Chest Injury Assessment of Reclined Occupants in Frontal Impacts with the SAFER Human Body Model in Comparison to the THOR and Hybrid-III 50th Percentile Male ATDs

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I. INTRODUCTION

With new interiors in autonomous driving vehicles, occupants may be given the opportunity to sit in more reclined seating positions. These positions have led to the development of new seatback-mounted seat belts, aimed at preventing submarining, reducing the loading to pelvis and lumbar spine, and restraining the occupant early in the crash [1-2]. In this study, the objective was to examine the chest injury risk predictions related to rib deformations from three reclined occupant substitutes in frontal impacts, so that their predictions can be interpreted in future development of restraint systems. To do so, SAFER human body model (HBM) predictions were compared to those of mechanical tests with the 50th male anthropomorphic test devices (ATDs) THOR and Hybrid-III.

II. METHODS

The study was carried out for a belted, reclined occupant in the passenger side of a validated generic environment consisting of a semi-rigid seat and a seat-integrated, triple-pretensioned, load-limited, three-point belt system with a crash locking tongue [1][3] (Fig. 1). The SAFER HBM version 10 [4] was positioned in the generic interior in an approximately 50 deg. reclined sagittal torso angle (approximately 25 deg. from an upright seated posture) and subjected to a full-frontal 50 km/h, 35 g pulse. In this environment, the SAFER HBM was previously evaluated by comparison of upper-body trajectories, belt and seat forces to that of post-mortem human subjects (PMHS) tests [3]. In the current study, the SAFER HBM chest injury predictions were compared to the results from six previously conducted matching sled tests [5] with THOR and Hybrid-III ATDs [6].

Chest injury assessment was carried out for 45- and 65-year-old (YO) occupants. Peak resultant- and x-deflections were extracted from the four IR-TRACC sensors of the THOR and the maximum deflection value for each criterion (Rmax and Xmax) was used to calculate AIS3+ chest injury risks [7]. For the Hybrid-III, the AIS3+ chest injury risk was calculated from the peak chest deflections [8]. For the SAFER HBM, maximum principal strains were extracted from the middle integration point of the rib cortical bones and used to predict fracture risk with a probabilistic method [9-10].

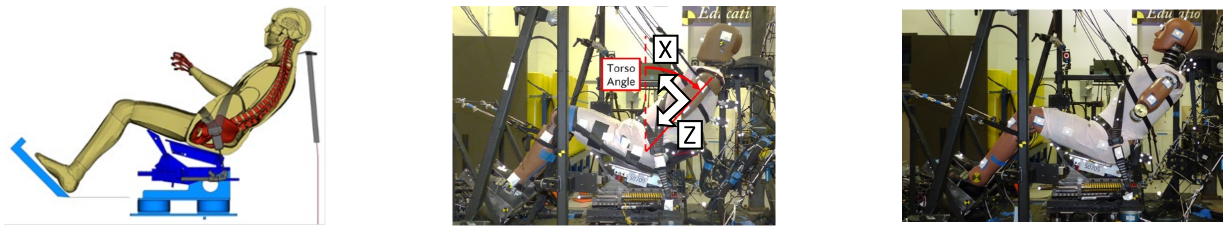

Fig. 1. SAFER HBM (left), THOR with the IR-TRACC coordinate system (middle, [5]) and Hybrid-III (right, [5]).

III. INITIAL FINDINGS

Maximum Rmax values (46–52 mm) were measured in the upper right IR-TRACC position for the THOR, which for the most part was due to the large deflections in the z-direction (45–51 mm) (Fig. 2). Maximum Xmax values (27–32 mm) were measured in the upper left IR-TRACC position. For the criteria Rmax, THOR predicted AIS3+ injury risks of 46–59% and 81–91% for a 45YO and 65YO, respectively. For the criteria Xmax, the corresponding injury risks were 12–19% and 28–43%. Peak chest deflections of 22–26 mm were measured at the sternum for the Hybrid-III, which corresponded to injury risks of 3–5% and 9–15% for a 45YO and 65YO,

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respectively. SAFER HBM predicted maximum rib cortical bone strains of 1.0% and 1.1% on the left and right side of the rib cage (Fig. 3), respectively, which corresponded to zero risk of three or more fractured ribs for both ages.

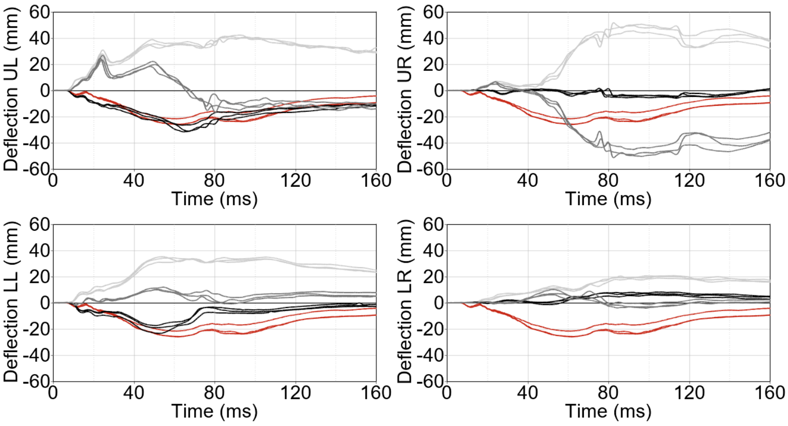

Fig. 2. THOR IR-TRACC x- (black), z- (grey) and resultant (light grey) deflections for the upper left (UL), upper right (UR), lower left (LL) and lower right (LR) measurement points. Hybrid-III chest deflections (in red) are given in all plots for comparison.

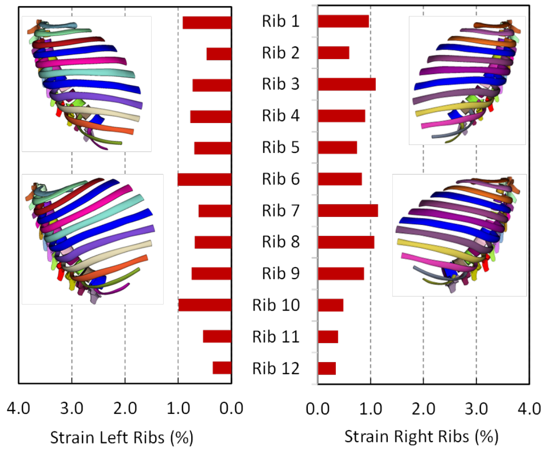

Fig. 3. SAFER HBM peak rib cortical bone strains. Right and left side rib cage deformation at 0 (upper) and 70 ms (lower, at time of peak strain).

IV. DISCUSSION

Chest injury risks for reclined occupants in a frontal crash were assessed using matched virtual (SAFER HBM) and mechanical (THOR, Hybrid-III and PMHS) tests. The whole chest injury risk for the recline THOR was based on the upper right deflection measurements, on which there is no direct loading from the diagonal belt. The dominating z-deflections and very small x-deflections (less than 6 mm) in this location differed from the upright seated THOR, for which the x-deflections values constitute the dominant component [11]. Largest x-deflections (defining Xmax) for the recline were measured on the left rib cage, which is to be expected due to the tendency of the seat belt to slide towards the neck during the crash. The rib cage of the SAFER HBM deformed in the superior direction similar to THOR, as measured by the negative IR-TRACC z-deflections (Fig. 3), but contrary to THOR to a level where very small rib fracture risk was predicted. The SAFER HBM peak strains were generally slightly higher on the right side of the rib cage (Fig. 3).

In addition to ATD tests, matching reclined PMHS tests were also carried out previously in the same generic environment [12]. Three PMHS matched the weight of an average male, PMHS 901 (age 72), PMHS 930 (age 66) and PMHS 662 (age 25). Two out of three PMHS sustained three or more fractured ribs; the two older PMHS sustained 11 and 15 fractured ribs, while no fractured ribs occurred for the younger PMHS. The fractured ribs were equally distributed between the left and right rib cage for PMHS 901, while the higher number of the fractured ribs occurred on the right side for PMHS 930.

We can compare injury risk prediction of the three occupant surrogates with the PMHS tests, but we cannot assess the injury mechanism as the z- and other deflections were not measured in the PMHS tests. Therefore, the injury risk related to z-deflections is unknown. We can only observe that SAFER HBM and THOR are very different in predicting consequences of z-deflections. Pure x-directional deflections in THOR and Hybrid-III appear promising to better predict observed PMHS injuries, but there are few PMHS tests to conclude. In the future, more work is needed to investigate to what degree THOR z-deflections, as well as shoulder belt sliding laterally on the chest, correlate with chest injury risk.

V. REFERENCES

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