Sensitivity of Q10 and Q6 chest measurements to restraint and test parameters

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ABSTRACT

Upcoming test procedures and regulations consider the use of Q-dummies. Especially Q6 and Q10 will be introduced to assess the safety of child occupants in vehicle rear seats. Therefore detailed knowledge of these dummies is important to improve safety. As recent studies have shown, chest deflection measurements of both dummies are influenced by parameters like belt geometry. This could lead to a non optimized design of child restraint systems (CRS) and belt systems. The objective of this study is to obtain a more detailed understanding of the sensitivity of chest measurements to restraint parameters and to investigate the possibilities of chest acceleration as an alternative for the assessment of chest injury risks.
A study of frontal impact sled tests was performed with Q6 and Q10 in a generic rear seat environment on a bench. Belt parameters like modified belt attachment locations were varied. For the Q6 dummy, different positioning settings of the CRS (booster with backrest) and of the dummy itself were investigated. The Q10 dummy was seated on a booster cushion. Here the position of the upper belt anchorage point was varied. To simulate the influence of vehicle rotation in the ODB crash configuration, the bench was pre-rotated on the sled in additional tests with the Q10. This configuration was tested with and without pretensioner and load limiter.
Chest deflection in Q6 showed a high sensitivity to changes in positioning of the CRS and the dummy itself. A more slouched position of the CRS or dummy resulted in a reduction of measured chest deflection, whereas chest acceleration increased for a more slouched position of the CRS. Chest deflection in Q10 is sensitive to belt geometry as already shown in other studies. In a more outboard position of the shoulder belt anchorage the measured chest deflection is higher. Chest acceleration shows the opposite tendency, which is highest for the rearmost location of the upper belt anchorage. On a pre-rotated bench the highest chest deflection within this test series was observed without load limiter/pretensioner and an outboard belt position. By optimizing the belt location and the use of pretensioner/load limier the chest deflection was significantly reduced.
For the Q6 a criterion based on chest acceleration as well as deflection measured at two locations might be the most reliable approach, which requires further research with an additional upper deflection sensor. In the Q10 the measured chest deflection does not always correctly reflect the severity of chest loading. The deflection is depending on initial belt position and restraint parameters as well as test conditions, which result in different directions of belt migration. A3ms chest acceleration might be a better indicator for severity of chest loading independent of different conditions like belt geometries. However, in some cases the benefit of an optimized restraint system could only be shown by deflection. These findings suggest that further research is needed to identify a chest injury assessment method, which could be based on deflection as well as acceleration or other parameters related to belt to occupant interaction.

INTRODUCTION

To assess the safety of child occupants in the rear seat the dummies Q6 and Q10 are considered in upcoming test procedures (EEVC WG12 2015, EEVC WG12/18 2008). Recent studies with these dummies have shown sensitivity of chest deflection to parameters like belt path. Due to this, the design of protection systems for children based on chest deflection might be misguiding. An alternative to evaluate the chest injury risk could be the assessment of chest acceleration instead. Therefore, the objective of this study is to get a better and more detailed understanding of the sensitivity of chest measurements to test parameters.
Other studies with the Q10 have shown a high sensitivity of chest deflection to restraint parameters like belt geometry (Bohman et al. 2012, Croatto et al. 2013). However, chest acceleration was not discussed in these studies. The objective of this study was to investigate sensitivity of chest deflection and chest acceleration in dummies Q6 and Q10 to test conditions and restraint parameters. The main focus of the Q6 study was to investigate the influence of the position of the dummy in the CRS and position settings of the CRS itself. The focus of the Q10 study was the investigation of chest assessment parameters to belt geometry in a test configuration without backrest.

METHODOLOGY

For this purpose a series of sled tests was conducted with the dummies Q6 and Q10. A generic rear seat environment was created represented by a bench with deformable cushion based on ECE-R 129 specifications, mounted on a

deceleration sled with a hydraulic deceleration system (Figure 1). The test environment included a three-point-belt system with a 4 kN load limiter and a retractor pretensioner in the baseline configuration. The upper belt anchorage attachment point was variable to investigate different belt geometries. The pulse used for testing was based on the x-component of a 64 km/h ODB Euro NCAP deceleration pulse of a midsize vehicle with a peak of 30g and duration of 125 ms. The two dummies could be tested in parallel on the sled on separate benches. The Q10 dummy was positioned on a booster without backrest. The Q6 dummy was placed in a booster with backrest.

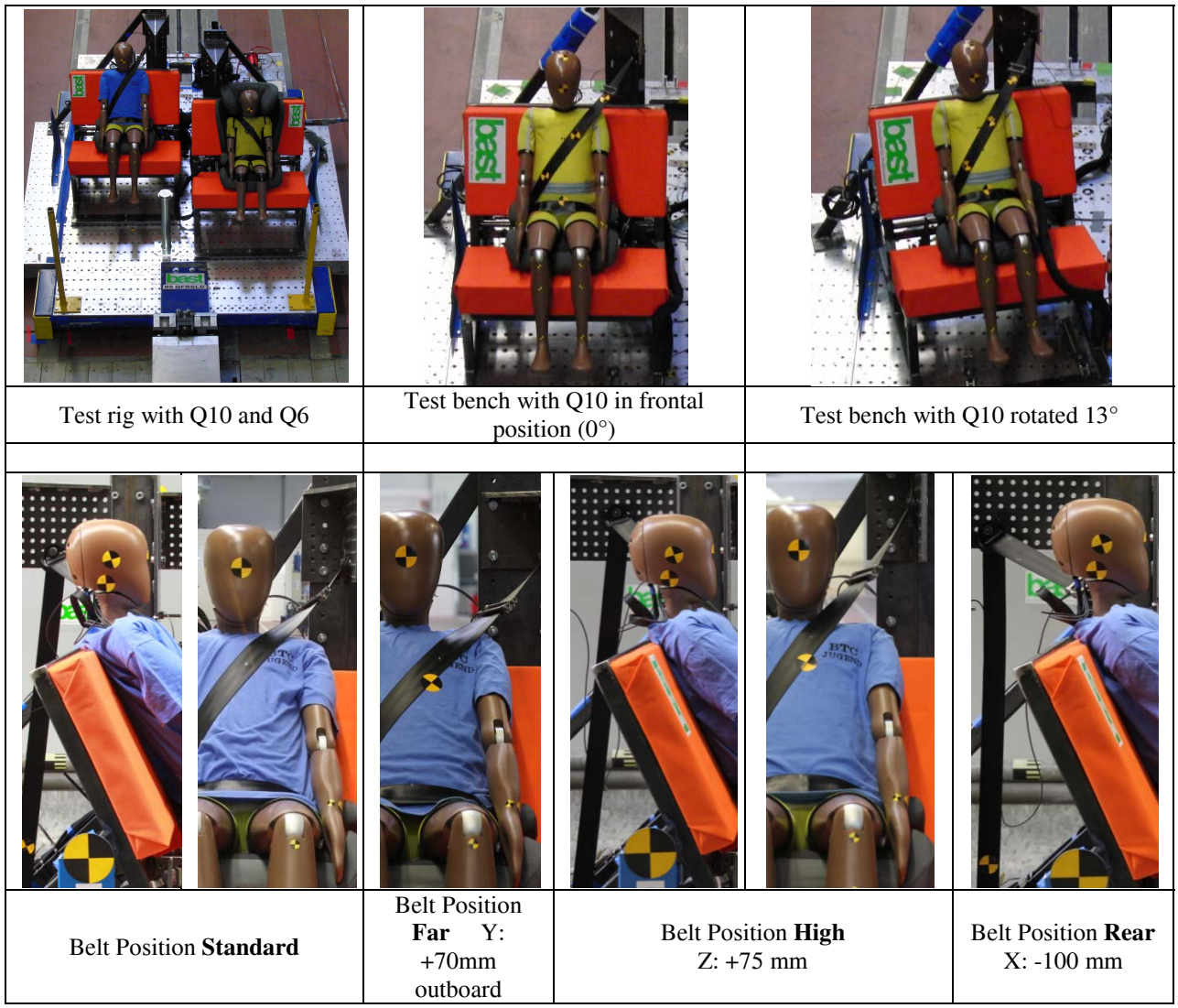
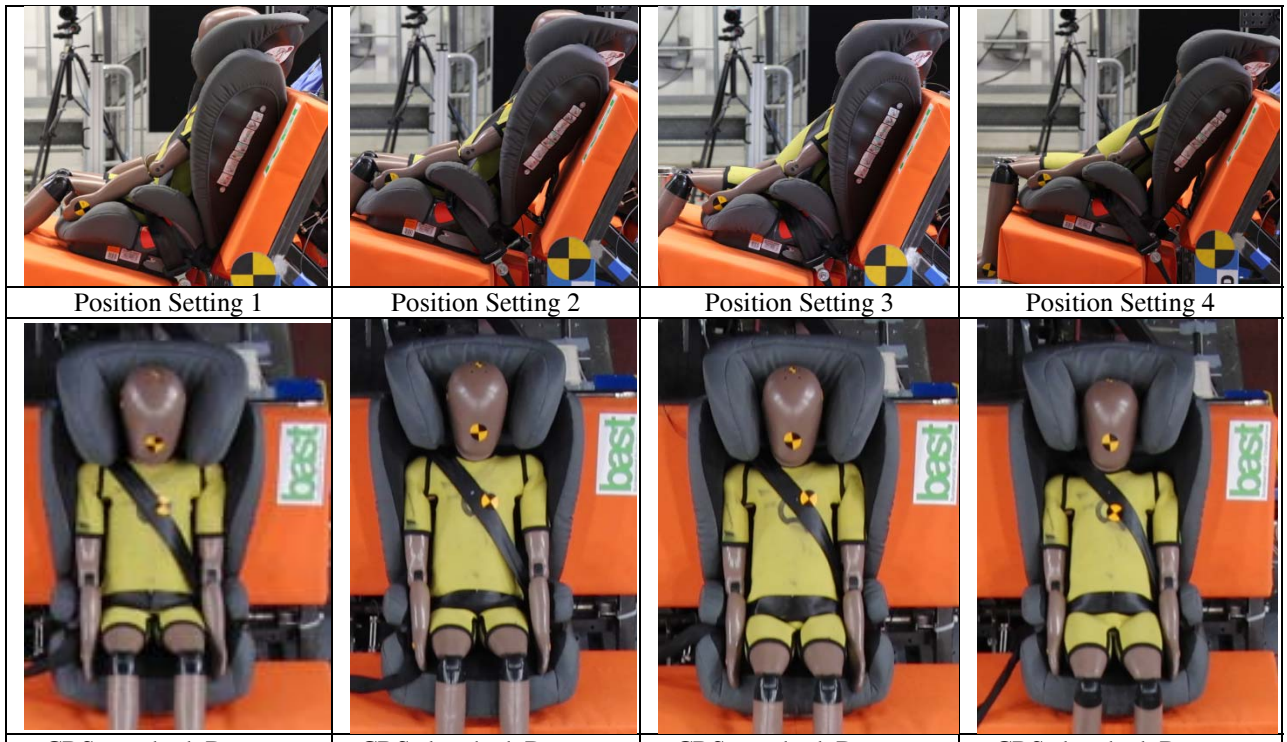


Figure 1. Test rig for sled tests with Q6 and Q10 dummies.

Test parameters

For the Q6 dummy a study of different positioning settings of the dummy and/or CRS was conducted, using a booster with backrest, a standard position of the upper belt anchorage point and a 4 kN load limiter with a pretensioner. Figure 2 shows the CRS and dummy in standard position (Setting 1). By placing a tube with a diameter of 70 mm behind the dummy in the CRS a slouched dummy position was defined (Position Setting 3). This led to a forward movement of the knees of 68 mm in x. The tube was removed before testing. When using the relax function of the CRS the backrest joint of the CRS was moved 72 mm in x direction, which was defined as slouched CRS position (Position Setting 2). The positioning of both, dummy in slouched position and CRS in slouched position resulted in a forward movement of the knees in comparison to the standard position of 134 mm in x-direction (see Figure 2 Setting 4). The parameters of all tests are shown in Table 1.



Position Setting 1	Position Setting 2	Position Setting 3	Position Setting 4
CRS standard, Dummy standard	CRS slouched, Dummy standard	CRS standard, Dummy slouched	CRS slouched, Dummy slouched
	Backrest joint: X: 72 mm forward	Knee joint: X: 68 mm forward	Backrest joint: X: 72 mm forward Knee joint: X: 134 mm forward

Figure 2. Different combinations of position setting of the Q6 dummy and CRS

Table 1: Test matrix

Test	Dummy	Load Limiter	Pretensioner	Orientation	CRS	ISOFix	Belt Position	CRS Setting	Dummy Setting
1	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	standard	standard
2	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	slouched	standard
3	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	standard	slouched
4	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	slouched	slouched
5	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	high	standard	standard
6	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	far	standard	standard
7	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	rear	standard	standard
8	Q10	No	No	frontal (13°)	booster w/o backrest	yes	far	standard	standard
9	Q10	4 kN	Yes (20ms)	frontal (13°)	booster w/o backrest	yes	far	standard	standard
10	Q10	4 kN	Yes (20ms)	frontal (13°)	booster w/o backrest	yes	standard	standard	standard

In the tests with the Q10 dummy the effect of different belt geometry on dummy chest measurements were investigated by changing the upper belt anchorage point. Four different locations of the upper anchorage point were defined: “standard”, “far”, “high” and “rear” as indicated in Figure 1. The geometry of the belt, defined different attachment points of the upper anchorage and the location of buckle and lower belt anchorage, were based on average measurements taken from real vehicles confirmed by measurements of a study by Reed et al. (2008). From the standard position of the upper belt anchorage point position “far” is defined by moving the attachment plate 70 mm outboard. For position “high” the D-ring attachment screw was moved 75 mm upwards from the standard position and the “rear” position is defined as 100 mm behind the standard position keeping the same vertical height (see Figure 2)

To investigate the sensitivity of chest deflection measurement in oblique loading condition additional tests were conducted with the Q10 with a 13° pre-rotated bench to simulate the vehicle rotation in the ODB crash configuration. In these tests a backless booster with ISOFix attachment was used. Parameter variations in this test configuration include a modification of upper belt anchorage position. In addition the tests were conducted with and without load limiter and pretensioner. The test parameters are summarized in Table 1.

RESULTS

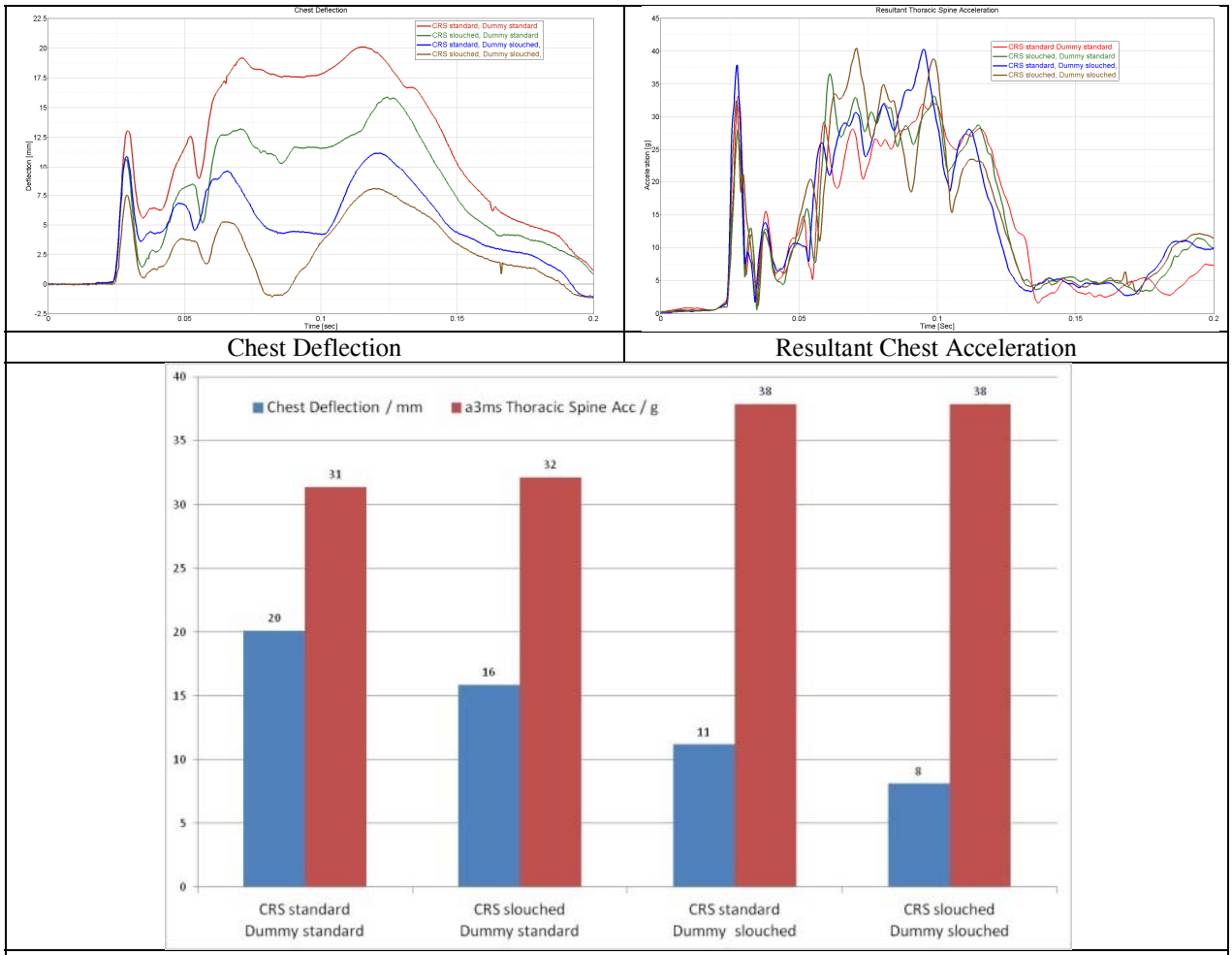
Q6 – position settings

The changes in the positioning settings of the Q6 led to different belt routings during the deceleration which are shown in Figure 3. Compared to the dummy and CRS in standard position the slouched position of the CRS supports an upward movement of the diagonal belt, in both cases the diagonal belt stays close to the IR-Tracc during impact. With the dummy in slouched position the diagonal belt shows a clear tendency to move toward the neck and away from the IR-Tracc. The slippage of the belt was also observed with the dummy and the CRS in slouched position. Here the diagonal belt moved up to the neck and under the arm of the dummy.

01	02	03	04
CRS standard, Dummy standard	CRS slouched, Dummy standard	CRS standard, Dummy slouched	CRS slouched, Dummy slouched

Figure 3. Comparison of kinematics of Q6 relative to shoulder belt during deceleration phase at 60 ms after impact

The chest deflection decreases when the diagonal belt moves away from the sensor towards the neck, especially with dummy and CRS in slouched position the deflection is low (Figure 4). The chest acceleration seems to be less sensitive for the belt position. Peak values for deflection and acceleration over the tests 1-4 showing the different positioning settings of the dummy and/or CRS are shown in (Figure 4). The chest deflection decreased with the distance of the belt from the IR-Tracc. Chest acceleration is only affected by the dummy position with an increase for the dummy in slouched position.



Chest Deflection | Resultant Chest Acceleration

Peak Values Chest Deflection Resultant Chest Acceleration (a3ms)

Figure 4. Q6 – Time History and Peak Values for Chest Deflection and Chest Acceleration

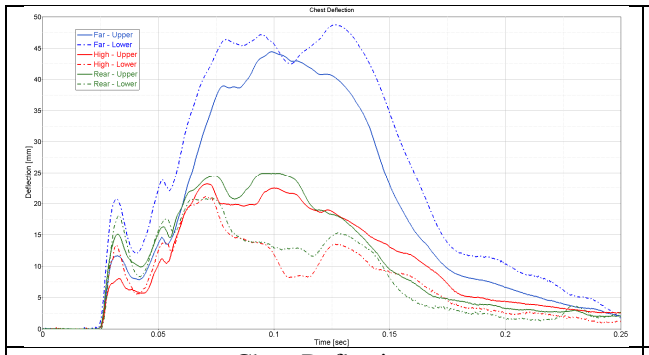
Q10 – belt position variation

For the Q10 in the tests 5-7 the upper belt anchorage was varied to “far”, “high” and “rear”. In the initial position the D-ring position “far” led to a belt routing close to the shoulder joint of the Q10 whereas the belt routings “high” and “rear” resulted in a belt position closer to the neck, especially for the position “high”. During impact (Figure 5), the belt in position “far” stays in the middle of the shoulder and on the chest close to the IR-Traccs. In both other positions the belt slides towards the neck during impact.

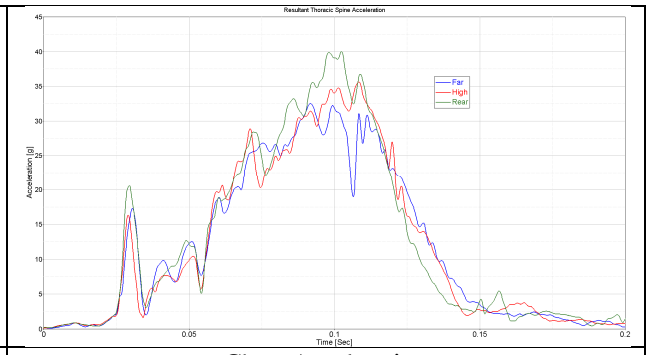
Looking at the chest deflection measured by the upper and the lower IR-Tracc, the deflection in the position “far” is nearly twice as high as in both other positions. For the chest acceleration differences are less, with the highest acceleration for the “rear” position (Figure 6). This tendency can also be seen in the peak values. Were the highest deflections are found for the D-ring position “far”, 44 mm (upper) and 49 mm (lower), the a3ms acceleration is the lowest in this test series (31 g). The peak values for both other belt position are only halve for deflection (23/ 25mm upper deflection; 21/ 21 lower deflection) while the resultant acceleration is slightly increasing (34 g for “high”; 39 g for “rear”).

06	05	07
Belt Position Far	Belt Position High	Belt Position Rear

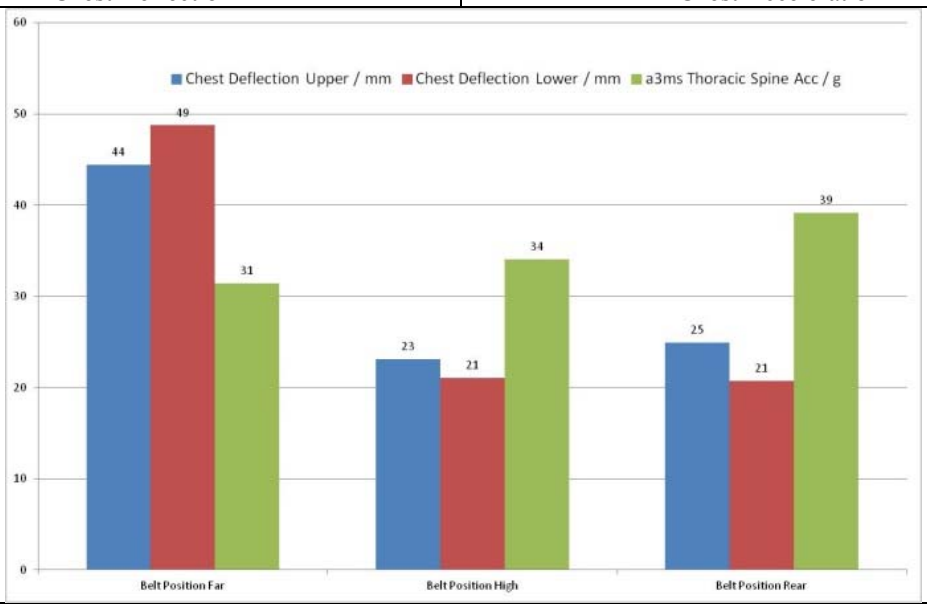
Figure 5. Kinematics of Q10 relative to shoulder belt at 90 ms start of deceleration



Chest Deflection



Chest Acceleration



Peak Values Chest Deflection Resultant Chest Acceleration (a3ms)

Figure 6. Q10 belt position variation – Time History and Peak Values for Chest Deflection and Chest Acceleration

Q10 – tests in 13° rotated bench

The kinematics of the Q10 on the 13° rotated bench at 80 ms after impact are shown in Figure 7. With the D-ring in "far" position the dummy rotates around the diagonal belt and slippage from the shoulder was observed. The belt gets trapped in the shoulder joint between shoulder and arm. Without load limiter and pretensioner the rotation is even more. Here also the lower part of the diagonal belt intrudes below the rib cage.

08	09	10
No Load Limiter, no Pretensioner, Belt Position Far (at 80 ms)	Load Limiter, Pretensioner, Belt Position Far (at 80 ms)	Load Limiter, Pretensioner, Belt Position Standard (at 80 ms)

Figure 7. Kinematics of Q10 relative to shoulder belt at 80 ms after beginning of deceleration

With load limiter and pretensioner and especially in combination with the standard D-ring position the Q10 stayed within the belt system.
For the cases tested with pretensioner and load limiter the load limiter level was reached (see upper plot in Figure 8). Without load limiter and pretensioner very high chest deflections were observed, especially at the lower IR-Tracc. Also the chest acceleration was higher. Load limiter and pretensioner reduced the chest deflection for both sensors and also the chest acceleration. Additional reduction for the chest deflection was achieved by the use of the "standard" D-ring position. These observations are supported by the peak values of chest deflection and resultant chest acceleration a3ms. The deflection at the lower IR-Tracc was more than halved by the use of load limiter, pretensioner and standard D-ring position. The chest acceleration slightly increased using the standard D-ring position compared to the use of pretensioner and load limiter in the far position.

DISCUSSION

Q6 – position settings

The deflection measured in the Q6 by the IR-Tracc is sensitive the position of the dummy within the CRS as well as the CRS position setting itself. The highest deflection is observed for the dummy and CRS in standard position, which would correspond to the position that would be used in regulatory or consumer test procedures. In the other test configurations with the dummy and/or CRS in a slouched position the chest deflection decreases. The lowest deflection is measured in the configuration with both dummy and CRS in a slouched position.
The chest deflection decreases even though a CRS with backrest including belt guidance for the upper shoulder belt is used. Thus the effect of belt migration towards the neck, which was provided as an explanation for reduced chest deflection in other studies without backrest is not the reason in this test series.

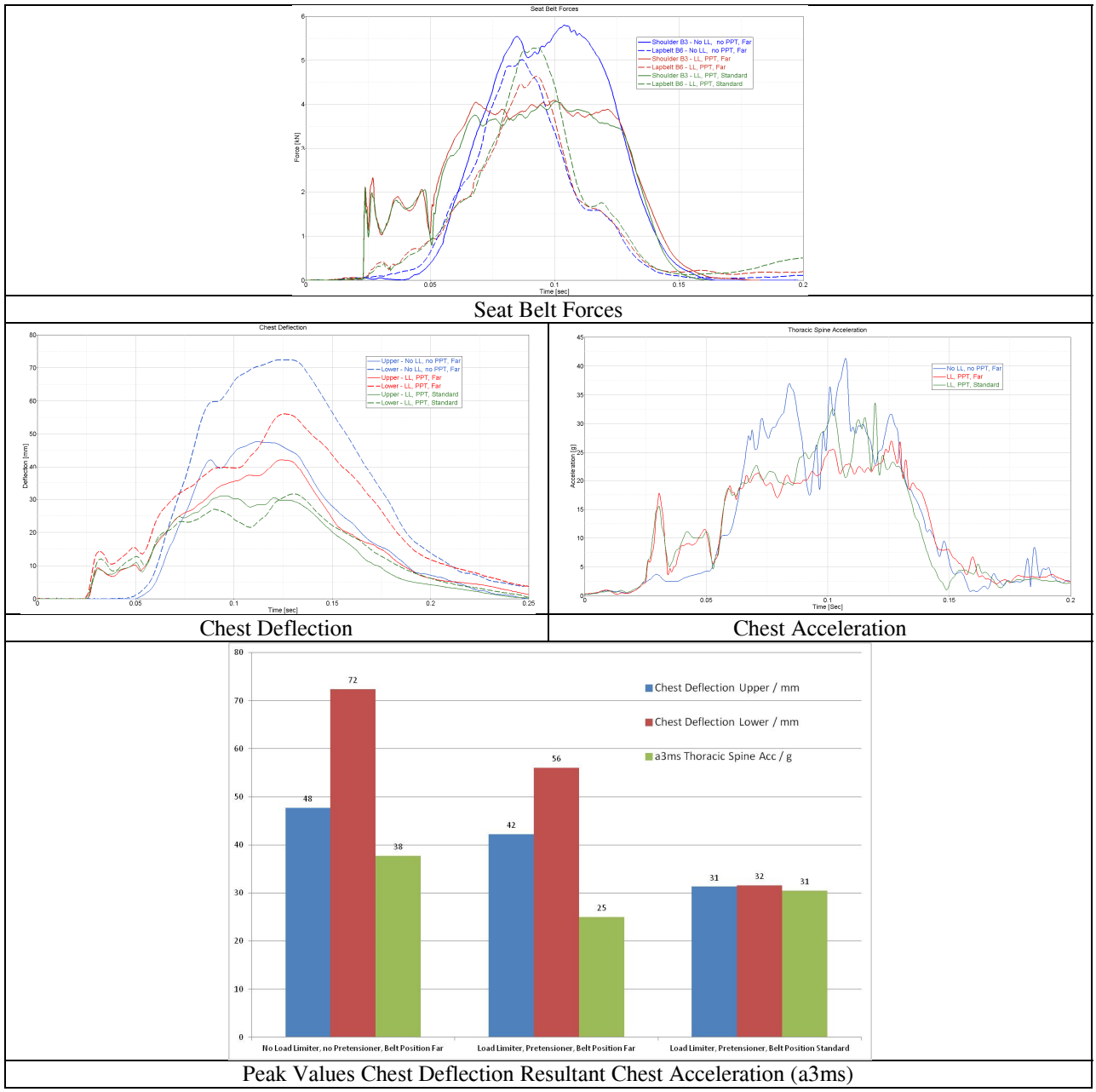


Figure 8. Q10 tests in 13° rotated bench – Time History Seat Belt Forces, Time History and Peak Values for Chest Deflection and Chest Acceleration

The decrease of measured chest deflection can be explained by the belt position relative to the IR-Tracc measurement location, which results from the dummy moving forward under the shoulder belt due to its inclined position. Due to this the belt moves up closer to the neck and does not apply direct load to the center of the chest where the IR-Tracc sensor is located. However, a slouched dummy position resulting in the observed belt kinematics could be realistic regarding the real world position of a real child in a CRS and should be considered for assessment of the CRS in a worst case scenario. On the other hand, the deflection sensor cannot assess the severity of this dummy to belt interaction, which seems to be worse compared to a standard position, correctly. A possible solution could be an additional upper deflection sensor in the Q6, which has already been proposed by other researchers. The a3ms value of chest resultant acceleration does not seem to be sensitive to dummy position in these tests. However, it increases with a more slouched CRS position setting. Based on this an acceleration based criterion seems to be more suitable than chest deflection measured only at the center of the chest.

Q10 – belt position variation

In the Q10 dummy the chest deflection shows a high sensitivity to changes in the position of the upper belt anchorage location. A more outboard location of the belt anchorage (position far) shows the highest chest deflection because the belt path is cloth to the location of the IR-Tracc sensors as shown in the photos during the deceleration event. Similar findings were also reported by (Bohman und Sunnevång 2012).
A higher belt anchorage location or a more rearward both lead to belt migration towards the dummy neck, which was also seen in the study by (Bohman und Sunnevång 2012). Belt migration towards the neck results in two effects. On the one hand part of the belt load will be transferred through the neck unloading the chest, which will lead to a reduction of actual chest compression. On the other hand a belt path close to the neck also leads to an increase of distance between the belt and the IR-Tracc measurement locations, which are in the centerline of the dummy. In this case the IR-Traccs will not measure the actual peak chest deflections and underestimate the maximum chest deflection. Due to this the observed sensitivity of deflection measurements to upper belt anchorage might not be biofidelic. Injury ratings based on chest deflection might underestimate the real injury risk.
Furthermore in studies with pediatric volunteers and child dummies by (Arbogast et al. 2013) an even higher magnitude of belt migration towards the neck was observed in volunteers compared to the Q10 dummy. If these finding would also be applicable to higher crash severities the possible above described underestimation of injury risk by chest deflection in the Q10 dummy might be even higher.
On the other hand a3ms values of peak chest acceleration shows the opposite trend for different upper belt anchorage locations. Chest a3ms is lowest for the “far” and the highest for the “rear” belt anchorage location. Based on this observation an acceleration based criterion might be more applicable to correctly rate the injury risk.

Q10 – tests in 13° rotated bench

In Q10 test with a test bench rotated by 13° without pretensioner and load limiter very high chest deflections were observed whereas the a3ms chest acceleration shows a comparable magnitude like in the 0° tests. The high deflections can be explained by the belt and dummy kinematics during the deceleration events. The shoulder belt completely slides of the shoulder and stays in the gap between arm and shoulder as can be observed in Figure 7. The lower part of the shoulder belt slides up the pelvis. As results the shoulder belt completely loads the thorax without any contact to the pelvis or shoulder structure.
Comparison to another test configurations shows that the dummy kinematics can be effectively controlled by introduction a pretensioner even this severe tests configuration with an oblique loading condition and a far position of the upper belt anchorage location. The belt still moves outboard during the deceleration event. However, the chest deflections are significantly reduced. A reduction of chest deflection by a belt load limiter was also found in a study by (Schnottale et al. 2013) with a Q10 in sled tests in a pre-rotated car body in white.
By an optimization of the location of the upper belt anchorage to an initial belt position in the middle of the shoulder the dummy kinematics can be further improved, which results in a further significant reduction of chest deflections at upper and lower IR-Tracc. The high importance of an optimized position of the upper belt anchorage in combination with a pretensioner and load limiter becomes clear by a comparison with the findings of a study by (Croatto und Masuda 2013). A sled test with the Q10 without backrest and a belt anchorage similar to the “rear” position was done as a base line test without pretensioner and load limiter. The shoulder belt was sliding towards the neck resulting in a low chest deflection. In another test with a pretensioner and load limiter the shoulder belt load was reduced. However, due to the pretensioner belt migration towards the neck was prevented, which resulted in increased chest deflection. Thus it highly depends on the belt geometry and the resulting direction of belt migration, whether a possible positive effect of a pretensioner to keep the belt in place and the positive effect of load limiter to reduce chest loading can be seen in a resulting reduction of chest deflection.
The a3ms value of the thorax acceleration shows a decrease by the introduction of pretensioner and load limiter in combination with the “far” belt location. However, an optimized belt anchorage location leads again to an increase of the a3ms value.
In summary in the tests with the rotated bench an optimization of the belt restraint system by introduction of a pretensioner/load limiter and adjustment of the belt anchorage location led to an improvement of dummy kinematics and dummy belt interaction. A chest deflection based assessment criterion would be able to show the benefit of this optimized restraint system. An assessment criterion only based on chest acceleration would not be able to show the benefit of an optimized restraint system in these test conditions.

CONCLUSIONS

For the Q6 it would be recommendable to implement an additional upper chest deflection sensor. An acceleration based assessment criterion seems to be more suitable than chest deflection measured only at the center of the chest, until further research has been done with this kind of sensor. Finally a chest injury assessment based on chest acceleration as well as chest deflection measured at two location in the chest might be the most reliable approach.
Chest deflection measured in the Q10 dummy is highly influenced by initial belt geometry. Belt migration towards the neck was observed in previous studies and also in this study for certain initial belt geometries and test conditions. This leads to a reduction of measured chest deflection, which does not correctly reflect the severity of chest loading. For initial belt positions far from the neck and restraint parameters as well as test conditions that result in a shoulder belt sliding outboard or staying in place on the shoulder the measured deflection might be correctly representing the severity of chest loading by the belt. Thus, only a deflection based criterion would not be able to correctly indicate the severity of thoracic loading under certain conditions and due to this has limitations.
A3ms chest acceleration seems to be a better indicator of severity of chest loading for different belt geometries. However, in the tests with the rotated bench an acceleration based criterion would not be able to show the benefit of a restraint system optimized with pretensioner, load limiter and adjusted D-ring position. Thus, a chest assessment only based on acceleration is also not recommendable.
Further research on a meaningful use of a deflection based criterion is recommended. A possible solution could be a criterion taking into account both deflection as well as acceleration and/or assessment of interaction between dummy and belt system during the deceleration.

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