Q10 EURO NCAP 2020 UPDATE DUMMIES COMPARED TO CURRENT Q10 IN FRONTAL AND SIDE IMPACT SLED TESTS

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ABSTRACT

There is a need of improving the current Q10 (Q10original) due to unstable seatbelt interaction with the shoulder. Several design changes to shoulders and torso have resulted in a prototype Q10 (Q10update). Some design changes were removed which resulted in a second prototype Q10 (Q10light). The aim was to compare kinematics, shoulder belt interaction and dummy responses of the Q10update and Q10light with the current Q10original in frontal impacts. Q10original and Q10update were also compared and evaluated in side impacts.

Q10original, Q10update and Q10light were compared in frontal sled tests in a midsize SUV, for two different crash pulses. Three different belt geometries were evaluated. Dummy kinematics and loadings were analysed. The dummies were positioned on booster cushions and restrained by seatbelt with pretensioner and load limiter.

Q10original and Q10update were included in eleven side impact sled tests simulating a Euro NCAP 2020 Side AE-MDB impact, using a midsize passenger car. The dummies were positioned on booster cushions and restrained by seatbelt and combinations of thorax side airbag (SAB) and inflatable curtain (IC), in addition to a reference test without SAB and IC. All tests included a retractor with pretensioner and load limiter. Two arm positions were evaluated in one restraint configuration.

In the frontal sled tests, the Q10update was less sensitive to initial shoulder belt position far out on the shoulder than the Q10original. The shoulder belt had a tendency to move inboard on the Q10update during the crash, even if the shoulder belt was initially positioned far out on the shoulder, possibly influenced by the soft tissue at upper chest and forward shift of the shoulder joint compared to Q10original. The Q10light had a similar shoulder belt interaction as the Q10original. Both update dummies showed a greater forward excursion of the head and a larger tilt of the upper torso than the Q10original, potentially due to the mass redistribution from pelvis to upper body. The increased excursion is considered an improvement, since the mass redistribution is more biofidelic compared to Q10orginal. Both update dummies had higher chest deflection, lower chest acceleration and lower neck tension compared to the Q10original.

The differences in dummy responses in the side impact sled tests were mainly due to mass redistribution. Especially in tests without SAB, lower chest acceleration, but higher chest deflection was obtained for the Q10update compared to Q10original. Furthermore, the shoulder force was higher for Q10update compared to Q10original for the three restraint combinations, while in the reference test head impact to the vehicle interior occurred. Angled arm position resulted in both reduced shoulder force and reduced chest deflection, compared to aligned arm position.

Due to its improved kinematics and sensitivity to changes in seatbelt geometry, the Q10light was preferred of the three tested dummies for frontal impact testing. Q10light was not evaluated for side impact loading. For side impact testing, this study provides no firm recommendation on the Q10update, acknowledging that a biofidelity evaluation needs to be made. Further dummy refinements and lateral validation and certification tests are encouraged.

BACKGROUND

Children younger than age 13 accounted for a significant proportion of the serious injuries (35.7%) and deaths (42.9%) to restrained rear row occupants, highlighting the challenges vehicle and restraint system manufacturers have in providing optimal protection to a wide range of rear occupants according to Durbin et al. (2015). Hence, there is a need of adequate tools, from children to adults, to develop the rear seat occupant protection.

During the 90s, the development of the Q dummies was initiated in to replace the P dummies (EEVC, Wismans et al. 2008). The Q10 crash test dummy was developed in the European project EPOCh (Enabling Protection for Older Children). In 2015, Euro NCAP revised the protocol for rear seat evaluation, by replacing the Q1.5 and Q3 dummies with the Q6 and the Q10, in both frontal Offset Deformable Barrier (ODB) and side impact test. The Q10 was positioned behind the passenger in the ODB, resulting in an inboard movement during the crash. In the side impact test, the Q10 was positioned behind the driver, meaning the near side.

The Q10 has been criticized for an unstable shoulder belt interaction in frontal impacts, but also of a pronounced shoulder belt slippage towards the neck. Bohman and Sunnevang (2011) showed that the chest deflection of the Q10 was more sensitive to belt geometry than to any other countermeasure. Arbogast et al (2013) compared shoulder belt interaction of child volunteers with the HIII10 year-old crash test dummy and Q10 in low speed sled tests. They found that the shoulder belt moved to greater extent towards the neck on the Q10 compared with the child volunteers, resulting in an underestimate of chest deflection in the Q10.

In order to improve the Q10 behaviour in frontal impacts, Humanetics updated the dummy to a second version, referred to as Q10update in this paper. Five changes were implemented including shoulder joint movement of 20mm forward, head and neck shifted 20mm forward and 5.3° nose up, soft tissues representation at nipples, continuous shoulder liner and mass redistribution change, by moving 1.7 kg from the pelvis to the torso (Waagmeester et al. 2017). In a CAE comparison of Q10originial, Q10update and Thums v4 10 year-old Human Body Model (HBM), it was found that the Q10update was not sensitive to an outboard shoulder belt geometry; the shoulder belt stayed on the shoulder while the other two dummies showed shoulder belt slipping off (Schnottale et al. 2017). In order to make the Q10update a bit more sensitive to various shoulder belt geometries, only three of the changes from the Humanetics Q10 was included in a third version of Q10, referred to in this study as Q10light. This version included the following design changes; the head and neck shift 20mm forward and 5.3° nose up, continuous shoulder liner and mass redistribution change, by moving 1.4 kg from the pelvis to the torso. This Q10light update kit was supplied by Cellbond. Recently, Euro NCAP has decided to include the Q10light in the rating program in 2020. Ipek (2018) compared the Q10light with Q10originial and concluded that Q10light had a more realistic shoulder geometry and a more realistic head position. The shoulder liner included in the Q10light also provide a clear understanding of shoulder belt slippage, since the belt can no longer get stuck in the gap between the shoulder and the arm.

In the current Euro NCAP protocol, the Q10 is positioned with the arms along the side of the torso. However, since children can choose a wide range of sitting postures, for example playing on their electronic devices with forward angled upper arms, it is of interest to understand if the arm position has any effect on the dummy responses in a side impact crash.

The aim of this study is firstly, in frontal impacts, to compare kinematics, shoulder belt interaction and dummy responses of the Q10update and Q10light with the current Q10original in different belt geometries. Secondly, in side impact, the study aims to compare the dummy responses of the Q10update with the Q10original for varying side airbag configuration and also highlighting the responses of the Q10 update for alternative arm position and booster cushion.

METHOD

This study includes both frontal and side impact sled testing. Three versions of the Q10 child crash test dummy are compared: Humanetics Q10original, Humanetics Q10update with full update kit including five updates and Humanetics Q10 with update kit light from Cellbond, Q10light, including three updates. The details on the update is shown in Table 1.

In the frontal impact tests, all three versions of the Q10 dummy were tested. In the side impact tests, the Q10original and Q10update were tested, while instrumented with the original side impact kit (EEVC WG, Wismans et al. 2015). When a Q10 dummy is rebuilt with a side impact kit, the scapula and arms are changed from front to side impact versions, and the sensors are moved to enable measurement of lateral chest deflection. The kit also includes shoulder force sensor. Hip shields were used in all frontal tests and for the Q10original in side impact tests while the hip liner was used for the Q10update in side impact tests.

Table 1. Q10 versions and details on included updates.

Dummy	Supplier dummy	Supplier update kit	Shoulder joint shift	Head and neck shift	Soft tissue at upper chest	Cont. shoulder liner	Mass re-distribution
Q10 original	Humanetics	N/A	N/A	N/A	N/A	N/A	N/A
Q10 update	Humanetics	Humanetics	X	X	X	X	X
Q10 light	Humanetics	Cellbond		X		X	X

Frontal Impacts

A series of frontal sled tests were performed in a reinforced sled body of a midsize SUV mounted using an acceleration sled, at Volvo Cars Safety Centre, Sweden. Two different crash test pulses were simulated (Figure 1) replicating; a typical 35mph full frontal crash and a typical 64km/h Euro NCAP ODB (offset deformable barrier) crash, with the sled body rotated 18 degrees.

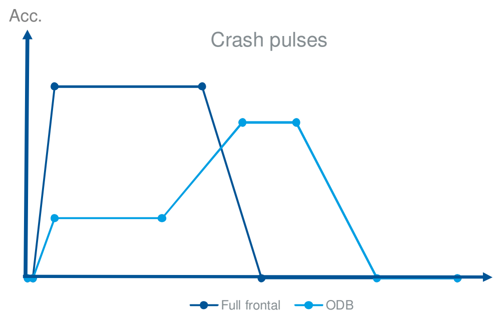


Figure 1. Frontal impact crash test pulses used in the study; a full frontal pulse and an ODB pulse.

The crash test dummies were restrained with a three point seatbelt with pretensioner and load limiter, and seated on a Volvo Booster Cushion (BC) without backrest. In all tests except two, the booster cushion was positioned centralised in the seat and the dummy was centred on the booster cushion. The spacer behind lumbar spine were used when positioning the dummy according to Euro NCAP's current testing protocol (2019). Load cells were placed on the diagonal belt above the dummy shoulder level and on the outer part of the lap belt. Three different belt geometries were tested, as illustrated in Figure 2. The left and mid belt geometries were achieved by routing the diagonal belt above and under the inner guiding loop of the BC, resulting in belt geometries closer to the neck and further out on the shoulder, respectively. These two geometries were tested in both full frontal and ODB. The third belt geometry, shown to the right in Figure 2, resembling a belt position far out on the shoulder, was achieved by routing the diagonal belt under the inner guiding loop of the BC and move the dummy and BC 15mm inboard. This geometry was tested in one full frontal test and in one ODB.

Diagonal belt above inboard guiding loop of booster cushion | Diagonal belt under inboard guiding loop of booster cushion | Diagonal belt under inboard guiding loop, and dummy/booster cushion moved 15mm inboard

***Figure 2. The three seatbelt geometries included in test setup*.**

In the full frontal sled tests, the Q10original and Q10update were tested simultaneously, Q10original seated on the left hand side (LHS) of the rear seat and Q10update seated on the right hand side (RHS). In the ODB tests, the Q10original, Q10update and Q10light were tested in separate tests, all on the RHS, resulting in an inboard motion of the dummy relative to the sled body during the test. The test matrix is presented in Table 2. As can be seen, all three dummy versions were run in two comparable configurations with the ODB pulse, while the Q10original and the Q10update, only, were run in the three comparable configurations with the full frontal pulse and one configuration with the ODB pulse.

***Table 2. Test matrix with overview of pulse, dummy and belt geometries*.**

Test number	Pulse	LHS	RHS	Belt geometry
1	full frontal	Q10 original	Q10 update	Diagonal belt above guiding loop
2	full frontal	Q10 original	Q10 update	Diagonal belt above guiding loop
3	full frontal	Q10 original	Q10 update	Diagonal belt under guiding loop
4	full frontal	Q10 original	Q10 update	Diag. belt under guiding loop, BC moved 15mm inboard
5	ODB		Q10 original	Diagonal belt above guiding loop
6	ODB		Q10 original	Diagonal belt above guiding loop
7	ODB		Q10 update	Diagonal belt above guiding loop
8	ODB		Q10 light	Diagonal belt above guiding loop
9	ODB		Q10 original	Diagonal belt under guiding loop
10	ODB		Q10 original	Diagonal belt under guiding loop
11	ODB		Q10 update	Diagonal belt under guiding loop
12	ODB		Q10 update	Diagonal belt under guiding loop
13	ODB		Q10 light	Diagonal belt under guiding loop
14	ODB		Q10 update	Diag. belt under guiding loop, BC moved 15mm inboard

High speed cameras captured a front view, LHS and RHS views and a top view of the dummy. Dummy kinematics responses and seatbelt-to-body interactions during the forward motion of the dummy were analysed and compared. Head accelerations (CFC1000), neck forces (CFC1000), chest accelerations (CFC600), chest deflections (CFC600) and diagonal belt (CFC60) and lap belt forces (CFC60) were captured and used in the analysis. The position of the shoulder belt during the event was categorised as on the shoulder, moved outboard on the shoulder from initial position during the event, and off the shoulder. For the Q10original in which the continuous shoulder liner is not included, shoulder belt slip-off was defined as shoulder belt in the gap between the torso and the arm.

Side Impacts

A series of side impact simulations was performed in a deceleration sled system at Autoliv Research, Sweden. A generic pulse replication of the Euro NCAP 2020 side Advanced European Mobile Deformable Barrier (AE-MDB) test for a midsize passenger vehicle was used, as shown in Figure 3. The 2020 side AE-MDB test method includes a barrier weight of 1400kg and barrier speed of 60km/h. The sled system comprises three sleds; one vehicle sled carrying the rear seat, a rigid-door-side sled where the interior (pre-tilted door and trim panel) are mounted and a load carrier sled. The vehicle and door sleds are accelerated by the load carrier sled to mimic a door sled intrusion velocity (peak approximately at 10m/s) and a vehicle sled response velocity. A feed-back system provides a realistic drop of the door sled intrusion velocity to meet the vehicle sled velocity at an almost unified velocity level (approximately 8m/s) before final braking. The initial position of the door interior in relation to the child dummy was replicated from an estimated average door intrusion. This was obtained from several tested midsized cars, based on accelerometer signals at different heights using a pre-tilted door (approximately 10 degrees, lower inboards) at a mid-point door position. The door panel is cut just above the seat bench, in order not to deform the seat bench. The side structure rear of the door panel on the door sled is simulated by a foam block to support the side airbag when deployed and preventing the arm to slide off the door panel.

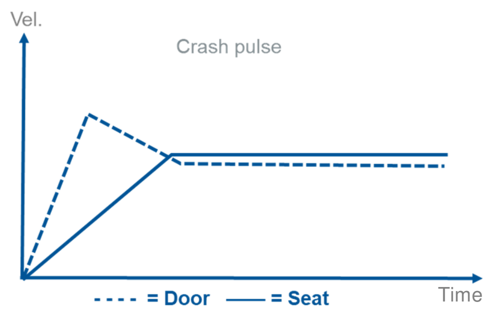


Figure 3. Door and seat velocities during side impact.

Six different test setups were used, see Table 3, combining inflatable curtain (IC) and thorax side airbag (SAB), in addition to arm position and a comparison between two types of boosters. The five first test setups were conducted for both the Q10original and Q10update enabling comparison between the two dummy models. Test setup 6 (IC/SAB/IBC) was conducted for the Q10update only, hence enabling evaluation of the capabilities of the Q10update to differentiate between two different types of boosters, when comparing to Q10update in test setup 4 (IC/SAB/BC). In addition, test setup 5 (IC/SAB/45) enabled evaluation of influence of arm position, when comparing to test setup 4 (IC/SAB), for both dummies.

In test setups 1-5, the child dummy was positioned on the BC without backrest (as in the frontal test series), while a Volvo integrated booster cushion (IBC) was used in test setup 6. The booster cushions and some of the test setups are shown in Figure 4. In each test, the child dummy was restrained with a three-point seatbelt including both a retractor load limiter function and a retractor pretensioner. The pretensioner was activated at 7ms after the pulse started. The diagonal belt was routed, as recommended by the manufacturer, above the inboard guiding loop of the booster cushion (as shown in Figure 4). A combination of SAB and IC was used, as shown in Table 3. The IC was inflated with pressurized air to a representative static pressure (appr.40kPa), while the SAB was dynamical inflated with a standard inflator. None of the restraint components were tuned prior to the tests for this load case. In test setup 5 (IC/SAB/45) the arm was angled 45 degrees forward, as an alternative to the standard arm position, which is aligned with the body, see Figure 4.

*Table 3. Side impact test matrix for both dummies, Q10original and Q10update, except for IC/SAB/IBC, *)Q10 update only.*

No.	Test Setup	Seatbelt	Inflatable Curtain	Side Airbag	Arm +45°	Booster Cushion
1	Reference	Yes	No	No	No	Yes
2	IC	Yes	Yes	No	No	Yes
3	SAB	Yes	No	Yes	No	Yes
4	IC/SAB	Yes	Yes	Yes	No	Yes
5	IC/SAB/45	Yes	Yes	Yes	Yes	Yes
6	IC/SAB/IBC*	Yes	Yes	Yes	No	No

Figure 4. Side impact test set-up, Reference test (Q10original left), IC/SAB/45 test (Q10original mid) and IC/SAB/IBC (Q10update right).

High speed cameras captured front, side, top and oblique views. The following measurements were captured and analysed in the tests: x, y, z acceleration of the head (CFC1000, 3ms clip), chest (CFC180, 3ms clip) and pelvis (CFC600, 3ms clip), upper neck forces (CFC1000), upper and lower chest deflection (CFC600), left shoulder forces (CFC600), pubic force (CFC600), accelerations (CFC60) of door and seat sled.

RESULTS

Frontal Impacts

In total 14 sled tests were performed; four full frontal impacts and 10 ODB impacts. The Q10original and Q10update, only, were compared in the full frontal tests, while all the three dummy versions were compared in the ODB tests. Two pair of repetitions of tests were run for each of the Q10original and Q10update; tests 1 and 2; 5 and 6; 9 and 10; 11 and 12 (see Table 2). The responses showed repeatable dummy behaviour. In repeated tests, the difference in response varied in a range from 1% to 10%, with an average difference in responses of 4%.

Dummy responses: Overall, the dummy responses were affected by the dummies' kinematics and their seatbelt-to-body interaction. The dynamic interaction with the seatbelt was greatly influenced by the initial seatbelt geometry and by the dummy designs. When the seatbelt was initially positioned close to the neck by routing the diagonal belt above the inboard guiding loop, a more similar seatbelt-to-body interaction between the dummy designs were seen. However, when the seatbelt was routed under the inboard guiding loop resulting in an initial position further out on the shoulder, belt slip-off occurred more frequently in the Q10original and Q10light compared to the Q10update (Table 4).

Figure 5 provides a summary of the head, neck, chest and seat belt responses in all the frontal tests. In the full frontal (FF) tests, the Q10original showed decreased head acceleration, neck tension, chest acceleration and lap belt force as the initial seatbelt position was moved outboard on the dummy's shoulder. The chest deflection increased, while the diagonal belt force remained the same. The Q10update showed a small increase in the head and chest accelerations and the chest deflection as the initial seatbelt position on shoulder was moved outboard, while the neck tension and lap belt force decreased and the diagonal belt force remained the same (Figure 5). When the initial seatbelt geometry was close to the neck, higher upper neck tension and chest acceleration were seen in the Q10original compared to the Q10update, while the Q10update showed higher upper chest deflection. When the initial seatbelt geometry was further out on the shoulder, the neck tensions and upper chest deflections were similar to both dummies, while Q10update had higher chest acceleration compared to Q10original. In the full frontal tests, the lap belt forces were always higher in the Q10original, while the diagonal belt forces were similar between the dummies. When comparing the full frontal tests with the ODB tests, higher pulse peak accelerations were obtained in the full frontal tests, which likely correspond to the relatively higher crash severity of the full frontal test. In general, this resulted in increased dummy neck tension, and head and chest accelerations in the full frontal tests, regardless of dummy.

In the ODB tests a wider spread in dummy-to-seatbelt-interaction between the three Q10 versions was seen. This influenced the dummies' responses to a greater extent, as compared to full front tests (Figure 5). With the seatbelt initially positioned close to the neck similar seatbelt-to-body interactions were seen between the dummy designs. When comparing the results, the Q10original showed higher neck tension and lap belt force as compared to the update dummies, while the chest deflection was lower.

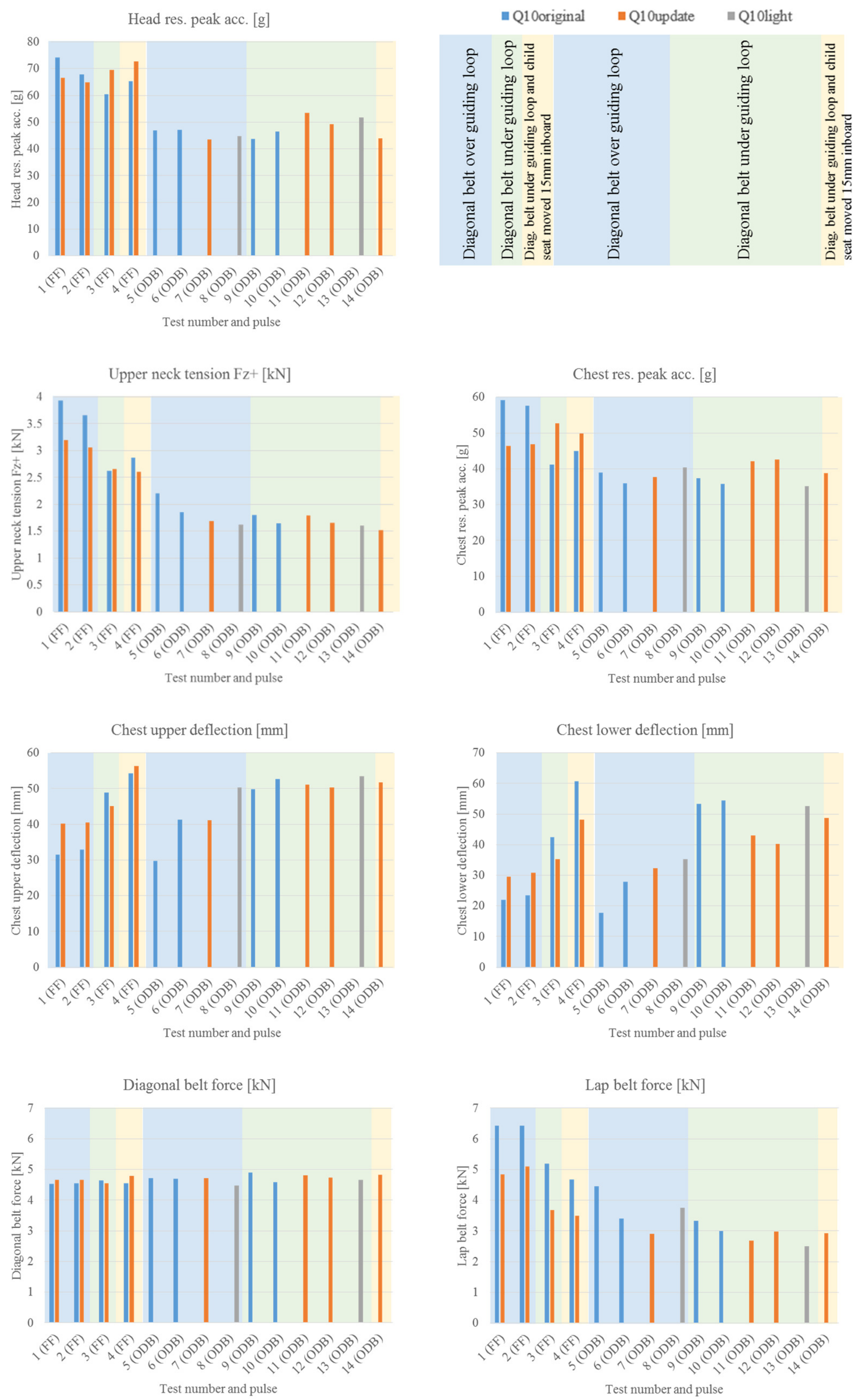


Figure 5. Head, neck, chest and seat belt maximum responses for the three dummies. The shoulder belt geometries are shown by the background colour of the graph, see figure at the top right for colour coding.

Kinematics: The initial position of the dummies differed due to the changes made to the Q10update and Q10light compared with the Q10original. The initial head positions of the Q10update and the Q10light were more perpendicular to the horizontal plane, compared to the Q10original, where the head had a greater forward rotation.

In the full frontal tests, the Q10update showed greater head excursion and upper body tilt, as well as more pronounced shoulder excursion as compared to the Q10original, regardless of initial seatbelt geometry. The pelvis excursion of the Q10update showed less forward excursion as compared to the Q10original, see Figure 6.

In the ODB tests with the diagonal belt guided above the inboard guiding loop of the booster cushion, the seatbelt remained on the shoulder for all three dummy versions. The Q10update and Q10light had more head excursion and upper body tilt compared to the Q10original. The Q10update was the one with the most forward excursion of the head, followed by the Q10light and the Q10original, see Figure 7.

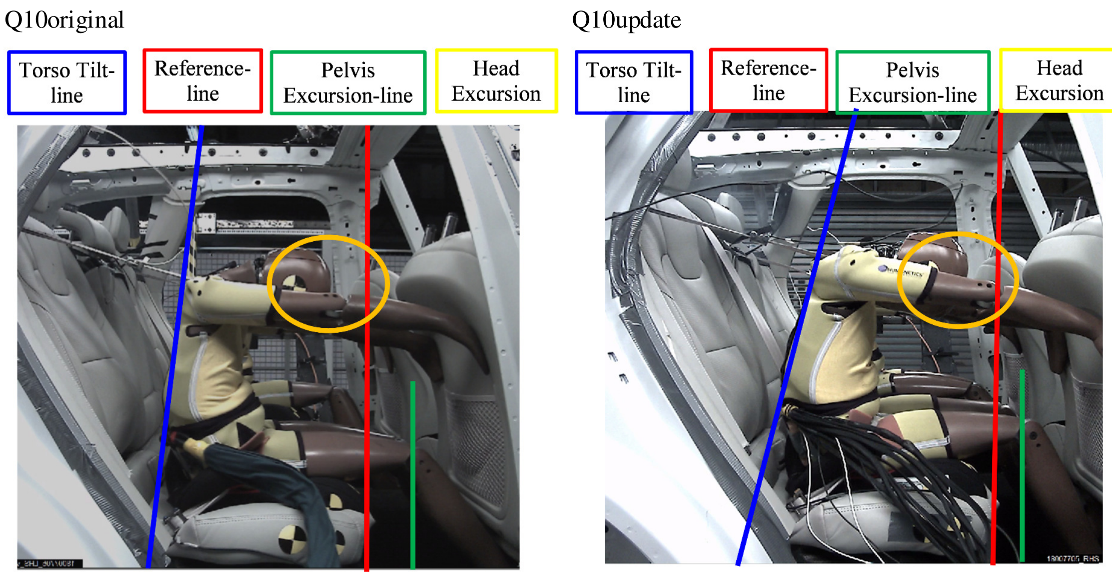


Figure 6. The kinematics of the Q10original and the Q10update in full frontal test at the time of max head excursion.

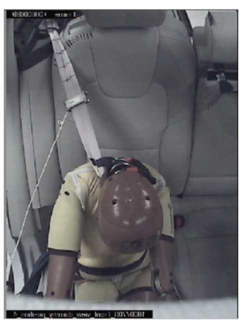
Figure 7. The kinematics of the Q10original (left), the Q10update (mid) and the Q10light (right) in the ODB test at time of maximum head excursion (vertical line).

Seatbelt-to-body interaction:

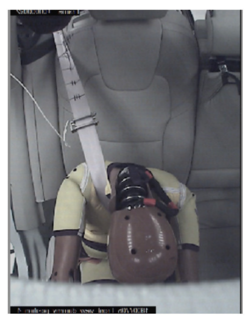
An overall summary of the diagonal belt position relative to the shoulder, for each dummy and test condition, is shown in Table 4. In the full frontal test with diagonal belt under the guiding loop and BC moved 15 mm inboards, the diagonal belt slipped off the shoulder for the Q10original, while for the Q10update the diagonal belt moved further out on the shoulder but it did not slip off (see Table 4 and Figure 8).

Table 4. The diagonal belt position relative the shoulder at maximum head excursion of the dummy in the various seat belt geometries for the three dummies.

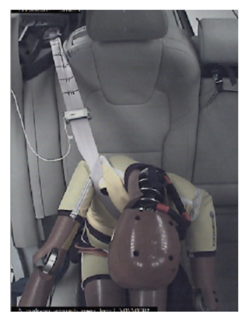
	Full front			**ODB**		
Dummy	**Diagonal belt above guiding loop**	**Diagonal belt under guiding loop**	**Diag. belt under guiding loop BC moved inboard**	**Diagonal belt above guiding loop**	**Diagonal belt under guiding loop**	**Diag. belt under guiding loop BC moved inboard**
Q10 original	on shoulder	outboard motion	off shoulder	on shoulder	off shoulder	
Q10 update	on shoulder	on shoulder	outboard motion	on shoulder	outboard motion	off shoulder
Q10 light				on shoulder	off shoulder	



Q10original: Diagonal belt above inboard guiding loop

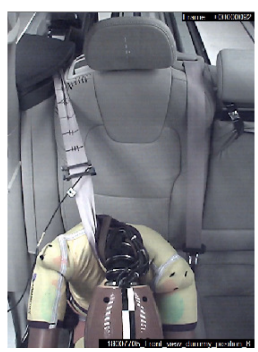


Q10original: Diagonal belt under inboard guiding loop



Q10original: Diagonal belt under inboard guiding loop, BC moved 15mm inboard

Q10update: Diagonal belt above inboard guiding loop



Q10update: Diagonal belt under inboard guiding loop

Q10update: Diagonal belt under inboard guiding loop, BC moved 15mm inboard

Figure 8. Full frontal tests, comparing Q10original (top) and Q10update (bottom), at time of maximum head excursion.

Figure 9 shows the maximum forward head excursion in the ODB tests, comparing the three dummy versions and the three different belt geometries. For all the three dummies, the diagonal belt stayed on the shoulder when the diagonal belt was routed above the guiding loop. This also corresponded to when the starting position was closer to the neck. In the tests with the diagonal belt routed under the guiding loop, the diagonal belt slipped of the shoulder for both the Q10original and the Q10light, while it stayed on the shoulder for the Q10update. In the single test with the BC moved 15mm inboards (and shoulder belt under the loop), the diagonal belt slipped off the shoulder on the Q10update as well (see Figure 9).

For the Q10original, the diagonal belt got stuck in the gap between the arm and the shoulder, as the belt slips of the shoulder. The shoulder liner in the Q10update and Q10light prevents this, as can be seen in Figures 7 and 8.

Q10original: Diagonal belt above inboard guiding loop

Q10original: Diagonal belt under inboard guiding loop

N/A

Q10update: Diagonal belt above inboard guiding loop

Q10update: Diagonal belt under inboard guiding loop

Q10update: Diagonal belt under inboard guiding loop, BC moved 15mm inboard

Q10light: Diagonal belt above inboard guiding loop

Q10light: Diagonal belt under inboard guiding loop

N/A

Figure 9. ODB tests, comparing Q10original (top), Q10update (mid) and Q10light (bottom) at time of maximum head excursion.

Side Impacts

In total 11 tests were performed. The two dummy versions were compared for four different combinations of side impact protection systems (including a reference test) and when varying the arm position in the combination of SAB and IC. In addition, a comparison was made between the BC and the integrated booster cushion (IBC) together with SAB and IC using the Q10update only.

Different side impact protection systems: Figure 10 displays a comparison of the maximum responses of head acceleration, neck resultant force, shoulder resultant force, chest and pelvis accelerations for the Q10original and the Q10updated in all the tests, as listed in Table 3.

Figure 10. Head, neck, chest, shoulder and pelvis maximum responses for the Q10original and Q10update in the side impact tests.

In the reference test, a head-to-door contact occurred at 50ms for the Q10update but not for the Q10original (see Figure 11). In the test with the IC only, no head-to-door contact occurred for any of the two dummies. For the Q10update, lower head acceleration and upper neck force were obtained, while the chest acceleration increased, as compared to the reference test (Figure 10). In the test with SAB only, no clear head-to-door contact was observed. Compared to the reference tests, both dummies measured lower chest acceleration, pelvis acceleration and pubic force, while the head acceleration increased slightly if not considering the head-to-door contact reference test case (Figure 10).

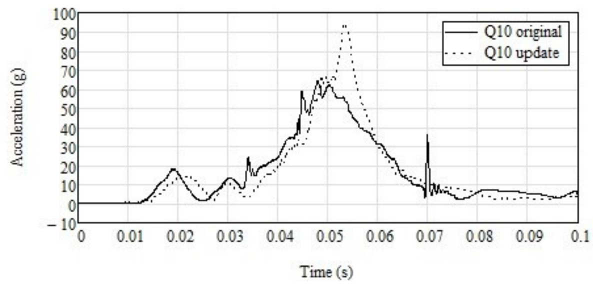


Figure 11. Head accelerations Q10original (solid) and Q10update (dotted) in reference tests.

Compared to the reference tests, both the dummies measured a relative decrease of all responses, except the upper chest deflection, for the combination of IC and SAB, se Figure 10. A comparison of head, chest and pelvis responses for the Q10update and the Q10original, in the test with the combination of IC and SAB and the reference test is shown in Table 5. The relative difference of the Q10 update compared to the Q10original is higher head accelerations (9-26%) and pelvis accelerations (35-46%), while lower chest accelerations (7-22%), for the reference and the IC/SAB setups. Higher chest deflections were seen in the Q10update (5-21%) in both the test configurations.

Table 6 presents the results from the tests with the IC and SAB and arm angled 45 degrees forward. The difference between the Q10update and the Q10original results are similar to the IC/SAB situation with the arm in in-line with the torso; however more pronounced in the chest area, and only a marginal difference between the dummies in head acceleration (Table 5). The difference in chest deflections were more within the same range as the dummy comparisons in the reference test.

Table 5. Comparison between Q10update and Q10original in the reference and IC/SAB tests.

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.
Reference test					
Q10original	58.4	69.1	70.2	20.2	28.2
Q10update	73,1*	54.1	102.3	24.5	31.5
Update vs. Original	[26%]	-22%	46%	21%	12%
IC/SAB test					
Q10original	54.3	40.1	45	21	26.8
Q10update	59.1	37.3	60.8	22.1	28.5
Update vs. Original	9%	-7%	35%	5%	6%

*) Head-to-door contact

Table 6. Comparison between Q10update and Q10original in IC/SAB/45 tests.

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.
IC/SAB/45 test					
Q10original	53.1	41.3	45.1	16.4	20.6
Q10update	52.3	38.8	58.5	20.2	22.8
Update vs. Original	-2%	-6%	30%	23%	11%

Different arm positions: Tables 7a and 7b summarize a comparison of the different arm positions (IC/SAB/45 versus IC/SAB) for the same dummy (Q10update and Q10original respectively). It can be seen that the 45 degrees angled arm position mainly resulted in a decrease in shoulder resultant force and chest deflection and to some extent head acceleration, while chest and pelvis accelerations were less influenced. The IC/SAB/45 lower chest deflection showed the lowest chest deflection of all performed tests.

Table 7a. Comparison between IC/SAB/45 and IC/SAB tests for the Q10update.

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.	Shoulder res. force
Q10update						
IC/SAB	59.1	37.3	60.8	22.1	28.5	1453
IC/SAB/45	52.3	38.8	58.5	20.2	22.8	793
+45° vs. Std. Pos.	-12%	4%	-4%	-9%	-20%	-45%

Table 7b. Comparison between IC/SAB/45 and IC/SAB tests for the Q10original.

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.	Shoulder res. force
Q10original						
IC/SAB	54.3	40.1	45	21	26.8	1142
IC/SAB/45	53.1	41.3	45.1	16.4	20.6	846
+45° vs. Std. Pos.	-2%	3%	0%	-22%	-23%	-26%

The influence on shoulder resultant force for the Q10update, was also seen for the Q10original. Figure 12 displays shoulder resultant force plots for the two dummies in the two different arm positions. Although some differences in amplitude, the two dummies follows the same load pattern for each of the test setups. In the test with the raised arm (IC/SAB/45), the "twin peak" characteristics is seen for both dummies.

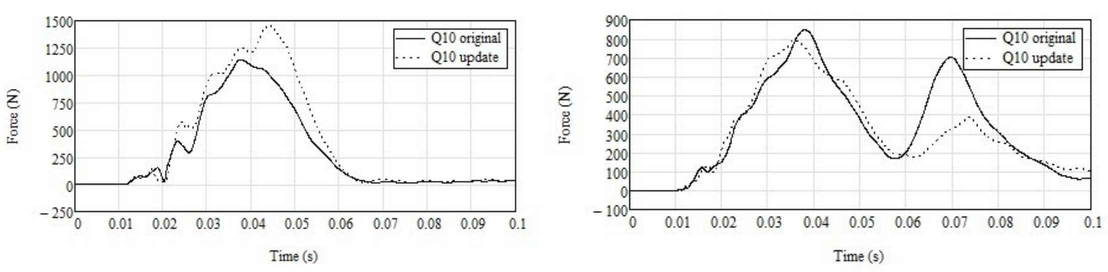


Figure 12. Shoulder resultant force Q10original (solid) and Q10update (dotted) in IC/SAB (left) and IC/SAB/45 (right) tests.

Different booster cushions: Table 8 summarizes the responses from the Q10update tests with the two booster types in a test setup including both SAB and IC. For these tests, there is no comparison to the Q10original. All responses were lower when using the IBC as compared to the BC. This was most pronounced for the pelvis acceleration and shoulder resultant force. A plot of the pelvis acceleration is displayed in Figure 13, showing a flattening out for the IBC at 30ms, while the BC continues to increase. This is due to differences in contact time and the difference in stiffness between the direct contact of the belt guiding loop and the side airbag that results in a difference of pelvis displacements.

Table 8. Comparison between IC/SAB/IBC and IC/SAB tests for the Q10update.

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.	Shoulder res. force
Q10update						
IC/SAB	59.1	37.3	60.8	22.1	28.5	1453
IC/SAB/IBC	54	37	41.6	19.4	25.3	1172
IBC vs. BC	-9%	-1%	-32%	-12%	-11%	-19%

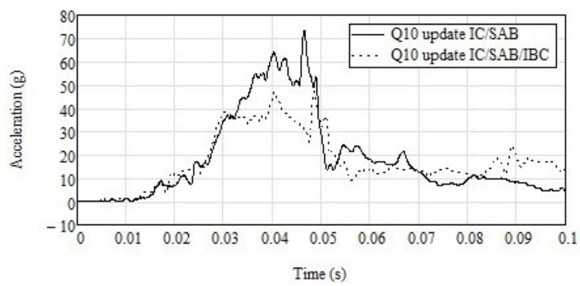


Figure 13. Pelvis accelerations IC/SAB (solid) and IC/SAB/IBC (dotted) using the Q10update.

DISCUSSION

The Q10 dummy was introduced in consumer rating procedures and regulatory tests at Euro NCAP, UNECE 129 and ETC (ADAC) and is used in both frontal and side impact tests. An update of the Q10 was initiated for the introduction of Euro NCAP 2020. The experience gained so far has initiated a request for an update, primarily in frontal but also in side impact load cases. Regarding the Q10 performance at side impact the priority has been lowered in favour for the frontal impact performance. This study provides feedback on the comparison of the updated version in a variety of test configurations in frontal and side impacts. The study does not include any comparisons performance according to biofidelity corridors.

Frontal impacts

Overall, both update-dummies showed a difference in kinematics compared with the Q10original dummy. Especially the Q10update showed difference in dummy responses compared to the Q10orginal.

The Q10update showed more head excursion and torso tilt compared to the Q10original in full frontal tests regardless of initial shoulder belt position, even though the Q10original had the diagonal belt further out on the shoulder during the event allowing a more forward motion. The increased mass of the upper body contributed to this change in kinematics. Furthermore, the shoulder joint shifted 20mm forward allowing more forward motion of arms that are clearly stretched forward, which also contribute to the forward motion of thorax. Schnottale et al. (2017) showed that the Q10update dummy’s kinematics included an increased upper torso tilt, which was more like the kinematic pattern of the Thums v4 10 year-old HBM than to the Q10original.

In the ODB tests performed in this study, the Q10light and Q10update showed more head excursion and torso tilt as compared to the Q10original. Comparing the Q10light and the Q10update, the Q10light had slightly less head excursion and torso tilt than the Q10update. The Q10light only had a mass distribution change of 1.4kg compared to 1.7kg, also, the shoulder joint shift of 20mm was not included in the Q10light. This difference in update design features explains the difference in kinematics of the two dummies. The change in mass distribution is more biofidelic (Waagmeester et al. 2017), and therefore, the changes in kinematics due to this design change is viewed as improvements of the dummy.

The differences in dummy response between the Q10original and the Q10update were mainly seen in reduced neck tension and increased chest deflection in the Q10update. The increased mass to upper torso contributed to increased chest deflection in the updated versions of the dummy in tests when the seatbelt remained on the shoulder. Small differences between the Q10original and the Q10light in dummy responses were seen. They included mainly differences in upper neck tension (greater in the Q10original) and in chest deflection results in the ODB tests with diagonal belt guided above the inboard guiding loop resulting in greater chest deflection in the Q10light. In the ODB tests with guiding loop under the inboard guiding loop, the shoulder belt slipped off the shoulder for both Q10original and Q10light and no distinct difference in dummy responses was seen.

The Q10update showed limited sensitivity to seatbelt geometries when the initial seatbelt position was far out on the shoulder, as compared to the two other dummies. This is potentially due to the combination of design changes in the Q10update resulting in a shoulder belt motion towards the neck rather than off the shoulder. The shoulder belt interaction with the shoulder in the Q10update was influenced by the soft composition of shoulder liner contributing in stabilising the belt over the jacket. In addition, the shoulder rubber design together with the shoulder joint shifted 20mm forward contributed in holding the shoulder belt in position. The Q10light and the Q10original showed similar sensitivity to various seatbelt geometries. However, if the diagonal belt slipped off the shoulder, the belt slipped completely off the shoulder due to the shoulder liner on the Q10light, while the belt slipped into the gap between the arm and the torso on the Q10original.

The Q10update was repeatable in both loading and kinematics. There were no repeated tests conducted for the Q10light, so it was not possible to evaluate this. This may be an issue, since this has been one of the drawbacks of the Q10original (Bohman and Sunnevang, 2012).

In all three dummies, the lap belt was intruding into the gap of the thighs and the pelvis, despite the hip shields. In the final Q10light version, Cellbond has modified the femurs such that the intruding of the lap belt into the pelvis/thigh gap will not occur.

Side Impacts

This study also compared the Q10update to the Q10original in side impact tests including standard arm position and positioned on the booster cushion. The Q10update showed a lower chest acceleration by 22% compared to the Q10original in the reference test and the reduction can be explained by the mass redistribution of 1.7 kg from the pelvis to the chest. A lower chest acceleration for the Q10update compared to the Q10original was also noticed in the IC and IC/SAB tests but not in the SAB only test. The consequence of reduced chest acceleration in similar test setups results in reduced displacement of the chest (actual in spine) which will cause a lower neck and head displacement as well. This behaviour reduced the distance between the head and intruding side structure, potentially leading to higher head loadings, which could also result in a head-to-side structure impact. This was the case in the Q10update reference test in which the head contacted the side structure and the acceleration was increased by 26% compared to the Q10original where no contact was observed. In the IC/SAB tests the head accelerations were increased by 9% for the Q10update, consequence of mass redistribution was also noticed in the response of the pelvis acceleration. The pelvis accelerations increased with 46% and 35% for the reference and the IC/SAB tests respectively. The proposed mass redistribution for the Q10update was referred to a more biofidelic mass distribution (Waagmeester et al. 2017) and is thereby more relevant to consider although the sensitivity of mass distribution was less in the tests including the side impact protection systems, such as inflatable curtains and thorax side airbags, compared to the reference tests. A possible explanation to less sensitivity of mass distribution when using inflatable curtains and thorax side airbags is the fact that the contact time is earlier and the duration time of load transfer is longer resulting in lower acceleration level compared to the reference test without any airbags.

The load paths in a side impact are mainly covered by the pelvis, chest and shoulder interaction with the intruding door or side structure of the car for a near-side impact rear-seated passenger. All these three load paths are possible to control and measure in the tested Q10update and Q10original. The pelvis (pubic) and shoulder are equipped with load cells, the spine (in the chest area) is equipped with an accelerometer and the chest is equipped with rib deflection measurements. The Q10 dummies have a side impact kit, including a short arm and the shoulder force load cell mentioned above, for side impact testing. The arm is positioned vertically aligned to the thorax according to the Euro NCAP's current testing protocol (2018).

Wismans et al. (2015) presented an evaluation of the Q10 reporting that the responses in the biofidelity assessment pendulum tests were not within the required corridors of force, and that the chest could be considered as too stiff. Discussions are ongoing regarding the side impact kit and the certification test of the thorax. Wismans et al. (2015) did not include the Q10update versions. The side impact load paths and dummy response need to be further investigated, before any conclusions can be drawn regarding which of the dummy versions tested in this study is to be preferred. From a usability perspective, in case of an approved update of the Q10 dummy in lateral and side impact Euro NCAP rating tests it would be desirable to harmonize the dummy development and version implementation with the UN Regulation No 129 to avoid confusion and not use different dummy versions. At this stage, the conclusions are that both are sensitive to different side impact protection configurations, which is a good starting point for developing restraint system in order to reduce child injuries in side impacts.

The test with the Integrated Booster Cushion (IBC) provided the possibility to evaluate the Q10update sensitivity for differences in door-to-pelvis contact time. This was achieved due to the different designs of the boosters. The increased door-to-pelvis contact time resulted in substantial differences in pelvis acceleration, as shown in Figure 9. A later contact time between door and pelvis could have a preventative effect of body rotation towards to door, in combination with the relative earlier engagement of the side airbags, resulting in lower levels of shoulder resultant force. The Q10update's sensitivity to differences in booster design, is valuable when developing restraint systems. However, the Q10original was not tested using the IBC, whereby no conclusions regarding the differences between the two dummy version regarding this can be made.

Arm positioning influenced the dummy responses substantially. Gierczycka et al. (2015) studied a detailed representation of the thorax using a human body model and an ES-2re dummy model in a midsized sedan vehicle and investigated occupant response from a moving deformable barrier in side impact. The human body model demonstrated significant sensitivity, relative to the dummy, to different arm positions with lesser sensitivity to the door interior properties. This implies that the arm aligned with the body can act as a source of load transmission to the thorax for the HBM, increasing the potential for injury. This load transmission is not sufficiently reflected by dummies. Although different in setups, the tests with the angled arm in the present study have some similarities with the study by Gierczycka et al. (2015). The tests with the Q10update, using a thoracic airbag and an inflatable curtain and forward angled arm, showed reduced lower and upper chest deflections by 20% and 9% respectively and a reduced shoulder resultant force by 45%. The interference of the side impact arm kit was not only causing chest deflections to increase but was also "bridging" loads from the arm area into the shoulder in standard arm position. The influence of this alternative load path did not influence the pubic force, pelvis or chest accelerations but could be noticed in neck resultant forces and a slightly reduction of head accelerations. If chest deflection-based criteria were to be used or evaluated in the future, then the performance of the ribcage and the arm in combination with a new mass redistribution would need to be evaluated further.

The "twin peak" shoulder resultant force characteristic (Figure 12) is related to the loading of the arm and the inward bending of the forward angled arm, creating a y-directional compression force in the initial phase of the impact and causing a tension force in the later part of the impact when the arm is moving back towards the initial position. This behaviour could strictly be related to the choice of the initial position of the arm not neglecting the difference of chest deflection influence of the arm position. A thorax stiffness based biofidelity corridor and a potential shoulder-force criteria should be considering the influence of the arm position during impact.

An alternative side impact dummy, the WorldSID 5th percentile, was evaluated in comparison to the Q10 by EEVC WG12 (Wismans et al. 2015) and had a better compliance than the Q10 to specified requirements regarding biofidelity corridors in the thorax area. Awaiting a next generation of Q10update, we suggest that the WorldSID 5th percentile could be used as a complement to the Q10 in side impact testing and simulation. In addition, Brolin et al. (2015) concluded and presented in their review a need for enhanced tools, such as child human body models, to take into account the requirements of children of different ages and sizes in the development of countermeasures.

Limitations

After the tests in this study was conducted, additional changes to the Q10light was added, which were decided to be included in proposed Euro NCAP 2020 protocol. These changes include feet shortened by 30 mm and the thighs are produced of material properties from Cellbond, which are different to those of Humanetics that was used in this study.

Side impact tests were not repeated in the same condition, hence repeatability and reproducibility cannot be commented upon. The observed differences in dummy responses must be interpreted with caution and with consideration of expected repeatability.

CONLUSIONS

In the frontal tests, the Q10update was less sensitive to seatbelt geometry far out on shoulder compared to the Q10original and Q10light. For the Q10update, the seatbelt moved inboard towards the neck regardless of initial belt geometry. Both updated dummies, showed increased head excursion and upper torso tilt, which is considered as a more biofidelic behaviour compared to Q10original, due to the biofidelic mass redistribution. Due to its improved kinematics and sensitivity to seat belt geometry, the Q10light was preferred of the three tested dummies, for the frontal load cases.

In the side impact tests, the Q10update showed lower chest acceleration compared to the Q10original but also led to head-to-structure contact in one test and increased pelvis acceleration. The chest deflections were overall higher for the Q10update compared to the Q10original. The standard arm position increase chest deflection and influence the loads path into the shoulder compared to a forward angled arm. The proposed mass redistribution is considered as more biofidelic and that effect will shift focus from chest acceleration to chest deflection, pelvis acceleration and head acceleration criteria. This study provides no firm recommendation on the Q10update, acknowledging that a biofidelity evaluation needs to be made. Further dummy refinements, lateral validation and certification tests are encouraged.

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