female (73 kg, BMI = 28). The EFD includes a number of unique design features including: a segmented lumbar spine, the shoulder includes a sliding scapula, liver and spleen in the abdomen, and the majority of the EFD is 3D-printed allowing for parts to be altered and rebuilt quickly. Instrumentation in the EFD includes four IR-TRACCs (Infrared Telescope Rod for Assessment of Chest Compression) in the thorax along with two more in the abdomen. Due to the 3D-printing of the EFD, this instrumentation can be placed for either frontal loading, lateral loading, or both.

The Ohio State University Injury Biomechanics Research Center, recently published kinematic responses of 5th percentile female, elderly post-mortem human subjects (PMHS) to a side impact Shurtz *et al.* (2018). The side-impact loading condition replicated a near-side, moving deformable barrier (MDB) to vehicle impact for a driver. Realistic boundary conditions were accomplished by using the Advanced Side Impact System (ASIS) to mimic recorded door intrusions from previous run full vehicle MDB impacts. The ASIS was positioned on a HYGE sled system, which was used to replicate the acceleration profile of the impacted vehicle. The testing also included a mass-production driver seat equipped with a side airbag and a 3-point belt system with pre-tensioner. The kinematics of each PMHS were analyzed using a VICON motion tracking system along with a number of 6DX Pro (DTS, Seal Beach CA) motion blocks. To capture the thoracic deflection of the PMHS, two chestbands (Humanetics Innovative Solutions, Plymouth MI) were used, one at the level of the axilla and one at the level of the xiphoid process.

The main injury findings from the PMHS tests were AIS 3 level thorax injuries due to multiple rib fractures (AIS 2005, 2008 update). The number of rib fractures between PMHS varied between 5 and 20 rib fractures, but all tests resulted in a MAIS = 3. The chestband data revealed combined loading to the thorax of each subject; anterior-posterior compression due to the pre-tensioner and medial-lateral compression due to the interaction of the side airbag. The timing of rib fractures, determined by strain gages on each rib, revealed the AIS level 3 injuries were typically achieved within 20-25 msec of the start of the event. This timing was consistent with when the thorax was being compressed by the pre-tensioner as it initially contacted the side airbag.

In addition to PMHS tests, Shurtz *et al.* (2018) included current side impact ATDs, SID-IIs and WorldSID 5th female. These ATDs were tested in a similar set-up as the PMHS and revealed the occupant had less than a 10% chance for an AIS level 3 injury. In addition, the PMHS lateral thoracic deflections, calculated from the chestbands, predicted less than a 5% risk of AIS 3 level injury based on injury risk curves for 60-year-old occupants (Yogananden *et al*. 2007).

The aim of this project was to determine if the EFD could be retrofitted with IR-TRACCs to allow thoracic displacement to be measured in both anterior-posterior and medial-lateral directions during side impact sled tests. Shurtz *et al.* (2018) suggests there is a need to have an ATD, or instrumentation in the thorax of an ATD, that is capable of measuring combined thoracic loading, especially for a small elderly female occupant.

METHODS

Design Overview

The thorax of the EFD was recently revised based on testing feedback from researchers in Europe that used the EFD during sled testing for the SENIORS project (http://www.seniors-project.eu). In addition to these overall design changes, the thorax was revised to incorporate both frontal and side deflection measurements simultaneously in the thorax. Because the prototype EFD was developed with cutting-edge 3D printing techniques and materials, it greatly reduced the amount of time required to manufacture and develop parts needed for these alterations. Specifically, the thorax was revised to place four IR-TRACCs in a manner that allowed two IR-TRACCs to measure anterior-posterior compression and two to measure medial-lateral compression, as shown in Figure 1. Two of the IR-TRACCs were placed in the upper thorax, a similar height to the axilla-centered chestband, and two were placed in the lower thorax, a similar height to the xiphoid-centered chestband.

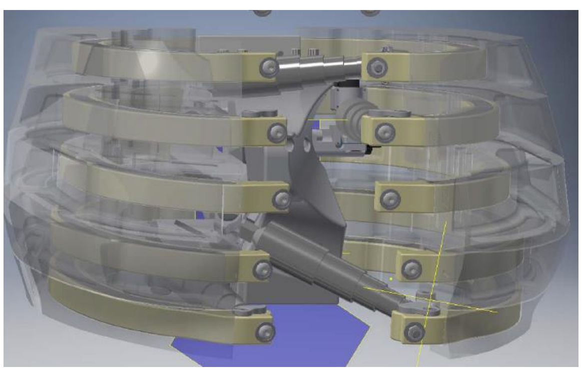

Figure 1. EFD Thorax with location of IR-TRACCs

Side Impact Sled Test Methods

After being retrofitted with the IR-TRACCs, the EFD was tested in a side impact scenario similar to the boundary conditions used for the PMHS series conducted by Shurtz *et al*. (2018), shown in Figure 2. The ASIS was placed on the sled next to the EFD, which was seated on a production seat. The same door liner and ASIS input was used to replicate the door intrusion applied to the PMHS during the PMHS test series. The set-up also included a 3-point belt system with pre-tensioner along with the side airbag as used previously in the PMHS tests (Shurtz *et al.* 2018). In addition to the four thoracic IR-TRACCs, the EFD was fit with the same two chestbands as used in the PMHS test series, a 59-channel chestband was placed at the level of the axilla of the EFD, while a 40-channel chestband was placed at the level of the xiphoid. The EFD was positioned similar to the PMHS, except for forearms and hands, which were angled down into the lap of the EFD instead of being up towards a steering wheel. The angle of the arms was kept constant between the tests at 45°.

Figure 2. EFD Sled Test Set-Up

RESULTS

While the majority of the boundary conditions for the EFD test were similar to the PMHS test series, the baseline sled pulse was slightly more aggressive as shown in Figure 3. Given the thoracic biofidelity of the EFD is still undergoing development and given the primary goal of the test was to investigate the ability of the EFD to document combined thoracic loading, a more aggressive pulse was intentionally selected to ensure loading to the thorax of the EFD was in multiple directions.

Figure 4 plots displacement-time for the IR-TRACC data from the upper thoracic region, which is at the equivalent height of the axillary chestband. The plot reveals that the x-axis displacement (solid line) was similar to the y-axis displacement (dotted line) in both peak displacement and displacement rate (Figure 4).

Similarly, Figure 5 plots the anterior-posterior displacement and medial-lateral displacement for the 59-channel chestband located at the axillary level. These data reveal a similar magnitude of displacement, 39 mm, though the rate of displacement and timing of peak displacement are different.

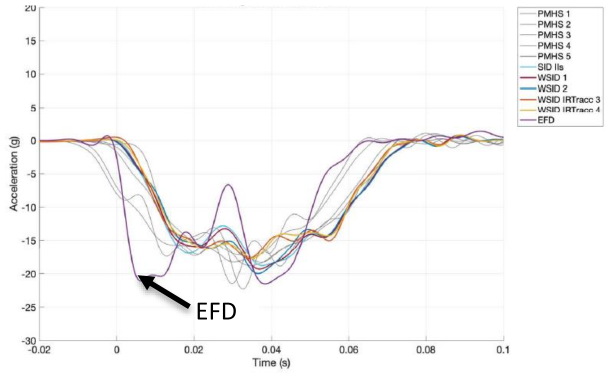

Figure 3. Sled Pulse for EFD vs PMHS

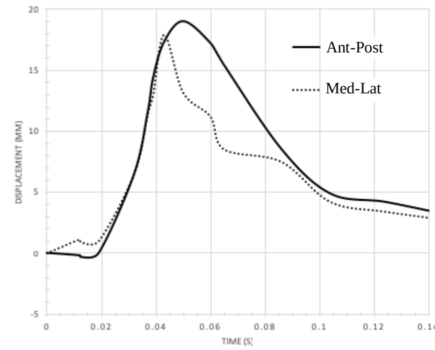

Figure 4. Upper Thoracic IR-TRACC Displacement

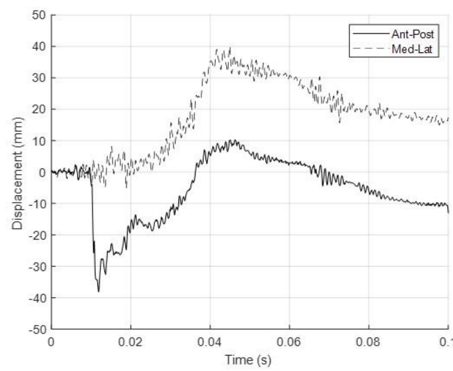

Figure 5. Anterior-Posterior and Medial-Lateral Displacement of the Chestband at the Axillary Level

DISCUSSION

The Elderly Female Dummy (EFD) was developed to fill a gap in the current available ATDs. In addition, the EFD uses new materials and processes which allow it to be 3D printed and quickly altered. For this test set-up the thorax was re-designed to allow room for 4 IR-TRACCs to be placed at both the upper and lower thorax, with two IR-TRACCs aligned with the x-axis and two aligned with the y-axis.

The chestband, which was applied externally, clearly showed a difference between x-axis displacement due to initial firing of the pre-tensioner (high displacement rate and early peak) and the y-axis displacement due to interaction with the airbag (later in the event with a slower displacement rate). The internal IR-TRACCs did record displacement in both the x-axis and the y-axis, but the timing of the displacements varied greatly form the chestbands. It is not surprising that the values of displacements were different between external and internal instrumentation, but it is important that the IR-TRACCs are able to discern between pre-tensioner and airbag-initiated displacement. While it may require additional alterations to improve Biofidelity, it is encouraging that the EFD thorax was able to record displacements due to combined loading.

CONCLUSION

The 3D printing process is an invaluable tool to design and develop ATDs quickly without the need to create molds. These new processes allowed for the EFD thorax to be retrofitted with IR-TRACCs to record displacement in both the x-axis and y-axis. This instrumentation allowed the EFD to measure combined loading from the belt pre-tensioner and a side airbag. The next step for the EFD is to revise the locations of the IRTRACCs in the thorax and begin biofidelity component testing in both lateral and frontal directions to improve thoracic biofidelity.

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