SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Evaluation of the Thoracic Response of Male Post Mortem Human Surrogates in the Rear Seat during Frontal Impacts

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ABSTRACT – Recent studies have found that rear seat occupant protection might not have progressed as rapidly as the front seat, resulting in higher rear-seat injury risk. The objective of this study was to evaluate the thoracic response and damage outcomes of 50th-percentile male PMHS in the rear seats of modern vehicles during frontal impacts. Rear-seat, frontal, 56-kph sled tests were conducted using twelve male PMHS and four vehicle test bucks, with a range of seat geometries and both conventional and advanced restraints (e.g., pretensioners and load limiters). Chestbands were used to quantify thoracic contours and compression on the upper and lower chest. Chest compression was typically greater for vehicles with conventional restraints compared those with advanced restraints. Within a restraint condition, submarining typically resulted in higher peak compression than when submarining did not occur. All tests resulted in AIS3+ thoracic damage. These results will be used in the future to evaluate the thoracic responses of ATDs collected during previously performed matched tests.

INTRODUCTION

There are a large number of thoracic injuries resulting from motor vehicle collisions (MVCs). In fact, the most commonly inured body region for both front and rear seated occupants is the thorax (Jermakian et al., 2019). Recent studies have found that rear seat occupant protection has not progressed as rapidly as for the front seat, resulting in higher injury risk for rear-seat occupants (Tatem & Gabler, 2019). Advanced restraints (i.e., load limiters, pretensioners, inflatable restraints, etc.) have been shown to lower thoracic injury risk values for rear-seated anthropomorphic test devices (ATDs) in frontal impact tests compared to conventional restraints (i.e., a three-point belt without a pretensioner or load limiter) (Forman et al., 2010). While advanced restraints are omnipresent in the front seat, they are less frequently equipped in the rear seat. Therefore, the lack of advanced safety restraint systems available in the rear seat compared to the front seat might contribute to the disparity in occupant protection between the front and rear. Previous studies investigating the response of PMHS (post mortem human surrogates) in the rear seat suggest that the presence of advanced restraints might lower injury outcomes (Michaelson et al., 2008; Forman, et al., 2009a, 2009b). However, these studies involved a single vehicle and a limited number of PMHS that included male and female specimens that were much larger and smaller than the standard 50th-percentile male anthropometry. The objective of this study was to evaluate the thoracic response and damage outcomes of PMHS approximating the 50th-percentile male in the rear seats of modern vehicles, which have various seat designs, belt anchorages, and seat belt technologies, during frontal sled tests.

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METHODS

A total of twelve (n=12) rear seat, frontal sled tests were conducted using twelve (n=12) male PMHS and four of the vehicle test bucks used in the ATD studies described by Bianco et al. and Guettler et al. as a part of a larger study focused on investigating rear seat occupant safety (Bianco et al., 2022; Guettler et al., 2022; Hardy et al., 2022). Three (n=3) PMHS tests were conducted for each vehicle. However, no chestband data were collected for one of the tests using Vehicle 13 (V13-6).

Of the seven vehicles that were used in the studies by Bianco et al. and Guettler et al., four vehicles were chosen for PMHS testing to represent the spectrum of vehicle performance (Table 1). Vehicle 14 (V14) and V19 had advanced restraints, whereas V13 and V15 had conventional restraints. Conventional restraints were defined as a standard three-point belt. Advanced restraints were defined as the same with the addition of a pretensioner and load limiter at the shoulder retractor. It should be noted that V19 and V15 had similar seat geometries and belt anchor points, which facilitates the most direct comparison between restraint types. The NCAP acceleration pulse for each vehicle was scaled to 85% to generate a deltaV of 56 kph (Bianco et al., 2022; Guettler et al., 2022). The resulting NCAP85 pulse specific to each vehicle was used in the PMHS sled tests. Additional information about the test pulses and vehicles can be found in the Bianco et al. and Guettler et al. studies.

Table 1. Vehicle and restraint information.

ID	Seat Pan Type	Restraint Type	Shoulder Belt Routing
V13	Flat	Conventional	Over seat With guide
V14	Gradual Slope	Advanced	Over seat No guide
V15	Steep Slope	Conventional	Over seat With guide
V19	Steep Slope	Advanced	Over seat With guide

Test Setup

The selection criteria for the PMHS were based on the Hybrid III 50th-percentile male ATD. The average age, stature, and mass of the specimens was 64±15 years old, 175±7 cm, and 77±10 kg, respectively. Each PMHS was screened based on serology, morphology, radiology, and pathology. The PMHS were seated in the left outboard rear seat and positioned as described in Bianco et al. (2022) and Guettler et al. (2022) for ATDs.

To quantify thoracic contour and deflection, two 59-channel chestbands (8641, Humanetics, Plymouth, MI) were used. The upper chest band was placed at the lateral aspect of rib 4, and the lower chestband was placed at the lateral aspect of rib 8. Data were collected using 20k samples per second (G5 and TDAS Pro, Diversified Technical Systems, Seal Beach, CA). The chestband data were used to quantify thoracic deflection for both chestband locations based on the contour data obtained from the RBandPC program (Conrad Technologies, Paoli, PA). Anterior and posterior points along the chest contour were paired within the same sagittal plane and the deflection between each pair was calculated as a chord deflection for each chestband at each time point. The anterior-posterior pair with the largest change in length was defined as the maximum thoracic deflection. Deflection was normalized by the initial chest depth at the sternum to compare compression across PMHS.

RESULTS

Maximum compression from the upper and lower chestbands is provided in Figure 1 and Figure 2. Submarining is indicated by "+", and no submarining is indicated by "-". Compression was larger for the upper chestband in all tests, except test V19-7. Compression for the upper band ranged from 0.304 to 0.524 in vehicles with conventional restraints, and from 0.206 to 0.355 in vehicles with advanced restraints (Figure 1). For the lower chest band, maximum compression ranged from 0.125 to 0.338 in vehicles with conventional restraints, and 0.054 to 0.352 compression for advanced restraints (Figure 2). All tests resulted in AIS3+ skeletal thoracic damage (i.e., rib and sternum fractures) (AIS 2015).

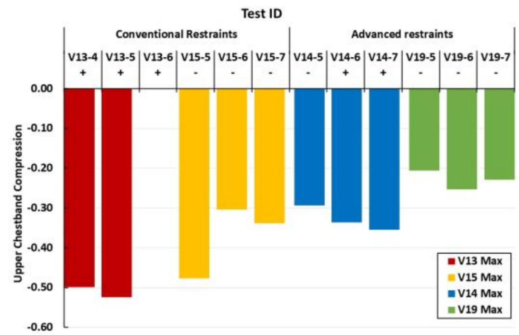

Figure 1. Maximum compression for the upper chestband.

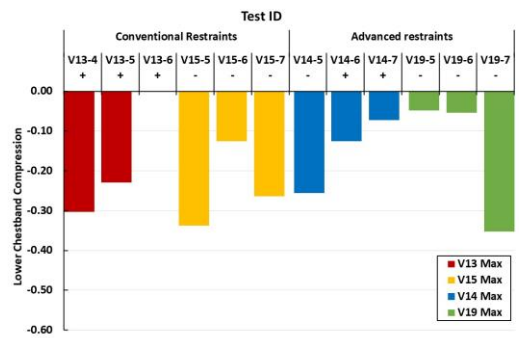

Figure 2. Maximum compression for the lower chestband.

DISCUSSION

Maximum compression was lower on average in vehicles with advanced restraints, illustrating that compression was sensitive to restraint type. This trend is consistent with the maximum deflections in the rear seat vehicle tests with advanced restraints and conventional restraints reported by Forman et al. (2009b) and Sundararajan et al. (2011). It is important to note that maximum compression observed in the lower chestband data was below 0.100 for tests V19-5 and V19-6, but above 0.350 for test V19-7. The PMHS used for test V19-7 was 29 years old (73 kg and 163 cm). In contrast to V19-5 and V19-6 in which bilateral rib fractures and sternum fractures were observed, the PMHS used for V19-7 sustained nine rib fractures on the right side of the thorax (one fracture at each level 1-9), but none on the left thorax nor a sternum fracture. The lower right quadrant of the chest was compromised along the belt path, resulting in large local deflection, with reduced associated damage overall.

There are differences in vehicle geometry that could affect loading of the ribcage. V13 and V15 have very different seat pan geometries (i.e., V13 has a very flat seat pan, V14 has a gradually sloping pan, and V15 and V19 have steeply sloped seat pans). PMHS submarined in tests V13-4, V13-5, V13-6, V14-6, and V14-7, but not in any test using V15 and V19. Submarining could alter loading of the thorax. Comparing within both conventional and advanced restraint vehicles, vehicles not associated with submarining produced lower peak chest compression across the upper and lower bands, test V19-7 notwithstanding. Comparing V15 to V14 suggests that conventional restraints combined with no submarining can result in chest compression roughly equivalent to tests having advanced restraints with submarining. Future analyses will include comparison of sternum compression, location of maximum compression, and examination of damage severity.

The observations in this study are limited by the complexity of the vehicle environments and PMHS variability. Multiple factors apart from restraint type might be contributing to the chest deflection outcomes for each test. For example, the seat pan geometry in V13 strongly contributed to the advent of submarining, which in turn can affect chest deflection. PMHS age and bone quality clearly contributed to the variation in chest compression observed in V19. Accounting for some of these variables does allow for more direct comparisons between restraint types. Specifically, V15 and V19 have the most similar seat pan geometries, but V15 was equipped with conventional restraints and V19 had advanced restraints. Comparing the outcomes for these two vehicles, it can be observed that the presence of advanced restraints was associated with lower peak chest compression, with the exception of V19-7.

CONCLUSION

PMHS chest compression was sensitive to measurement location (i.e., upper versus lower chestband), restraint type, and submarining. Maximum compression was larger for the upper chestband, typically. Advanced restraints generally lowered thoracic compression, agreeing with the literature. For both restraint types, submarining was associated with greater chest compression. These results will be used to evaluate the biofidelity of the Hybrid III and THOR-50M positioned in the rear seat during previously performed matched tests.

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