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Comparative Responses of the PIPER 6YO Human Body Model and the Q6 ATD for Simulated Frontal and Lateral Impacts

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ABSTRACT – Adult and pediatric human body models have focused on developing accurate representation of the human body in terms of anthropometry and kinetics/kinematics in correlation with published PMHS (Post-Mortem Human Subjects) data. This study focuses on comparing the PIPER 6-year-old human body finite element (FE) model with a Q6 FE model to generate comparable metrics. The FE models were simulated in a vehicle environment by positioning them on two different child booster seats with a 3-point lap-shoulder belt for frontal and lateral impacts. The overall kinematic response (head excursion) of the PIPER human body model (HBM) mimics the behavior of the Q6 ATD. However, there is a significant difference in the NIJ values between the PIPER HBM and Q6 ATD (minimum reduction of 67% in PIPER HBM). The head-neck complex of the PIPER is seen to be more flexible (minimum reduction of 12% in neck forces and 64% in neck moments) as compared to the Q6.

INTRODUCTION

Human body finite element models provide relatively accurate representations of the anthropometry of the human body and help provide insight into occupant injuries - especially to observe internal organ motion and understand injury causation during simulated crashes.

The PIPER (Position and Personalize Advanced Human Body Models for Injury Prediction) is a scalable open-source pediatric model (http://www.piper-project.eu) developed to gain insight into injuries in pediatric occupants and serve as a surrogate for injury assessment for children restrained in various child restraint systems (CRS).

The objective of this study is to compare the responses of the PIPER 6-year-old human body model to the 6-year-old pediatric Anthropometric Test Device (ATD) model; the Q6 ATD (Humanetics Innovative Solutions, Plymouth, MI) across booster CRS configurations in frontal and lateral simulated crashes.

METHODS

The study utilized the PIPER 6-year-old human body finite element model along with a Q6 ATD FE model to generate comparable metrics. The test environment used was a 2012 Toyota Camry obtained from the National Crash Analysis Center (NCAC) archives. The FE models were positioned on booster CRSs and restrained using a 3-point lap-shoulder belt modeled along with a retractor and pretensioner on the vehicle seat. Simulations were carried for frontal and side impact crash pulses. For the case of side impacts, all the simulations were carried out with and without side curtain airbag (SCAB).

The test matrix for this study consists of a low-back booster CRS (LBB) and a high-back booster CRS (HBB). In addition to this, a no booster condition was also modeled for the frontal impact crash pulse to simulate a baseline seating condition.

Sub-simulations were carried out to get the PIPER and the Q6 FE models to their most natural seating position. The CRS and the child model were positioned on the vehicle seat by simulating a gravity drop. The 3-pt lap and shoulder belts were then routed as per manufacturer recommendations and setup as per Federal Motor Safety Standard (FMVSS) #213 standard. A retractor, pretensioner was used along with a load-limiter of 2.5kN. Sensor models were used to trigger the retractor and pretensioner at time, t=4 milliseconds into the crash.

Fourteen simulations were carried out using an explicit solver in LS-DYNA ver. 917 (LSTC, Livermore, CA) and HyperMesh v17.0 (Altair Inc., MI) as the pre-processor. All post-processing of data was carried out using LS-PrePost v4.5 (LSTC, Livermore, CA) and solved using a 16-node computing cluster on a double-precision computing cluster.

HIC15, Head, Chest and Pelvis resultant acceleration, head excursion, neck forces, and neck moments were extracted and plotted. All the data extracted from the simulations was filtered as per SAE J211 sign convention and class filter.

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RESULTS

Table 1 tabulates the HIC15 (Head injury criterion), resultant head, chest, and pelvis accelerations for the two crash pulses across all the seating configurations. For the frontal impact crash pulse, there was a 13% increase in HIC15 and 10% increase in resultant head acceleration for PIPER as compared to the Q6 ATD for the low-back booster. The high-back booster showed 14.3% increase in HIC15 and 3.4% reduction in resultant head acceleration for PIPER. However for the no CRS condition, the PIPER showed a reduction of 51.7% in HIC15 as compared to the Q6 ATD (111.3 and 229.7 respectively) and 23.7% reduction in head acceleration (37.3G and 48.9G respectively).

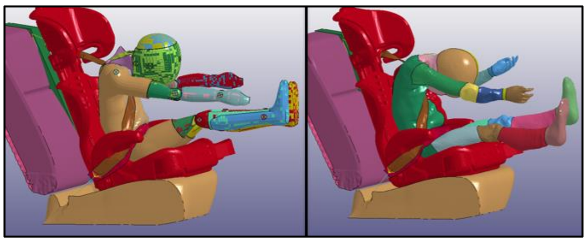

Figure 1: Frontal impact simulation for Q6 (left) and PIPER (right) on High-back Booster CRS

For the side impact crash pulse, contact was observed between the child model head and the vehicle inner side trims for the conditions without the side curtain airbag for both Q6 and PIPER in low-back booster CRS configuration, resulting in high values of injury metrics (HIC15 values of 1369 and 1838 respectively).

#	Crash pulse	CRS	Q6				PIPER			
			HIC15	Resultant Head Acc (G)	Resultant Chest Acc (G)	Resultant Pelvis Acc (G)	HIC15	Resultant Head Acc (G)	Resultant Chest Acc (G)	Resultant Pelvis Acc (G)
1	Frontal impact	LBB	146	40.8	37.5	49.8	165	44.9	70.6	59.4
2		HBB	182	49.8	43.9	44.0	208	48.1	44.8	60.7
3		No CRS	230	48.9	50.0	41.9	111	37.3	80.7	80.0
4	Side impact	LBB w/o SCAB	1369	486.4	135.9	125.9	1838	624.6	156.7	134.0
5		LBB with SCAB	196	56.2	140.2	103.8	421	97.9	85.7	50.9
6		HBB w/o SCAB	552	106.0	135.9	77.5	490	125.4	73.5	106.8
7		HBB with SCAB	312	82.5	116.9	77.2	235	65.2	64.2	108.3

Table 1: HIC15, Maximum Head, Chest, and Pelvis Resultant accelerations for PIPER HBM and Q6 ATD

Table 2 tabulates the neck forces and neck moment values for the Q6 ATD and PIPER 6YO HBM for different booster conditions for frontal and lateral impacts. A large variation was observed in the neck forces and moment values between the two models. The PIPER showed a reduction of 25.8% in the neck forces and 63.9% in neck moments as compared to the Q6 for the low-back booster in a frontal impact. The corresponding values for high-back booster were 21.5% and 72.9% and for the no booster condition there was 42.6% reduction in neck forces and 81.5% reduction in neck moments for PIPER as compared to Q6. This behavior was also reflected in the neck injury criterion - NIJ values (Figure 3).

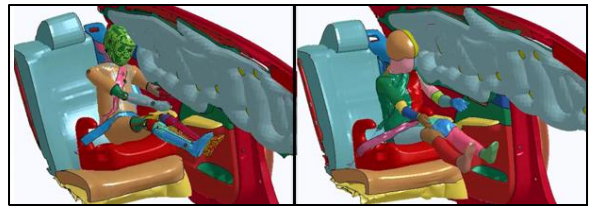

Figure 2: Side impact simulation with SCAB for Q6 (left) and PIPER (right) on Low-back Booster CRS

Sr. No.	Crash pulse	CRS	Q6		PIPER	
			Neck forces (N)	Neck moments (Nm)	Neck forces (N)	Neck moments (Nm)
1	Frontal impact	LBB	1247.3	16.7	925.0	6.0
2		HBB	1515.8	24.0	1190.0	6.5
3		No CRS	1500.4	25.7	861.2	4.7
4	Side impact	LBB w/o SCAB	2148.2	43.8	685.2	2.5
5		LBB with SCAB	935.2	60.0	483.1	4
6		HBB w/o SCAB	546.9	26.2	484.2	0.9
7		HBB with SCAB	576.6	20.3	219.3	3.9

Table 2: Neck forces and neck moment values for PIPER HBM and Q6 ATD

The difference in head excursion for the PIPER and Q6 was very negligible (0.2% increase for PIPER for high-back CRS, 9.6% reduction for low-back CRS, and 3.5% increase for the no booster condition).

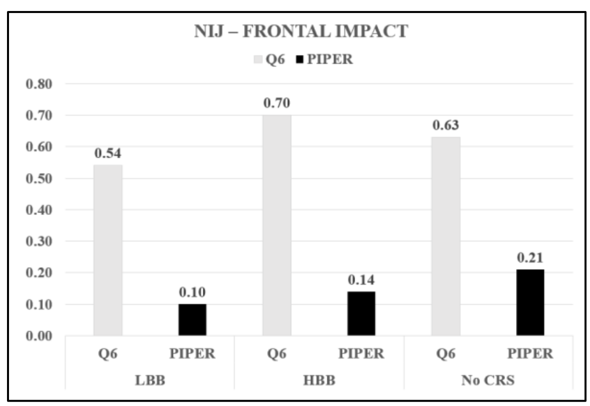

Figure 3: Comparison of Nij flexion values between PIPER 6YO HBM and Q6 ATD for frontal impact

The values for the chest displacement were measured at the chest potentiometer (Infra-Red Telescoping Rod for the Assessment of Chest Compression – IRTRACC) for the Q6 ATD and at the lower sternum for the PIPER HBM. For frontal impact, there was an increase of 77% in the chest displacement for PIPER in the no CRS condition as compared to the Q6. For the low-back booster there was a reduction in 18.1% in the PIPER HBM and an increase of 39.2% for the case of high-back booster.

Figure 4 shows the head trajectory of the child models by plotting the Z-displacement of the center of gravity of the head against its X-displacement.

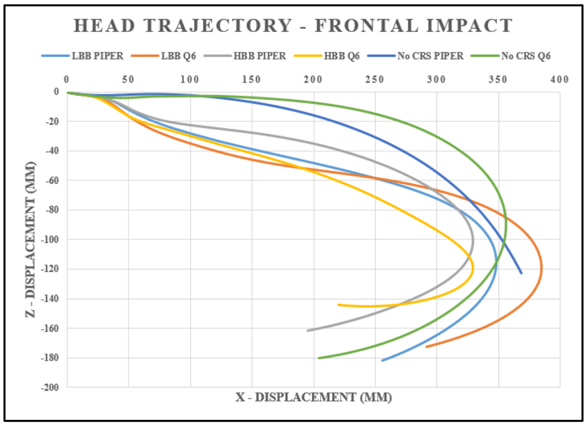

Figure 4: Head Trajectory comparison between PIPER 6YO HBM and Q6 ATD for frontal impact

DISCUSSION

The most noticeable difference observed between the PIPER 6YO HBM and the Q6 ATD was in the head-neck complex as can be seen from the Nij flexion, and neck forces and moment values. In all the cases, the neck forces and moment for the PIPER HBM were significantly lower than the Q6 ATD (minimum reduction of 11.5% in the neck forces and 63.9% in the neck moments). This behavior indicates more flexibility in the head-neck complex of the PIPER HBM when compared to the Q6 ATD.

In contrast, the overall kinematic responses of the PIPER and Q6 were very similar to each other across all booster seating conditions. From Fig. 4, it can be seen that the head trajectory of both PIPER HBM and Q6 ATD are similar to each other (lowest difference in head excursion is 0.2% and highest is 9.6%).

For the lateral impact, high values of resultant head acceleration (106G for Q6 and 125G for PIPER) were observed on the high-back booster for the condition without the usage of SCAB. This can be attributed to the child model head impacting with the extrusion on the sides of the high-back booster resulting in the observed high injury metrics.

CONCLUSION

From the results of the FE simulations it can be concluded that the most significant difference in the PIPER 6YO HBM and the Q6 ATD is in the head-neck complex. Additionally the overall kinematic responses of the models is very similar to each other.

In conclusion:

- The neck of the PIPER HBM exhibits a more flexible behavior as compared to the Q6 ATD.
- The values of neck forces and moment in the PIPER HBM were significantly lower than in Q6.
- No CRS condition for frontal impact showed the largest difference in the injury numbers between PIPER and the Q6.
- Overall kinematic response (head trajectory) of the models were very similar to each other.

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