Relative Kinematics of the Shoulder Belt and the Torso: Comparison of the Q10 ATD and Pediatric Human Volunteers

Kristy B. Arbogast, Caitlin M. Locey, Katarina Bohman, Thomas Seacrist*

Abstract Previous studies have raised concerns about the biofidelity of the shoulder belt-torso interaction of the Q10 ATD in frontal impacts in that the belt appears to move close to the neck and offload the chest deflection sensors. This study used the only known pediatric human volunteer sled test data to evaluate this phenomenon. From this previous study, three subjects (n=11 trials) whose anthropometry was within ±15% of the ATD were compared to the Q10. The ATD and humans were tested according to similar protocols. Restrained subjects were exposed to a non-injurious crash pulse. Photoreflective markers, placed along the belt and on T1 to define the torso, were tracked using a 3D motion analysis system. In both the ATD and the human volunteers, the shoulder belt moved toward the neck during the loading. However in the ATD the magnitude was greater (37 mm versus 24 mm for the volunteers). Similar findings were observed when the lateral belt movement was computed relative to T1 and when normalized by single shoulder width. Although the magnitude of movement was greater for the Q10 compared the volunteers, two other characteristics were quite similar: first, the rate of lateral shoulder belt movement and second, the tendency for the belt to move lateral and then begin to return towards initial position. Compared to other ATDs that approximate a young adolescent, the lateral movement of the shoulder belt was greatest for the Q10 both when raw values were considered and when presented relative to T1. Overall, these results suggest that the shoulder belt interacts with the torso of the Q10 differently than in humans and may underestimate chest deflection due lateral belt motion towards the neck, ultimately offloading the chest deflection sensor.

Keywords biofidelity, anthropomorphic test devices, kinematics, pediatric

I. INTRODUCTION

In Europe, the regulation (ECE R.44) and EuroNCAP consumer ratings currently use P dummies as anthropometric test devices (ATD) to assess child safety. The P dummies represent children from 9 months to 10 years and were developed in the 1970s primarily as loading devices with limited measurement capabilities. In the 1990s, the development of the Q dummies began with the goal to replace the P dummies [1]. In particular, the Q10 dummy, designed to represent a midsized child of 10.5 years, was developed in the European project EPOCh and is the oldest child dummy in the Q dummy family, which includes the Q0, Q1.5, Q3 and Q6 dummies. Formal evaluation of the Q10 ATD demonstrated its repeatability, durability and sensitivity to important restraint and crash conditions [2]. The Q10 is suggested to be one of the new child dummies to be used in the revised EuroNCAP test protocol 2015 for both frontal and side impact tests.

Previous testing using the Q10 raised questions about the sensitivity of the chest injury metrics to shoulder belt initial position. In tests conducted at Autoliv Research, the Q10 was placed in the right rear vehicle seat on a booster seat with and without a back. Sled tests were conducted using the x-acceleration of a EuroNCAP oblique deformable barrier test at 64 km/h and different belt geometries were explored [3]. Contrary to previous tests conducted as part of the original evaluation of the Q10 ATD [2] , chest deflection varied substantially depending on the initial position of the shoulder belt. If the shoulder belt was positioned mid-shoulder, it moved towards the neck during the crash and produced low chest deflection in that it off-loaded the chest deflection sensors. If, however, the shoulder belt was 20 mm further outboard on the shoulder at initial position, chest deflection increased by 50%. Similar findings were observed by Lubbe [4] in the Q6 ATD.

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He observed shoulder belt movement towards the neck on the Q6 but not on the Hybrid III 6 year old ATD and attributed it to the anthropometry of the Q6 rib cage and clavicle which are both inclined towards the neck. Tylko and Bussieres [5] did however document similar phenomena in the Hybrid III 10 year old ATD. In an analysis of frontal full-scale rigid barrier tests conducted with the Hybrid III 10 year old ATD in the rear outboard seat, 25 of 29 tests demonstrated neck loading from the shoulder belt at peak excursion. Poor positioning of the shoulder belt, defined as upward displacement of the belt on the torso, resulted in lower chest deflection.

These tests have raised the question as to the biofidelity of the shoulder belt movement towards the neck and its influence on the accuracy of the chest injury measures. Such movement may drive design that promotes closeness of the belt to the neck which in the real world may translate to the child placing the shoulder belt under the arm or behind the back for comfort thus compromising overall safety. To our knowledge, only one study exists with pediatric human volunteers or post mortem human subjects for which evaluation of the biofidelity of the torso-shoulder belt interaction is possible. We previously conducted low speed frontal sled tests with restrained human volunteers, age 6-14 years [6] and similar tests with the Q10 ATD [7]. These studies provide data on how the shoulder belt interacts with a human torso in a restrained frontal crash condition and offer comparative information for the Q10. Therefore, the purpose of this study was to examine the relative kinematics of the shoulder belt and torso on the Q10 ATD and compare it to similar metrics from tests of pediatric human volunteers. Low speed frontal sled tests were also previously conducted for the similarly-sized Hybrid III 10 and Hybrid III 5th percentile adult female ATDs [7]; a secondary comparison of shoulder belt interaction with the torso was also made across the dummy families.

II. METHODS

This study reexamines data previously collected from 6-14 year old children [6], the Q10 and Hybrid III 10 year old (HIII 10) pediatric ATDs [7], and the Hybrid III 5th percentile female (HIII 5th%ile) small adult ATD in a low-speed frontal sled test. For this analysis, pediatric subjects were selected for inclusion if mass and erect seating height were within ±15% of the average HIII 10 and Q10 ATD values. Of the 20 pediatric volunteers within the 6-14 year old age range, three were size-matched to the 10-year-old ATDs (SM10) and had kinematic data for the analyses described below.

Experimental Testing

A comprehensive description of the test method can be found in Arbogast et al. [6]. Briefly, healthy male pediatric subjects between the ages of 6 to 14 years whose height, weight, and body mass index (BMI) were within 5th and 95th percentile for the subject's age were recruited. The study protocol was reviewed and approved by the Institutional Review Boards of the Children's Hospital of Philadelphia and Rowan University. A variety of anthropometric dimensions were collected using calipers and a flexible tape measure.

Subjects were seated in a pneumatically-actuated, hydraulically-controlled low acceleration sled. A safe, non-injurious crash pulse applicable to the pediatric population was derived from an amusement park bumper car impact. The volunteer sled exhibited a maximum acceleration pulse of 4.3 g in 61.9 ms, resulting in a maximum occupant delta-V of 2.58 m/s. The volunteer sled was equipped with an on-board accelerometer and two six axis load cells placed under the seat pan and foot rest.

Subjects were restrained using an automotive three-point belt system (Takata Corp., Tokyo, Japan) consisting of commercially available components. The shoulder portion of the belt went from the subjects' left shoulder to their right hip. The belt geometry was such that the D-ring is located 283 mm rearward of the H-point of the ATD. The height of the shoulder belt anchor was adjusted to provide similar fit across subjects; specifically, the shoulder belt angle at the D-Ring (defined as the angle the shoulder belt makes with the horizontal) was set at 55° at initial position for all the subjects. The lap belt anchor locations were fixed throughout the test series. Lightweight belt webbing load cells (Model 6200FL-41-30, Denton ATD Inc, Rochester Hills, MI) were attached 125 mm from the D-ring location on the shoulder belt between the subject and the D-ring and on the right and left locations on the lap belt.

Photoreflective markers were placed on anatomical landmarks of interest including the head, neck, spine, and pelvis, and were tracked using a 3D near-infrared video target tracking system (Model Eagle 4 Motion Analysis Corporation, Santa Rosa, CA). The belt system was tracked using photoreflective markers placed on the D-ring front, D-ring rear, buckle top, and the belt webbing above the left shoulder. The marker on the shoulder belt was positioned 152 mm from the D-ring anchor location along the midline of the belt (Figure 1).

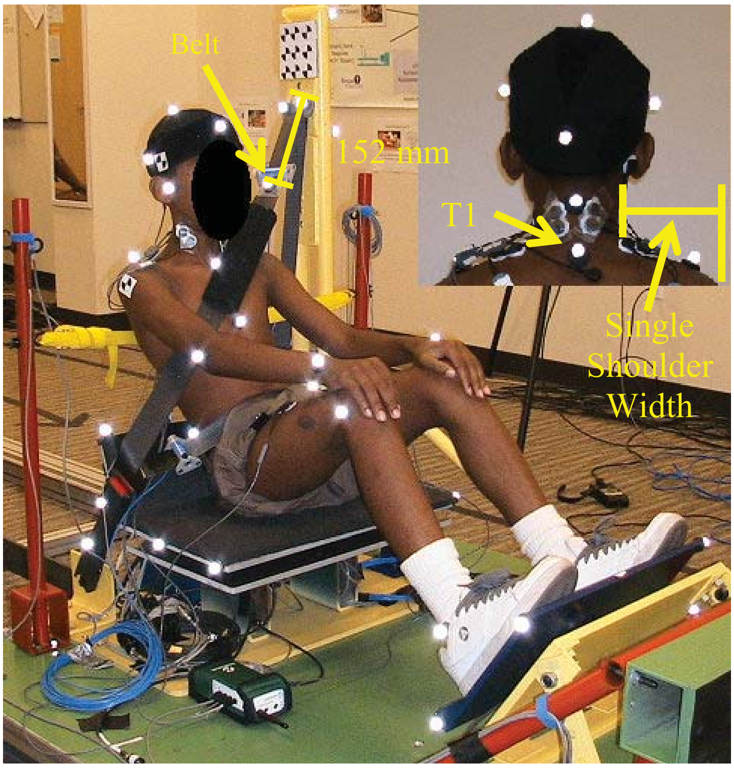


Figure 1: Occupant in seating configuration. Markers of interest are highlighted.

The initial torso and knee flexion angles were set to 110° by adjusting the fore-aft position of the footrest and vertical position and tightness of the nylon strap backrest. Knee/torso angle and seat belt angle were established using a goniometer and inclinometer, respectively. A single technician oriented all human volunteers and the ATD, eliminating inter-technician variability. Pediatric volunteer orientation was confirmed immediately prior (<10 sec) to triggering the sled, thus minimizing the time for subjects to deviate from initial position. To minimize the effect of initial head angle, subjects were asked to position their head by focusing on a point placed directly in front of them at the level of their nasion. Variation in human volunteer initial position was previously shown not to be a significant factor influencing trajectories for this data set [6]. Pediatric volunteers received six consecutive, repeated trials. ATD marker placement and initial position mimicked the methodology used for the pediatric subjects. The Q10, HIII 10, and HIII 5th%ile ATDs also received six repeated trials.

Data Acquisition and Processing

Signals from the accelerometer and load cells were sampled at 10,000 Hz using a T-DAS data acquisition system (Diversified Technical Systems Inc., Seal Beach, CA) with a built-in anti-aliasing filter (4,300Hz). The sled acceleration data, seat belt loads, and forces and moments at the seat pan and foot rest were filtered at SAE channel frequency class (CFC) 60, according to SAE J211 Recommended Practice (Society of Automotive Engineers 1995). The Motion Analysis data were acquired at 100 Hz and analyzed using EVaRT5 software (Motion Analysis Corporation, Santa Rosa, CA).

The time series motion analysis and T-DAS data were imported into MATLAB (Math works, Inc., Natick, MA) for data reduction using a custom written program. The outcomes of interest for this analysis were trajectories of the torso and shoulder belt, as well as belt reaction forces. The marker at the right rear of the seat pan was designated as the origin for the local (sled) coordinate system. For all markers, change in marker position (excursion) was computed in the Y direction (lateral). Peak excursion was calculated as the difference between initial position and maximum change in position. Maximum and time of maximum excursions and reaction loads were computed. Shoulder belt movement was also examined relative to the motion of the subject's torso. Because the T1 marker was most often visible in the Motion Analysis data during the frontal crash event (vs. suprasternal notch or xiphoid process, which were obscured due to flexion of the subject over the shoulder belt), this marker was chosen to represent the midline of the subject torso. Lateral excursions were presented as absolute values and normalized by the distance from the most lateral part of the shoulder to the ipsilateral neck. This distance was termed single shoulder width. The single shoulder width measurements were quantified from frontal photographs of the human volunteers and ATDs. Single shoulder width values as well as other anthropometric measures for all included size-matched 10-year-old human volunteers and ATDs are presented in Table 1.

Table 1: ATD and Pediatric Volunteer Anthropometry.

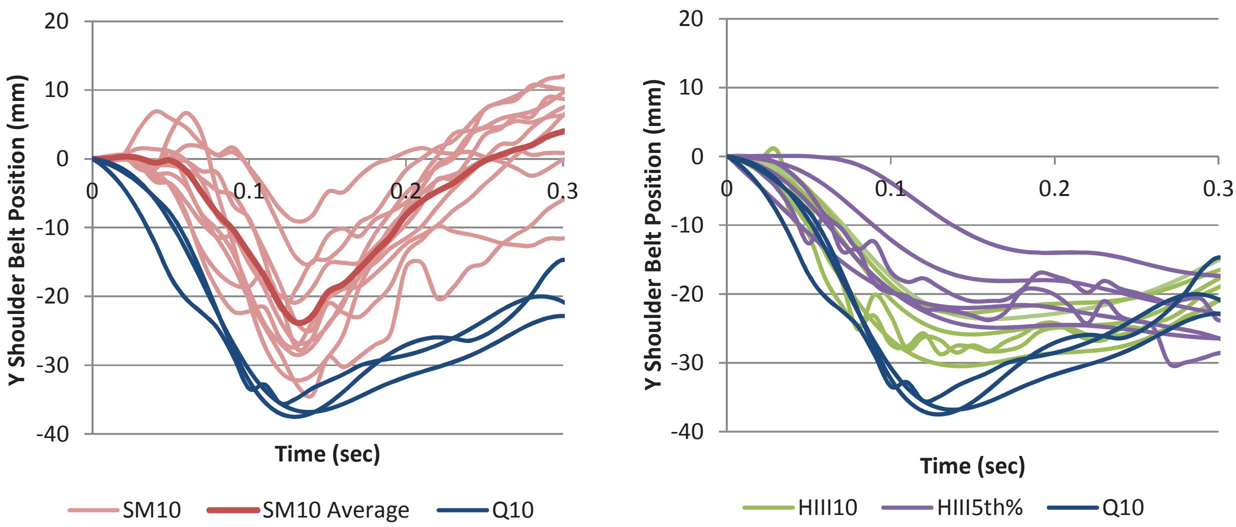
Subject	Mass (kg)	Erect Seated Height (cm)	Single Shoulder Width (mm)
SM10-1	34.5	72.5	122
SM10-2	33.2	73.5	131
SM10-3	40.5	72.5	134
Volunteer average±SD	36.1±3.9	72.8±0.58	129 ± 6
50th percentile 10 year old*	32.1	72.1	--
HIII 10	35.3	72.4	137
HIII 5th percentile	49.1	78.7	110
Q10	38.5	77.8	131

*http://ovrt.nist.gov/projects/anthrokids/

III. RESULTS

Three SM10 subjects had a total of 11 motion analysis trials that captured the belt marker for the entire event. For the ATDs, a total of 6 HIII 10 year old trials, 6 HIII 5th%ile trials, and 3 Q10 trials had usable belt marker motion data. Lateral shoulder belt motion is presented in Figure 2 below for: a) Q10 vs. SM10 human subjects and b) Q10 vs. HIII 10 and HIII 5th%ile. Per the SAE J211 sign convention, negative Y belt position values indicate shoulder belt shift to the occupant's right, toward the mid-sagittal plane.

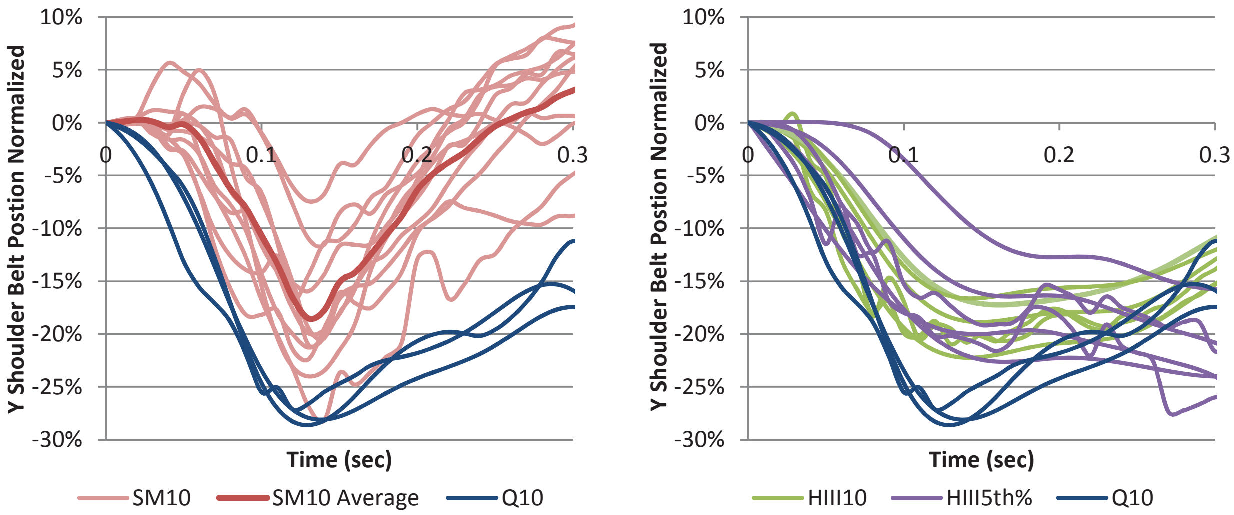
The average maximum lateral belt movement was greater and started somewhat earlier for the Q10 ATD (37 ± 1 mm) as compared to the SM10 human volunteers (24 ± 7 mm) (Figure 2), however the time of peak for both groups was identical (Table 2). The Q10 also had a greater lateral belt movement than either of the similarly-sized ATDs (37 ± 1 mm vs. 27 ± 3 mm for HIII 10 and 25 ± 4 mm for HIII 5th%ile). Time of peak was similar for the Q10 and HIII 10, however the time of peak for the HIII 5th%ile was not reached until the end of the data collection time window, indicating that the belt continued moving laterally during the entire event. The HIII 5th%ile lateral belt movement magnitude, however, was still less than that of the other ATDs. For the volunteers, the position of the shoulder belt reaches a maximum and then begins to return to initial position sometimes returning past its starting point. Qualitatively, it appears that the Q10 best mimics this motion; the HIII 10 begins to return but to a lesser degree and the HIII 5th%ile does not demonstrate belt return at all.



(a) (b)

Figure 2: Non-normalized shoulder belt lateral movement, for: a) Q10 vs. SM10 human volunteers, and b) Q10 vs. similar sized ATDs, HIII 10 and HIII 5th%ile female. The solid line on the volunteer data represents the average.

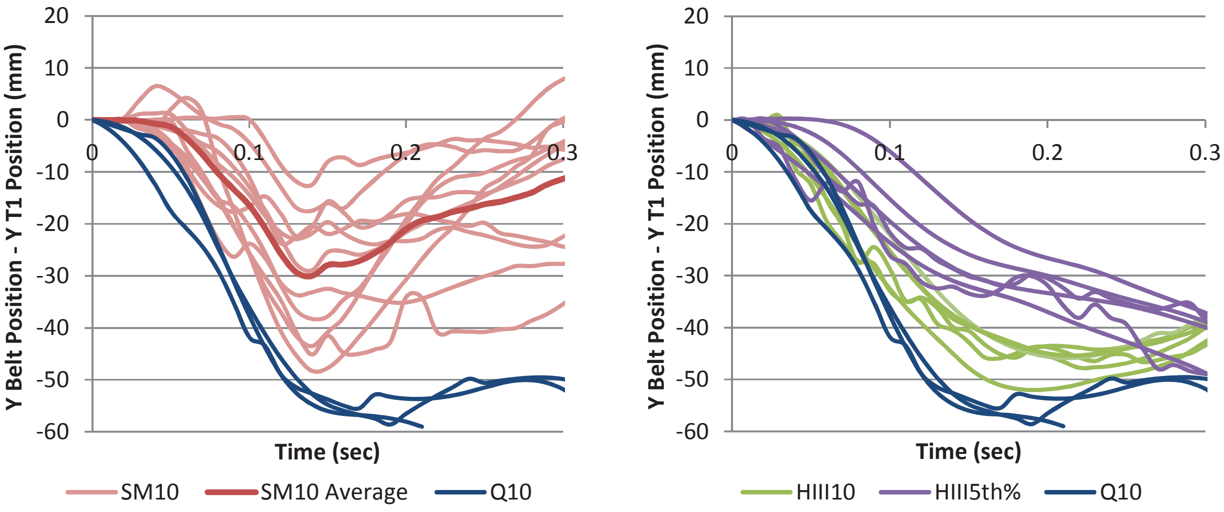
After normalizing by single shoulder width, the Q10 lateral motion was closer to the volunteer response than in the non-normalized comparison but its magnitude continued to be greater. On average, the shoulder belt moved across 28% ± 1% of the Q10 single shoulder, compared to 19% ± 6% of the SM10 human volunteer single shoulder. The Q10 showed greater normalized motion than the HIII 10 (19% ± 2%) and the HIII 5th%ile (22% ± 4%) (Figure 3).



(a) (b)

Figure 3: Shoulder belt lateral movement normalized by single shoulder width, for: a) Q10 vs. SM10 human volunteers, and b) Q10 vs. similar sized ATDs, HIII 10 and HIII 5th%ile female. The solid line on the volunteer data represents the average.

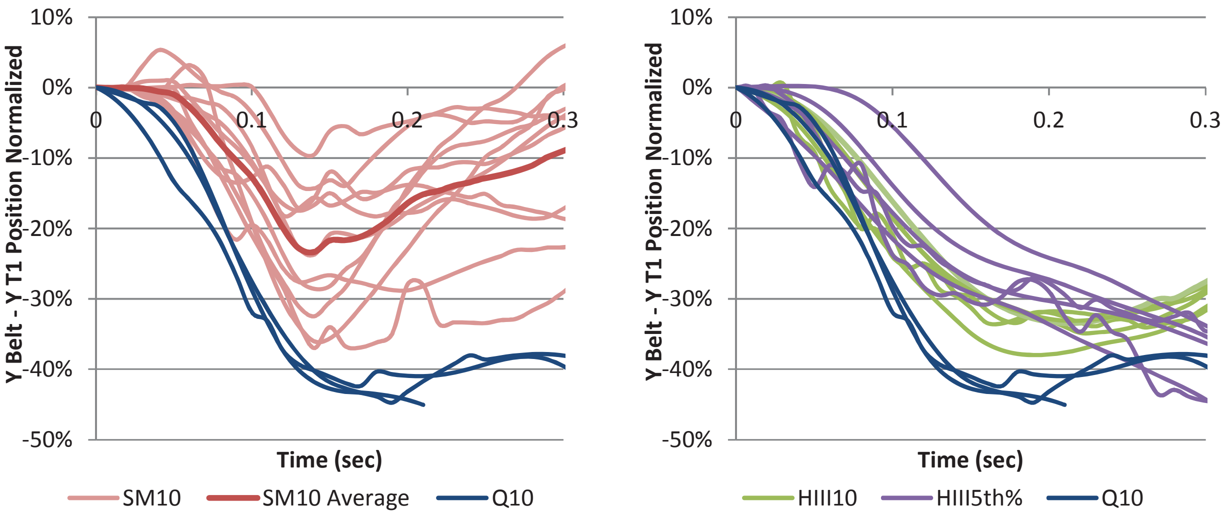
The average maximum lateral movement of the shoulder belt relative to the lateral movement of T1 was greater for the Q10 ATD (58 ± 2 mm) as compared to the SM10 human volunteers (31 ± 12 mm) (Figure 4). Time of maximum relative movement was similar for the Q10 vs. SM10. The Q10 also had greater lateral shoulder belt movement relative to T1 than either of the similarly-sized ATDs (58 ± 2 mm vs. 47 ± 2 mm for HIII 10 and 42 ± 5 mm for HIII 5th%ile). Again, time of maximum relative movement was similar for the Q10 and HIII 10, however the time of peak for the HIII 5th%ile was not reached until the end of the time window.



(a) (b)

Figure 4: Non-normalized shoulder belt lateral movement relative to T1, for: a) Q10 vs. SM10 human volunteers, and b) Q10 vs. similar sized ATDs, HIII 10 and HIII 5th%ile female. The solid line on the volunteer data represents the average.

After normalizing by single shoulder width, the Q10 belt lateral motion relative to T1 remained greater than that of the volunteers. On average, the relative lateral motion of the shoulder belt was 44% ± 1% of the total Q10 single shoulder width, compared to 24% ± 9% of the SM10 human volunteer single shoulder width. The Q10 showed greater normalized relative lateral motion of the shoulder belt than the HIII 10 (34% ± 2%) and the HIII 5th%ile (38% ± 5%) (Figure 5). Peak data for all conditions are summarized in Figure 6.

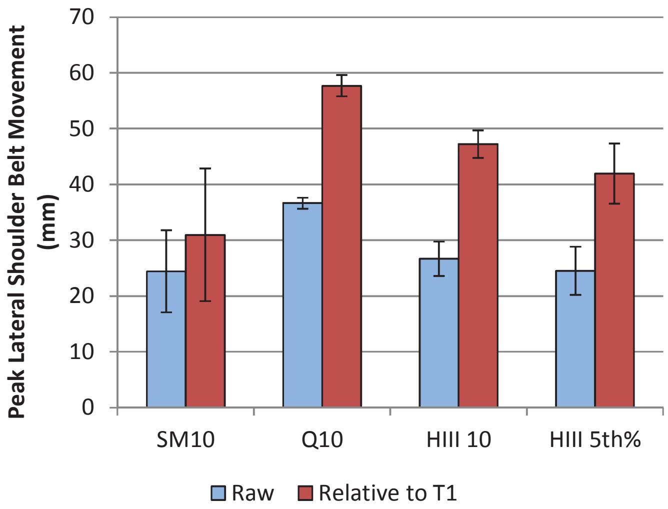


(a) (b)

Figure 5: Lateral movement of the shoulder belt relative to T1 normalized by single shoulder width, for: a) Q10 vs. SM10 human volunteers, and b) Q10 vs. similar sized ATDs, HIII 10 and HIII 5th%ile female. The solid line on the volunteer data represents the average.

Table 2: Average maximum Y belt movement and time of maximum across all included trials.

		Size-Matched 10 YO *Mean (± SD)*	Q10 *Mean (± SD)*	Hybrid III 10 *Mean (± SD)*	Hybrid III 5th%ile Female *Mean (± SD)*
Belt Lateral Movement	**Peak (mm)**	24 ± 7	37 ± 1	27 ± 3	25 ± 4
	Time (sec)	0.13 ± 0.01	0.13 ± 0.01	0.14 ± 0.01	0.30 ± 0.01
Belt Lateral Movement Relative to T1	**Peak (mm)**	31 ± 12	58 ± 2	47 ± 2	42 ± 5
	Time (sec)	0.17 ± 0.06	0.19 ± 0.02	0.21 ± 0.03	0.30 ± 0.00



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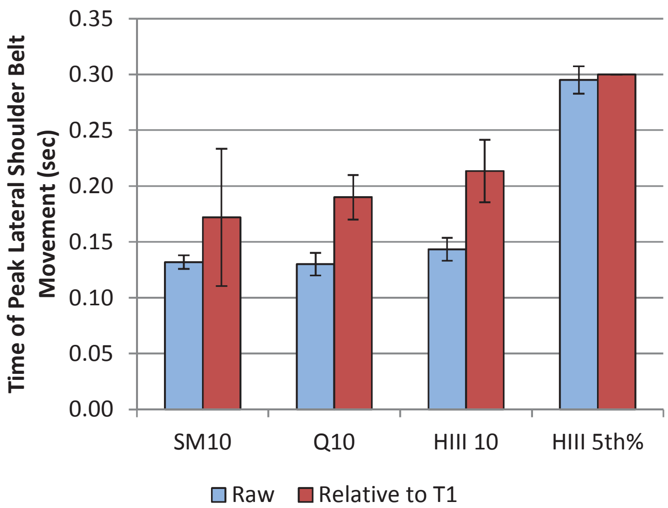

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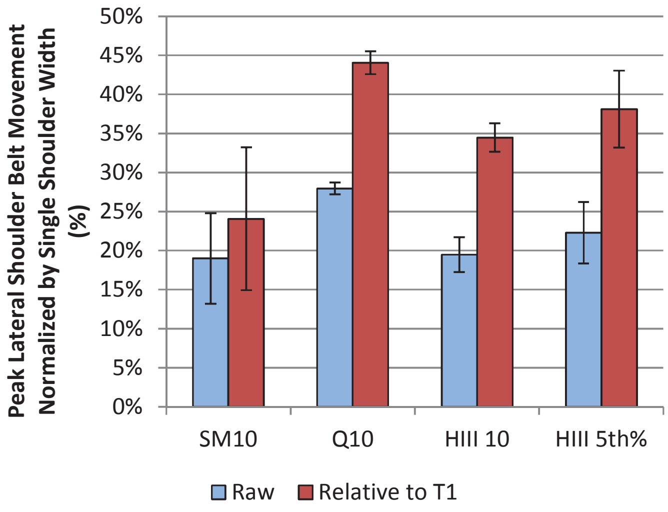

(c)

Figure 6: Summary of (a) peak lateral shoulder belt movement and (b) timing for absolute movement and movement relative to T1, and (c) peak lateral shoulder belt movement and movement relative to T1 normalized by single shoulder width.

The timing of the peak lateral shoulder belt movement for the SM10 human volunteers and each of the ATDs were compared to the times of peak shoulder belt load and forward head excursion previously reported in Seacrist et al [7] (Table 3). For the Q10 and HIII 10 ATDs and SM10 volunteers, both these events happened simultaneous to or after the peak lateral shoulder belt movement. The relative timing of these events is shown in Figure 7. Note the similarity in initial slope of the time history of the lateral belt movement for the Q10, the Hybrid III 10 year old and the volunteers.

Table 3: Average time of peak shoulder belt load and forward head excursion compared to time of peak lateral movement of the belt.

	Size-Matched 10 YO	**Q10**	**Hybrid III 10**	**Hybrid III 5th%ile Female**
Time of Peak Lateral Belt Movement (sec)	0.13	0.13	0.14	0.30
Time of Peak Shoulder Belt Load (sec)	0.15	0.14	0.14	0.15
Time of Peak Forward Head Excursion (sec)	0.21	0.15	0.16	0.16

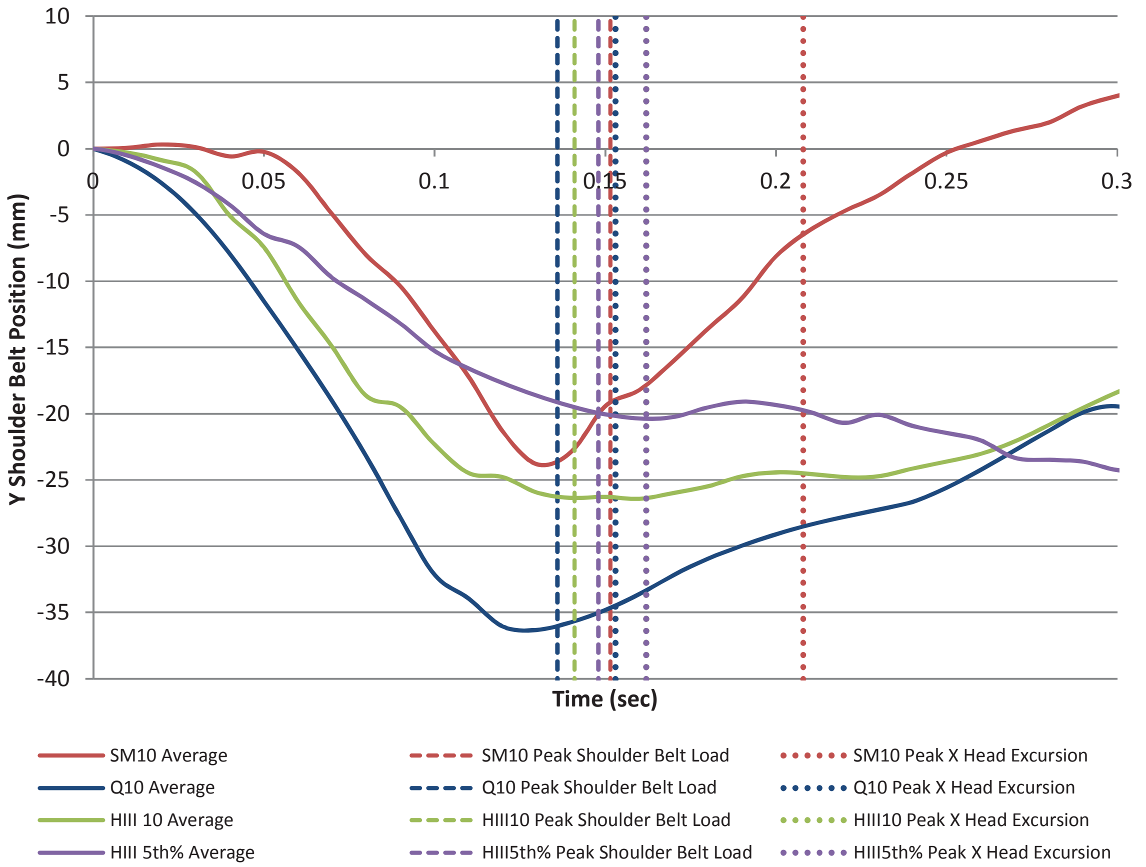

Figure 7: Timing of peak lateral change in shoulder belt position relative to previously reported peak shoulder belt load and forward head excursion. Vertical lines indicate average times of peak across all similar subjects and trials.

IV. DISCUSSION

This analysis compared previously collected data from low speed human volunteer frontal sled tests with similar tests on the ATDs approximating the size of a young adolescent – the Q10, the Hybrid III 10 and the Hybrid III 5th percentile. This analysis was motivated by previous high-speed sled test data using the Q10 ATD [3], which in some cases demonstrated 1) lateral movement of the shoulder belt towards the neck, and 2) upward movement of the lower part of the shoulder belt towards the axilla. In the absence of tests on pediatric post mortem human subjects in contemporary restraint systems, we utilized the only known pediatric human volunteer sled test data to evaluate the biofidelity of the shoulder belt-torso interaction of the ATDs.

Shoulder belt motion was examined both as absolute values of lateral movement and normalized by the available distance along the clavicle that the shoulder belt could move before it contacted the lateral neck. In both metrics, the Q10 ATD demonstrated greater magnitude of movement of the belt compared to the size matched pediatric volunteers. For the absolute values, the shoulder belt on the Q10 demonstrated greater than 50% (13 mm) more lateral movement that the belt on the human volunteers; while for the normalized motion, the Q10 shoulder belt moved across an additional 9% of the clavicle width than the belt on the human volunteers. The timing of maximum lateral movement was similar between the Q10 and the human volunteers.

It is important, however, to also understand the motion of the shoulder belt relative to the torso. Ideally, the lateral shoulder belt motion would be compared to the motion of a marker on the central anterior trunk such as the suprasternal notch or xiphoid process of the sternum. However, these markers quickly become obscured from the motion capture cameras as the subject flexes forward over the shoulder belt. As a result, we chose to use the marker on T1 as a measure of torso movement. Analysis of lateral movement of the shoulder belt relative to lateral movement of T1 showed approximately 25 mm greater relative movement for the Q10 as compared to the human volunteers. Examining this metric normalized by the available lateral distance on the subject's shoulder highlighted that the shoulder belt on the Q10 covered almost 20% more distance along the shoulder compared to the human volunteers. Analysis of the time of peak relative movement revealed similarities between the Q10 and the volunteers.

The magnitude of the difference between the Q10 and volunteers was greater in the data presented relative to T1 than in the raw data. This observation points to variability in the torso lateral movement between the Q10 and the human volunteers. In addition, the ability of the human to twist axially (around the vertical axis) around the shoulder belt likely influences the torso-shoulder belt interaction and the specific position of the shoulder belt along the clavicle. We previously noted asymmetric kinematics of the right and left acromion in the volunteer tests [6]. These data presented herein suggest that this axial twist is a response that is difficult for the ATD to mimic.

Of note is the intra-subject and intra-trial scatter of lateral belt movement vs. time for each of the three included human subjects. One of the primary differences between the ATDs and the volunteers is the presence of active muscle response and potential awareness of the event. Variations in muscle activity (voluntary or involuntary) may affect the interaction between the human volunteer and the restraint system/seating environment, producing variations in peak lateral belt movement.

In order to explore whether the differences between the Q10 and the human volunteers noted above were specific to the Q10 ATD, the Q10 was also compared to both the Hybrid III 10 and the Hybrid III 5th percentile female ATDs. In gross stature (150 cm) and weight (49 kg), the HIII 5th%ile ATD represents the 50th%ile 12 year old and 13.5 year old in height and weight, respectively. The Q10 had a greater lateral belt movement than either of the similarly-sized ATDs (37 mm vs. 27 mm for HIII 10 and 25 mm for HIII 5th%ile for absolute values and 28% vs 19% for the HIII 10 and 22% for the HIII 5th%ile). The Q10 also had a greater lateral shoulder belt movement relative to T1 than either of the similarly-sized ATDs comparing both the absolute values (~12-15 mm) and the normalized values (differences of 6-10%).

An important qualitative observation of the relative belt lateral motion shows that for human subjects, the belt moves toward the neck then away from the neck, sometimes returning beyond its start point. This response appears to be best mimicked by the Q10. The HIII 10 demonstrates some return to baseline values but not as pronounced as the Q10 and the HIII 5th%ile does not return towards baseline at all.

There are important differences in thoracic and shoulder anthropometry and mechanical response across the different ATDs that may influence these differences. The Hybrid III ribcage consists of six horizontal ribs whereas the Q10 ribcage is constructed from a single inclined piece. The Q10 ribcage is also more cylindrical than the Hybrid III 10. Similarly, the Q10 has a more rounded abdomen and exhibits a more slouched posture. In a comparison of the 6 year old ATD which are constructed similarly, these torso differences resulted in different shoulder belt interaction in a series of three high-speed sled tests; the shoulder belt slid up the Q6 thorax until it reached the neck whereas the Hybrid III 6 shoulder belt position remained in place (Lubbe 2010). Furthermore, the chest stiffness of the Q10 has been noted to be greater than that of the Hybrid III 10 year old [8]. Lastly, the shoulder design of the Q10 is extrapolated from the Q6 and has a human like clavicle structure while the HIII 10 has more of a mechanical joint with a combined clavicle and scapula aluminum shoulder. Analysis comparing differences in torso shape for the Hybrid III and Q-series pediatric ATDs as well as between the ATD and the human is currently underway (personal communication: Sriram Balasubramanian, Drexel University). Preliminary results suggest that the ATD have a greater chest depth than humans and the angle the sternum makes with vertical is smaller (i.e a flatter chest) in the ATD than in the humans.

The friction of the belt against the torso may be a contributing factor to the shoulder belt movement. The Q10 was wearing a tight suit of neoprene, but the chest plate where the seat belt is in contact with the suit is covered in Cordura®, a low friction material. This material was used to improve the durability of the suit however, it is after this change that movement towards the neck was reported by Waagmeester in 2012 [9]. It is possible that this is the reason why such lateral displacement of the belt was not noted in the original Q10 evaluation data of the EPOCh project [2]. In contrast, neither the Hybrid III dummies nor the volunteers wore clothing on the torso.

The Q10 is equipped with two chest deflection sensors, the upper chest deflection sensor is located on the centerline of the sternum just below the axilla and the lower chest deflection sensor is located on the centerline of the sternum just above the abdominal insert, 80 mm below the upper chest deflection sensor. During the impact, as the upper part of shoulder belt moves laterally towards the neck and then the lower part of the shoulder belt moves upwards the axilla, the shoulder belt load on the torso may not be captured by the chest deflection sensors as the primary load is not over the sensor location. We do not know whether this torso loading is a biomechanical disadvantage to a child, but the corresponding reduction of the observed chest deflection measures probably does not correspond to a similar risk reduction of actual thoracic injury to a child. This ATD-specific behavior may drive the development of the rear seat geometry and restraint design that in practice drives the shoulder belt towards the neck. The resulting discomfort to human rear-seated occupants may lead to the child putting the shoulder belt under the arm or behind the back, thus compromising his/her safety.

There are several important limitations of this study. The original human volunteer and ATD tests were not designed to collect the belt-torso interaction data analyzed herein and marker placement was not optimized for such analyses. As a result, of the seven total size-matched 10 year olds tested in the original series, only three had quality data for both the torso and the shoulder belt throughout the time history. Prospective collection of belt-torso interaction data would likely result in more targeted kinematic data collection from the torso-belt-shoulder region. Secondly, biofidelity must be evaluated with a human surrogate, and in the absence of contemporary data with pediatric post mortem human subjects, pediatric human volunteers represent the only data to which to compare the belt-torso interaction of the ATD. As a result, the differences noted between the ATDs and human volunteers were evaluated for a single, low speed crash condition. Results may differ in higher loading environments or other crash modes. Third, this setup was not designed to mimic any specific automobile, but rather an automotive-like environment in which to compare the ATDs and humans. The current study used a single seat belt geometry with a standard 3-point seat belt adjusted to the height of the ATDs and pediatric volunteers. Additionally, the difference in belt friction between the ATDs torso and human subject skin or the effect of clothing was not considered. Future research should examine the influence of friction on the observations highlighted in this study.

V. CONCLUSIONS

This analysis utilizes the only known pediatric human volunteer sled test data to evaluate the biofidelity of the shoulder belt-torso interaction of the newly designed Q10 ATD. These results highlight that in this low speed crash condition, the Q10 demonstrates greater absolute movement of the shoulder belt towards the neck compared to size matched pediatric human volunteers which suggests that the shoulder belt moves differently on the Q10. Similar findings were observed when the lateral belt movement was computed relative to T1 and when normalized by single shoulder width. Although the magnitude of movement was greater for the Q10 compared the volunteers, two other characteristics were quite similar: first, the rate of lateral shoulder belt movement and second, the tendency for the belt to move lateral and then begin to return towards initial position. Compared to other ATDs that approximate a young adolescent, the lateral movement of the shoulder belt was greatest for the Q10 both when raw values were considered and when presented relative to T1. The lateral movement of the belt on the ATDs may result in an underestimate of chest deflection due to offloading the chest deflection sensor. Future studies with other belt geometries and crash modes should be explored to confirm these findings.

VI. ACKNOWLEDGEMENT

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