EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

Q10 dummy Report

Advanced Child Dummies and Injury Criteria for Frontal Impact

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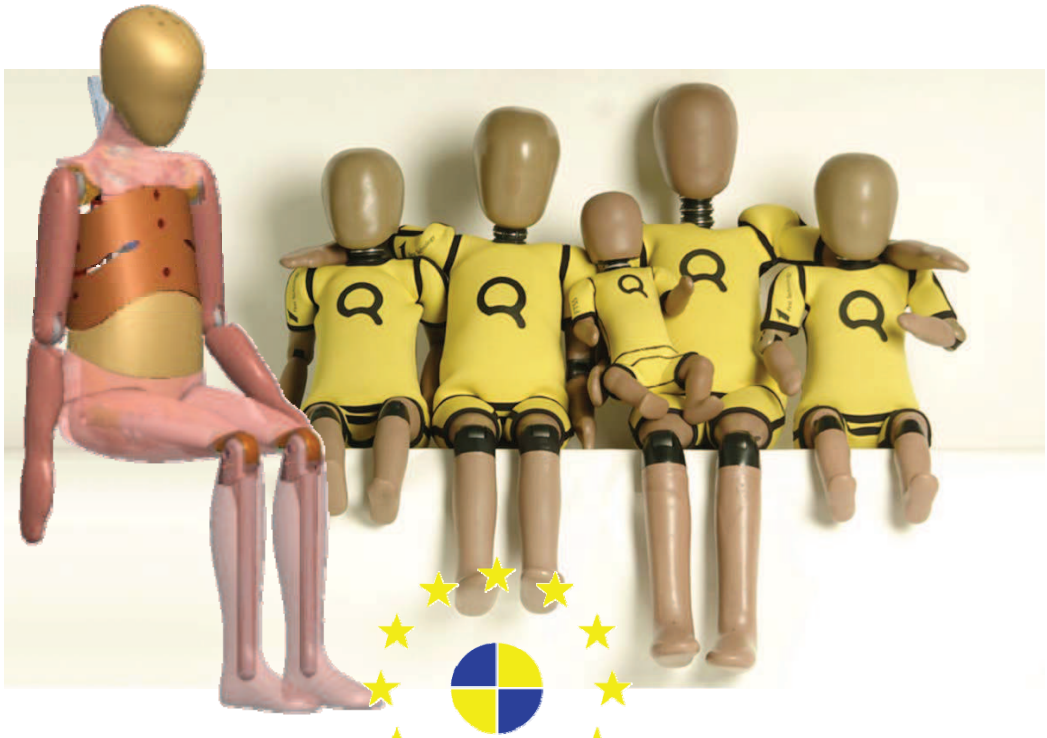

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EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

Q-dummies Report

Advanced Child Dummies and Injury Criteria for Frontal Impact

EXECUTIVE SUMMARY

This report describes the design and evaluation of the Q10 child dummy which is the latest extension to the new generation of child dummies called Q-dummies. The Q-dummies were developed to replace the P-dummies in the UN Regulation 44 and in consumer testing. EEVC Working Groups 12 (Biomechanics) and 18 (Child Safety) collaborated on joint research to evaluate the Q-Series and recommended that they replace the P-Series in UN Regulation 44 (Wismans et al., 2008, [1]). This 2008 report also proposed injury criteria and injury assessment reference values for use with the dummies in the Regulation. In 2008 the Q-Series comprised Q0, Q1, Q1.5, Q3 and Q6 dummies only; there was no dummy to represent older children in the highest mass group specified in UN Regulation 44.

The Q10 was developed in the European project EPOCh (Enabling Protection for Older Children, 2009-2011 [2]) and was extensively evaluated by the EPOCh partners and a number of interested stakeholders during a large programme of "third-party testing". With the introduction of this new dummy, the UN Informal Group on child restraint systems asked EEVC to provide a recommendation on its use in legislative testing.

Chapter 1 of this report gives some background on the research and development efforts that resulted in the Q dummy series and the Q10 dummy in particular. An overview of child injury causation for older children is presented in Chapter 2, which comprises a synthesis of frontal crash investigations performed under the CREST, CHILD, EPOCh and CASPER projects.

Chapter 3 describes the development and evaluation of the Q10. Two prototype Q10 dummies were extensively evaluated on anthropometry, biomechanical performance, sensitivity, repeatability and durability to impact loading in head drop, neck pendulum and full body wire

pendulum tests. Also tests with production version dummies were carried out to evaluate reproducibility and certification procedures.

Chapter 4 deals with experiences gained in testing the Q10 dummy within the EPOCh project as well as in testing by third parties. Tests were carried out on 2 prototype dummies to assess the ability of the Q10 dummy to perform as a measurement tool in sled and full-scale crash conditions. A large variety of aspects were evaluated, such as belt and airbag interaction, comparison with other dummy types, repeatability and reproducibility and sensitivity to restraint system features, including pre-tensioners and load-limiters. The tests included:

- Table top tests
- Low severity child volunteer sled tests
- Sled tests under UN R44 and NPACS test conditions
- Body-in-white sled tests as well as full-scale crash tests

In Chapter 5 the development and first evaluation results of the prototype Abdomen Pressure Twin Sensors (APTS) in Q10 is described. Chapter 6 deals with the proposed child dummy injury criteria and injury risk functions for the Q10, which are defined based on scaling from the smaller Q-dummies and scaling on the basis of adult data.

Chapter 7 concludes this reports with a Discussion and Conclusion section including a number of recommendations for further work. It is concluded that the Q10 dummy shows a significant improvement with respect to the P10 dummy currently used in UN R44 frontal impact tests. Based on the extensive evaluation and validation results described in this report EEVC recommends the use of the Q10 dummy in future child restraint homologation tests (UN R129). It is recommended to implement initially five injury criteria: Head acc. (3ms), Upper Neck tension (Fz), Upper Neck flexion, Extension bending moment (My) and Chest deflection complementary to the UN R129 excursion limits. Furthermore it is recommended, among others, to:

- Complete, with high priority, the work initiated on APTS
- Review the results of the work done by the Q-series Chest and Abdomen Injury Criteria Task Force (results expected to be available end of 2014)
- Evaluate the changes made in the production version Q10 dummy concerning prevention of lap belt sliding into the gap between pelvis and femur flesh

1 INTRODUCTION

UN Regulation 44 establishes a weight-based system of classification for child restraint systems and specifies performance requirements that are assessed during front and rear impact tests with the P-Series "family" of child dummies. These dummies were developed during the 1970s and were the most sophisticated child dummies in Europe when the Regulation was introduced in 1981. The P-Series have been instrumental in improving the quality of child restraints and have proven to be extremely durable for regulatory testing. Nevertheless, the dummies are often referred to as simple loading devices with minimal instrumentation. The anatomy and behaviour of the internal structures of the body are not represented, which is one of the fundamental shortcomings of these dummies. In addition, the method used to detect abdomen loading (a clay insert between the lumbar spine and abdomen) is somewhat subjective and does not allow for a complete assessment of injury risk.

The Q-Series were developed as possible successors to the P-Series in regulatory (and consumer) testing (see Figure 1). Work on the dummies was initiated in 1993 by the International Child Dummy Working Group and continued during the European Framework Programme projects CREST (Child REstraint System sTandard, 1996-2000) and CHILD (CHild Injury Led Design, 2002-2006). EEVC Working Groups 12 (Biomechanics) and 18 (Child Safety) collaborated on joint research to evaluate the Q-Series and recommended that they replace the P-Series in UN Regulation 44 (Wismans et al., 2008, [1]). They also proposed injury criteria and injury assessment reference values for use with the dummies in the Regulation. These were derived by logistic regression analysis on accident reconstruction data (from the CHILD project), supplemented with scaling, and equated to a 50% risk of AIS3+ injury. At this time, the Q-Series comprised Q0, Q1, Q1.5, Q3 and Q6 dummies only; there was no dummy to represent older children in the highest mass group specified in UN Regulation 44.

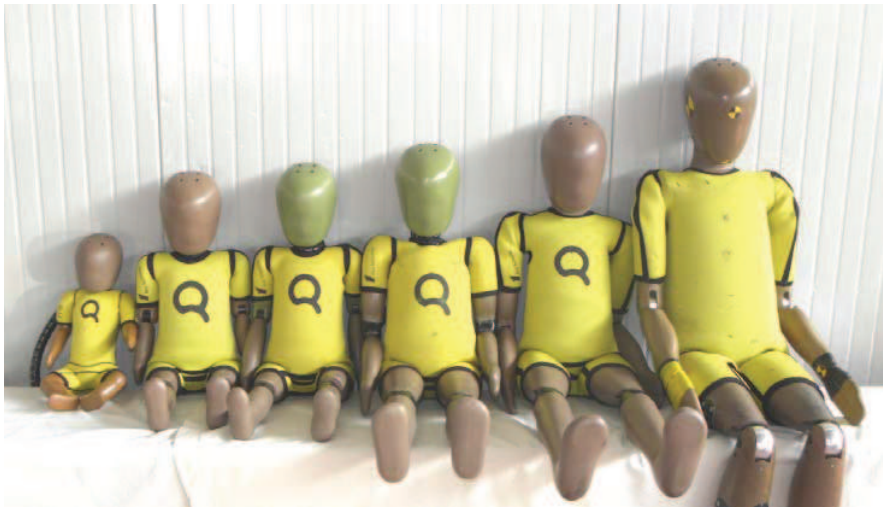


Figure 1: Q-series of child dummies (left to right Q0, Q1, Q1.5, Q3, Q6 and Q10)

In 2007, the UN Informal Group on child restraint systems was established by the Working Party on Passive Safety (GRSP) to develop a new UN Regulation on the approval of "Enhanced Child Restraint Systems". The new Regulation introduces the "i-Size" concept for child restraint to vehicle compatibility, a stature-based system of classification for child restraints, the new family of child dummies (the Q-Series) and a side impact test procedure. The first phase of the new Regulation was completed in 2011 and sets out performance requirements and test methods for integral ISOFIX child restraints. It was adopted by the World Forum for Harmonisation of Vehicle Regulations (WP.29) during its 158th Session held in Geneva in November 2012 and came into force in July 2013. The second phase is underway and incorporates non-integral child restraints. It is scheduled to be completed (in draft) for the 56th Session of GRSP in December 2014. The final phase will consider amendments to UN Regulations 44, 14 and 16, according to the outcome of the first two phases.

The UN Informal Group based many of its decisions regarding the use of the Q-Series in UN Regulation 129 on the work carried out by EEVC Working Groups 12 and 18 [1]. A production version of a new Q-Series dummy, the Q10, was released in 2013, which provides an "upper limit" dummy for the new Regulation. The prototype of the Q10 was developed and evaluated by EPOCh (Enabling Protection for Older Children, 2009-2011 [2]). It has also been used by various interested stakeholders during a large programme of "third-party testing". With the introduction of this new dummy, the UN Informal Group on child restraint systems asked EEVC to provide a recommendation on its use in legislative testing.

EEVC WG12 was not in a position to undertake a large programme of research on the use of the Q10 dummy. However, a great deal of experience has already been gained across Europe. Reviewing these data enabled a consensus to be reached on the use of the Q10 in front impact tests with child restraint systems, similar to that provided for other Q-Series dummies by Wismans et al. (2008) [1] for EEVC WGs 12 and 18.

This report starts with an overview of child injury causation for older children. Chapter 2 presents a synthesis of frontal crash investigations including those performed under the CREST, CHILD, EPOCh and CASPER projects. Chapter 3 describes the development and evaluation of the Q10. Chapter 4 deals with experiences gained in testing the Q10 dummy within the EPOCh project, as well as during testing by third parties. In Chapter 5, the development and evaluation of the Abdomen Pressure Twin Sensors (APTS) for the Q10 are described. Chapter 6 deals with the proposed child dummy injury criteria and injury risk functions for the Q10, which are defined based on scaling from the smaller Q-dummies and scaling on the basis of adult data. Chapter 7 concludes this report with a Discussion and Conclusion section including recommendations for further work. Background and detailed information is provided in Annexes.

2 ACCIDENT DATA AND INJURY CAUSATION FOR OLDER CHILDREN

INTRODUCTION

It is essential that the measurement capabilities of a new dummy reflect the injuries that are observed in the field among occupants of the same size. This enables the dummy to be used reliably in test procedures that target specific priorities for injury reduction. As part of the EEVC report "Advanced child dummies and injury criteria for frontal impact", EEVC WG18 reviewed the European accident statistics with respect to child car occupants. A broad range of sources were examined, including: CREST (Child Restraint STandard, a European collaborative research project), CCIS (the Cooperative Crash Injury Study in the UK), GIDAS (German In-Depth Accident Study), GDV (German Insurance), IRTAD (International Road Traffic Accident Database) and LAB (Laboratory of Accidentology and Biomechanics in France.

Although these sources used very different definitions and data collection methods, which made it difficult to merge data for analysis, sufficient information was available to classify injury causation according to the different groups of child restraint systems that were used. The EEVC findings have subsequently been updated and refined with more recent sources, such as CASPER (Child Advanced Safety Project for European Roads, a European collaborative research project) (see Kirk, 2012). Grouping the findings by child restraint type was necessary to highlight where performance improvements were needed. However, in many of these sources (including the most recent, from CASPER), restraint types that are now intended for older children only (i.e. booster systems) were also used by younger children in significant numbers (due to differences in the legislation from the time of the collisions). It is difficult, therefore, to separate the experiences of older children specifically.

A new, comprehensive analysis of the European accident data to target older children was not within the scope (and resources) of EEVC WG12 in preparing this report. Nevertheless, in developing the Q10, the EPOCh project undertook an analysis of the injury types and mechanisms experienced by older children (aged 6 to 12 years). Sections of an EPOCh deliverable that included an analysis of the United Kingdom Cooperative Crash Injury Study (for older children) are provided in ANNEX A: CHILD INJURY CAUSATION STUDY. Complimentary data from the Rhône Registry Injury Database in France are provided in ANNEX B: INJURIES TO OLDER CHILDREN IN FRANCE. The remainder of this section summarises the key findings from the EPOCh project, whilst also taking into account the original work of EEVC WG18, the work of CASPER and research carried out by TRL for the European Commission (Visvikis at al., 2014).

RESULTS AND DISCUSSION

There is limited in-depth and representative real-world data available for children of all ages (Visvikis et al., 2014). Such data is needed to draw meaningful comparisons between the type and frequency of injuries that children experience in collisions. Although analyses of the

sources described above cannot quantify statistically which body regions are more frequently injured, they can be used to highlight general trends.

For older children in front impact collisions the most important findings are:

- The head appears to be one of the most frequently injured body regions in older children (at AIS≥2 levels). Head injuries in front impacts typically occur due to head contact with the interior of the vehicle (rather than through non-contact, deceleration-only mechanisms).
- Neck injuries appear to be very rare in older children. The only reason for measuring and assessing neck loading in front impact would seem to be to prevent load transfer from other (regulated) body regions.
- Injuries to the chest are observed and many researchers note their importance due to the presence of vital organs in the chest cavity.
- Abdomen injuries are also found in older children. These occur through loading by the lap part of the seat belt, and are observed in non-integral child restraint systems (as well as belt-only cases).
- Injuries to the extremities are often reported in front impact, but the role of vehicle intrusion needs to be understood more fully (before drawing conclusions about the need for additional requirements to be placed on child restraints).
- The misuse of a child restraint system is likely to reduce its performance in a collision. Recent field observations in Europe found that around two-thirds of child restraints were misused, although the rate varied between the three survey locations/countries (Müller et al., 2012). Relatively few older children were observed, and most were restrained by the adult seat belt (or were unrestrained).

CONCLUSIONS

Injuries to older children in front impact collisions tend to occur in the head, chest, abdomen and extremities. Contact with the vehicle interior appears to be the principal mechanism for head and extremity injuries, whereas the chest and abdomen are injured by loading from the adult seat belt. Injuries to the neck appear to be particularly rare, even accounting for limitations in the availability of representative data. Fewer data were generally available from side impact collisions, but injuries tend to occur in the head, chest and abdomen. The principal mechanism for these injuries is contact with the interior of the vehicle, in areas with intrusion as well as areas with no intrusion.

These conclusions are derived from the work of the EPOCh project, described in ANNEX A: CHILD INJURY CAUSATION STUDY, whilst also taking account of the other sources mentioned above. When applying these conclusions, it should be noted that there is very limited representative data with enough depth to identify (with any statistical confidence) needs and priorities for improving the performance of child restraint systems for specific age groups. Although meaningful statistical analysis could not be carried out, trends in the data were highlighted, which can serve as a reference point until representative data are available.

3 DUMMY DEVELOPMENT AND EVALUATION IN CERTIFICATION TYPE TESTING

DUMMY DESCRIPTION

This description mostly follows section 4.3 of deliverable D25
of the COVER-project [3], which is based on work performed in the EPOCh-project [2].
Where appropriate, corrections and additions have been made.

Specific design features of the Q-dummies are: the anatomical representation of body regions, the modular design, the dummy-interchangeable instrumentation, the multi-directional use (frontal & side impact) (see note) and the easy handling properties (limited component count, easy assembly/disassembly and simple calibration).

Note: The initial goal was to develop dummies for multi directional use, however, priority has been given to reach compliance with frontal impact performance targets. As a result, the side impact performance is sub-optimal. Improved side impact performance is reached through the development of dedicated side impact versions of Q-dummies Q3s and Q6s in The United States of America and Canada. The Q3s is currently considered for rulemaking. For the Q10 there is a side impact kit under development. This kit comprises a modified shoulder joint with load cell and a new upper arm with flexible bone structure. In this report the focus is on frontal performance.

The dummy layout of the Q10 is rather similar to that of the other Q-dummy family members except for the pelvis structure, which is similar to the design of the WordSID dummies. The design of the head, the neck, the shoulder, the clavicle, the thorax, the lumbar spine, the abdomen and the extremities attempts to represent the main features of human anatomy. The head and the clavicle are made entirely from plastics. The neck and the lumbar spine are represented by a column composed of metal and a natural rubber that allows shear and bending deformation in all directions. The thorax consists of a deformable plastic ribcage and a metal thoracic spine. The clavicle is connected to the thorax at the front of the ribcage, at the back of the sternum, and to the shoulders at the arm sides. The shoulders are made of natural rubber with metal end plates, which are connected to the upper arm on one side and the thoracic spine on the other side. The end plates are connected with steel cable for failsafe reasons. The lumbar spine is mounted between the pelvis and the thoracic spine. The abdomen is a skin-covered foam insert, which fits in between the ribcage and the pelvis. The pelvis has a central sacrum block and two iliac wings at pubic symphysis location bridged by a load cell. This structure is cover by a soft plastic pelvis flesh. Finally, the extremities are a combination of plastic flesh over a metal skeleton with representations of the elbow, shoulder, hip and knee joints.

The following sections on anthropometry, biofidelity and other aspects give more background to the Q10 dummy. In the main text of this report lateral impact performance is left out because this report deals with frontal impact only. As an exception, the lateral performance for head and neck is shown because in frontal tests the head kinematics have a 3-dimensional character. (In ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION

REPORT the lateral impact biofidelity targets and performance validation can be found in full detail).

ANTHROPOMETRY

The Q10 design brief (ANNEX C: Q10 DESIGN BRIEF) specifies the anthropometry based on CANDAT (Child ANthropometry DATabase) [4], which has been the basis of all Q dummy family members. CANDAT comprises data from 12 different anthropometry data sets published between 1977 and 1992. In Figure 2, the Mass versus Stature of CANDAT is compared with more recent anthropometry data from The WHO 2007 (World Health Organization) and CDC 2000 (Centers for Disease Control and Prevention) [5]. It can be concluded that the CANDAT data matches with the more recently collected anthropometry.

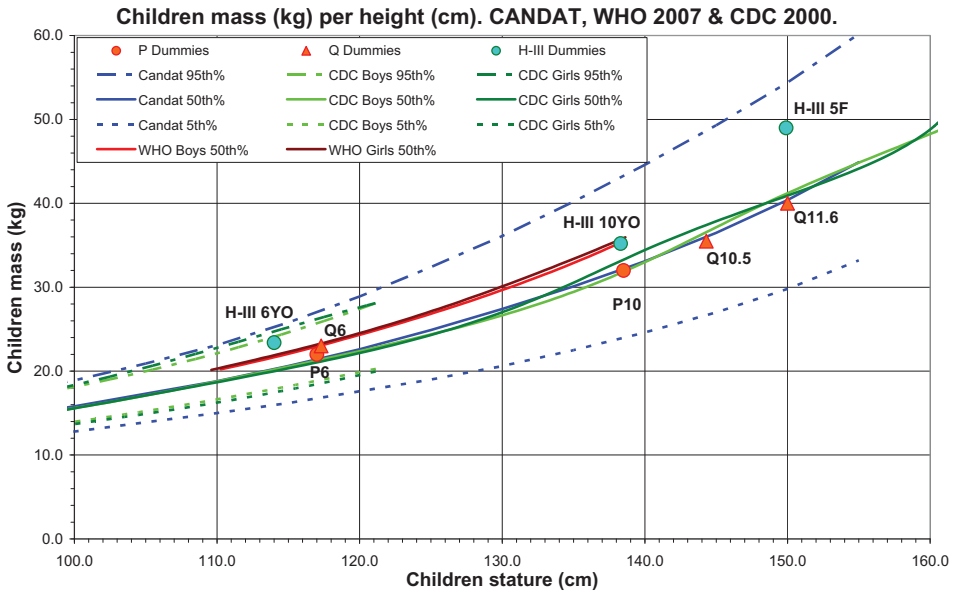


Figure 2: Comparison of CANDAT with more recent WHO 2007 and CDC 2000 data

Size Selection

The Q10 design brief (ANNEX B: Q10 DESIGN BRIEF) specifies the anthropometry of two possible options for a dummy that represents the oldest children that use child restraint systems in cars:

- Q10 50 percentile 10.5 years old Stature 1443 mm, Mass 35.5 kg
  (Represents average size of largest children that use CRS)
- Q12 50 percentile 11.6 years old Stature 1500 mm, Mass 40.0 kg
  (Represents ultimate height of children that use CRS)

In the Q10 design brief the size selection is extensively deliberated addressing aspects as:

- Comparison of CANDAT targets with existing dummies
- Anthropometry development for children from 10 and 12 year old
- Regulatory aspects and classification
- Practical constraints due to limited space in cars
- Optimal representation of the group of largest children

These aspects were discussed in a stakeholders meeting and a meeting of the GRSP Informal Group on CRS. After that, a broader group of experts and policy makers was approached to give feedback on the size selection. Based on the feedback received from the stakeholders the EPOCh team decided to proceed with the design of the Q10 dummy (Age 10.5 years old, Stature 1443 mm, Body mass 35.5 kg). For more details see ANNEX C: Q10 DESIGN BRIEF.

Anthropometry Validation

For the anthropometry validation, the overall dimensions as shown in Figure 3 were used. A comparison of the actual dimensions and mass distribution with the anthropometry targets specified in ANNEX C: Q10 DESIGN BRIEF is given in Table 1 and Table 2. The actual dimensions and mass distribution given in the tables in some instances deviates from earlier published drawing dimensions (ANNEX D: Q10 VALIDATION REPORT). The actual dimensional and mass distribution requirements were established after measuring 18 production dummies.

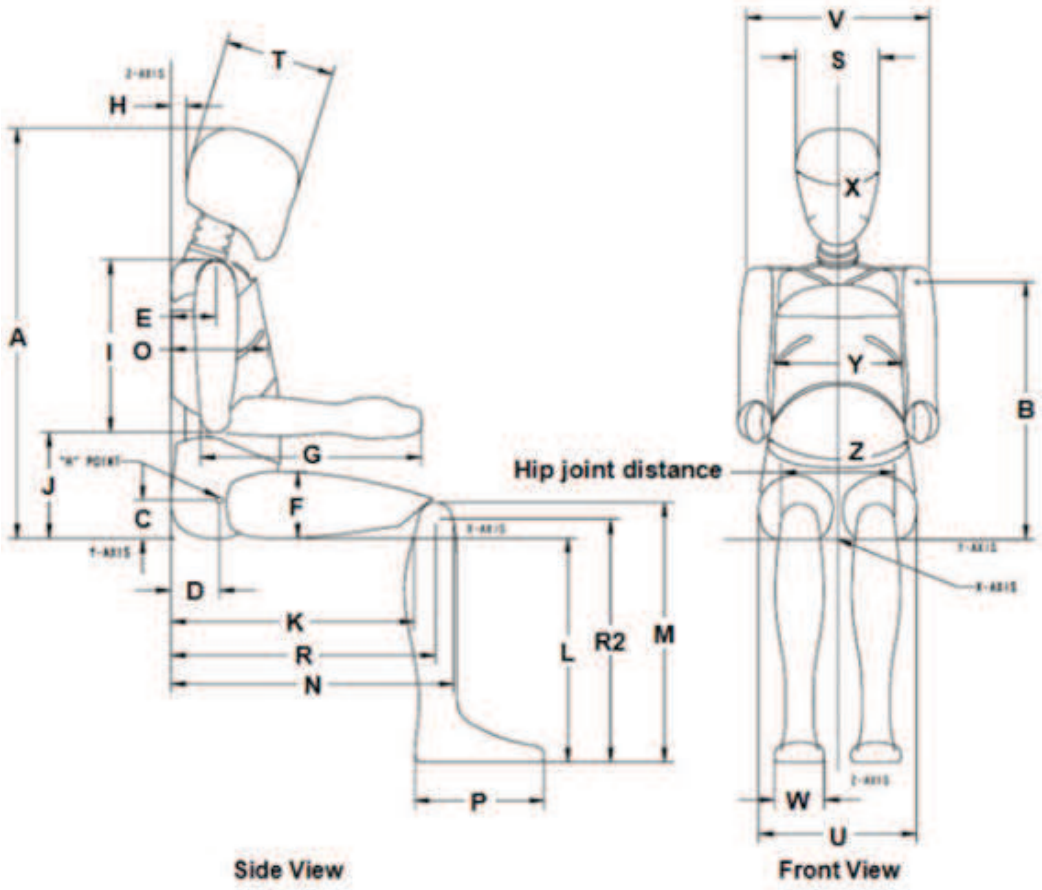


Figure 3: Q10 Overall dimensions

Table 1: Q10 production dummy dimensions versus anthropometry target

Description	Anthropometry target in [mm]	Actual dimension and tolerance of production dummies (see note) in [mm]
A - Sitting Height (head tilt)	747.6	733.7 ± 9
B - Shoulder Height (top of arm)	473	472.5 ± 6
C - Hip Pivot Height	65.9	65.9 ± 3
D - Hip Pivot from Back Plane	90.4 (1)	90.4 ± 3
D2- Hip Joint Distance	130.0 (1)	132.0 ± 3
F - Thigh Height	114.0	114.0 ± 3
G - Lower Arm & Hand Length	374.7	376.2 ± 6
I - Shoulder to Elbow Length	292.9	291.6 ± 3
J - Elbow Rest Height	189.6	181.0 ± 9
K - Buttock Popliteal Length	417.5	414.9 ± 6
L - Popliteal Height	405.7	405.7 ± 6
M - Floor to Top of Knee	445.6	451.0 ± 6
N - Buttock to Knee Length	488.4	485.4 ± 6
O - Chest Depth at Nipples	171.2	171.0 ± 3
P - Foot Length	220.0	222.0 ± 9
Q1- Standing Height (head tilt)	1442.5	1453.2 ± 9
R - Buttock to Knee Joint	(none)	448.4 ± 6
R2- Floor to Knee Joint	(none)	422.0 ± 6
S - Head Breadth	143.9	144.0 ± 3
T - Head Depth	187.4	186.5 ± 3
U - Hip Breadth	270.4	271.5 ± 6
V - Shoulder Breadth	337.8	334.8 ± 6
W - Foot Breadth	86.0	86.0 ± 3
X - Head Circumference	534.5	534.0 ± 6
Y - Chest Circumference at Axilla	687.3	(monitoring 604.6 ± 6)
Y1- Chest Circumference at Nipples	684.9	(monitoring 633.6 ± 6)
Z - Waist Circumference	593.5	(monitoring 664.6 ± 6)

Note: This in some instances deviates from earlier published drawing dimensions. The actual dimensional requirements are established after measuring 18 production dummies

Table 2: Q10 production dummy mass versus anthropometry target

Description	Anthropometry target in [kg]	Actual mass and tolerance of production dummies (see note) in [kg]
Head	3.59	3.695 ± 0.100
Neck	0.60	0.495 ± 0.050
Upper torso	(incl. suit partly) 5.15	4.482 ± 0.200
Lower torso	(incl. suit partly) 9.70	9.798 ± 0.300
Suit	(none)	(monitoring 0.570 ± 0.100)
Upper arm (each)	1.09	1.090 ± 0.050
Lower arm + Hand (each)	0.90	0.900 ± 0.050
Upper leg (each)	3.71	3.710 ± 0.100
Lower leg + Foot (each)	2.52	2.530 ± 0.120
Total body mass	35.5	35.500 ± 0.600

Note: This in some instances deviates from earlier published drawing dimensions. The actual mass distribution requirements are established after measuring 18 production dummies

Discussion and conclusion

From Table 1 and Table 2 it can be seen that the actual dimensions and masses in general compare well with design brief specifications that are based on the CANDAT database used for all Q-dummies (ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION REPORT).

Dimensions

The deviation in Sitting and Standing Height is explained by the fact that these dimensions are measured in a full erect posture while the dummy is assembled with the head-neck system 27 degrees tilted forward. To enable comparison with an erect posture, the dimension measured via T1 is given, in which case a good match is obtained. Also, it should be noted that for the Standing Height an extra deviation is introduced by the pin-joint knee. In the human it is a joint with condyles with varying curvature due to which the human knee joint does not have a single rotation axis. The leading dimensions for the optimum knee joint location were K, L, M and N (ANNEX D: Q10 VALIDATION REPORT). In addition to the sitting and standing height, the chest and waist circumferences show deviations. Actual dimensions are smaller for the chest circumference than the specified values because the soft muscle tissue at the nipple and axilla level are not represented in the dummy. Also the ribcage is made as a single curved conic part to prevent complex secondary bending stresses that would occur in a double curved rib cage. Overall, these differences lead to a more conical shape for the trunk of the dummy (larger waist, smaller chest) than the anthropometry.

Mass distribution

The mass of the prototype dummies revealed to be too small, especially for the upper and lower arms and the pelvis. With an addition of some ballast items to the upper arms (40 gram each), lower arms (70 gram each) and the sacrum block (970 gram), the dummy mass was increased towards the target level. The dummy design for the production version incorporates the additional mass properly distributed over the regular dummy parts.

BIOFIDELITY

In this chapter, the Q10 dummy biofidelity performance information for frontal impact is presented per body region. In addition, lateral impact is presented for head and neck and lumbar spine (lateral performance of shoulder, thorax and pelvis can be found in ANNEX D: Q10 VALIDATION REPORT). The biofidelity requirements of the Q10 are described in the design brief that was redacted as part of the EPOCh Project and which is provided in ANNEX C: Q10 DESIGN BRIEF. It includes response targets for head, neck, thorax, lumbar spine and abdomen, mostly obtained by scaling from adult data. See Table 3 for an overview of these requirements. Note that no targets were set for lower extremities (including hip flexion) and upper extremities

Table 3: Q10 biofidelity performance described in the design brief

Region or Type of response	Possible relevance, injury/loading mechanism	Target Source / method Type of test / target
Head impact	Head injury	EEVC requirements. Head drop / peak accel.
Neck bending	Affect head trajectory and neck injury	Isolated flexion, extension and lateral flexion tests.
Thorax stiffness	Affects belt interactions, thorax injury	Pendulum test and Table top testing (TRL, see Chapter 4)
Abdomen stiffness	Abdominal injuries	Belt compression derived from Rouhana et al., 1989). See also Chapter 5
Lumbar spine flexion	Kinematics, submarining risk	Isolated flexion and lateral flexion tests

Head

For the head biofidelity, three criteria for head drops on a rigid plate have been evaluated (ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION REPORT):

- Frontal 130 mm drop height: Biofidelity corridor limits based on EEVC scaling are: 113.1 – 194.2 g;
  - The average measured value is 120.0 g;
- Lateral 130 mm drop height: Biofidelity corridor limits based on EEVC scaling are: 116.1 – 200.0 g;
  - The average measured value is 133.7 g.
- Lateral 200 mm drop height: Biofidelity corridor limits based on ISO TR9790 scaling are: 107 – 161 g;
  - The average measured value is 179.5 g.

The head drops were performed with a half upper neck load cell replacement attached to the head base plate. In Figure 4 the resultant head accelerations versus time are shown together with the corridors specified above (Note: the corridor is an acceleration range and not timing requirements).

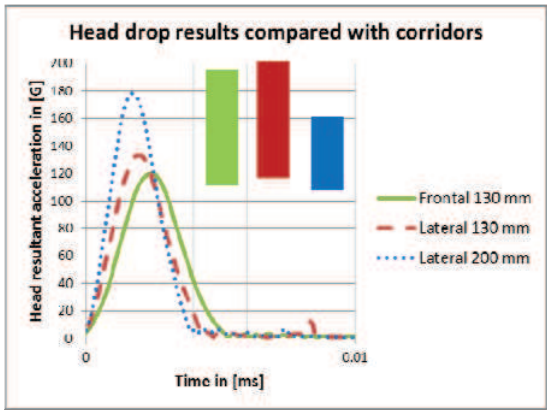


Figure 4: Head drop biofidelity results

It can be observed that the head meets the frontal (130 mm) and lateral (130 mm) requirements low in the EEVC corridors and the results for the lateral 200 mm ISO based test exceeds the corridor significantly. It was concluded that simultaneous compliance with EEVC and ISO lateral requirements was not possible with the current design and that for an

improved compliance with the EEVC requirement a stiffness increase was desired. Based on experience with other dummies, it seems likely that head stiffness will increase when the product ages. Therefore, it was decided to slightly increase the stiffness of the production dummy heads such that its performance will become closer to the middle of the biofidelity corridor. For the Q10 production version, the head performs in the certification corridors: Frontal between 124.2 and 151.8 G, Lateral between 128.7 and 157.3 (see paragraph on Certification in this Chapter).

Neck

For the neck, biofidelity requirements in flexion, extension and lateral flexion have been evaluated.

Flexion

In Figure 5, the neck flexion bending performance in a Part 572 neck pendulum test is given in comparison with the flexion biofidelity corridor (ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION REPORT). The flexion response is in the rather lower range of the corridor and the stiffness increase that should occur round about 30 to 35 degrees of head rotation is slightly late; actually it occurs round 45 degrees head rotation. The stiffness gradient is in line with the corridor. An improved performance could be obtained by increasing the rubber stiffness but that would affect the fracture toughness and therefore the durability of the part. Another possibility is to change the neck mould, but this may affect the response in other directions, so this mould change was not implemented.

Extension

In Figure 6, the neck extension bending performance in a Part 572 neck pendulum test is given in comparison with the extension biofidelity corridor (ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION REPORT). It can be concluded that the extension performance fits the corridor very well. No further adjustments are necessary and there is some room to allow changes as a result of the mould change recommended by EPOCh to improve flexion performance.

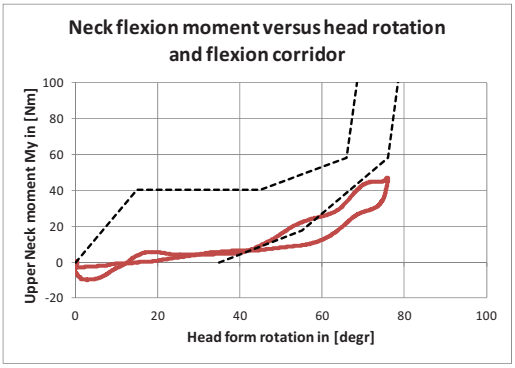


Figure 5: Neck flexion moment versus head rotation

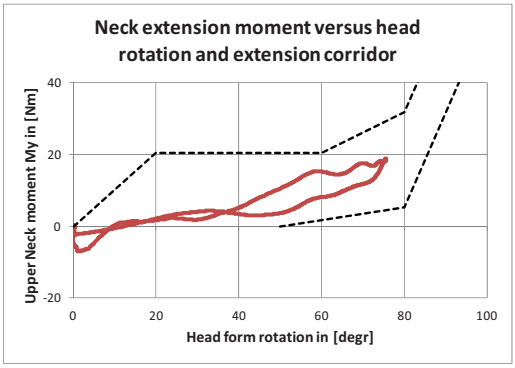


Figure 6: Neck extension moment versus head rotation

Lateral flexion

Figure 7 shows the neck lateral flexion bending performance in a Part 572 neck pendulum test, in comparison with the lateral flexion biofidelity corridor (ANNEX C: Q10 DESIGN

BRIEF and ANNEX D: Q10 VALIDATION REPORT). The Q10 development in the EPOCh project did not consider side impact performance tuning. It can be concluded that up to 45 degrees of head lateral flexion the response is within the corridor, and above 45 degrees, it is below the corridor.

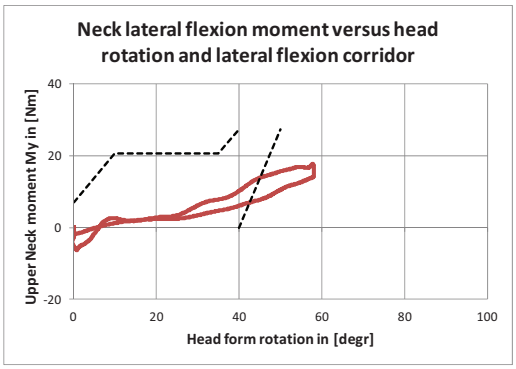


Figure 7: Neck lateral flexion moment versus head rotation

Discussion

EEVC considers the current performance of the Q10 neck, close to the lower boundary of the scaled Mertz corridor as shown in Figure 5, to be acceptable, in particular in view of the limitations of the Mertz corridors. The Mertz torque versus rotation corridor for neck flexion is rather wide. A study of Thunnissen et al. [6] showed that the response of well-trained young human volunteers (Navy staff) in sleds tests is located in the lower part of the Mertz corridor, indicating that the upper part of the Mertz corridor is not realistic and allows the application of too stiff neck designs.

Thorax

For frontal biofidelity, two pendulum test impact speeds are specified: 4.31 and 6.71 m/s. In Figure 8 and Figure 9 the pendulum test results for these two impact speeds are shown in terms of pendulum force versus average rib displacement in the impact direction. The average rib displacement for frontal impact is the average deflection of the upper and lower IR-TRACC attached to the rib cage sternum. The results are compared with the scaled biofidelity corridors (ANNEX C: Q10 DESIGN BRIEF and ANNEX D: Q10 VALIDATION REPORT). Besides the standard posture, two posture related variations are tested:

- Standard (certification) posture:
  Thoracic spine vertical with upper arms down along the thorax and the hand adjacent to the thighs (This posture is commonly used for Q-dummies thorax impact tests);
- Arms forward posture:
  Thoracic spine vertical with arms forward, supported with rods under the elbows;
- Tilt forward posture:
  Thoracic spine tilted forward about 12 degrees so that the sternum is parallel to the pendulum impactor face with upper arms down along the thorax and the hand adjacent to the thighs.

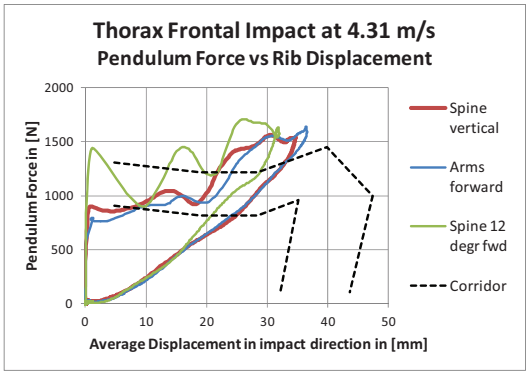


Figure 8: Thorax frontal pendulum impact 4.31 m/s

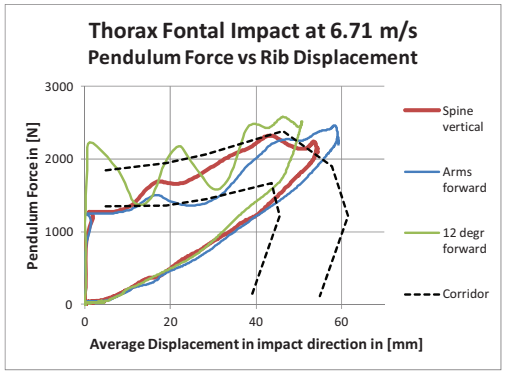


Figure 9: Thorax frontal pendulum impact 6.71 m/s

It can be observed that the rib cage response in general meets the corridors reasonably well during the loading phase, especially for 6.71 m/s. During the unloading phase, in both test conditions, the dummy exhibits an energy dissipation lower than the target, as observed in other dummies. For the lower impact speed at 4.31 m/s, the response is somewhat above the corridor, which is in line with the performance of the other Q-dummies that have been made stiffer to prevent early bottoming out of the rib cage to the thoracic spine. The Q10, however, having more room for displacement in the chest, has in comparison to other members of the Q family, a better compliance with the corridors (ANNEX D: Q10 VALIDATION REPORT). The different postures explored show that there is sensitivity in the dummy response to this variable. This phenomenon is also observed in other dummies, such as the THOR dummy currently under development in the THORAX- project [7]. However, there is no reason to deviate from the commonly used (certification) test posture for Q-dummies in thorax impact biofidelity tests. .

Lumbar Spine

The lumbar spine is made of a cylindrical rubber column. Therefore, its flexion and lateral flexion performance are approximately the same. In Figure 10, test results obtained in dynamic and quasi-static tests are presented. The stiffness (computed as straight lines, shown as dashed lines) in the dynamic tests is higher than the static tests:

- Dynamic: 80 Nm/58 degr = 1.38 Nm/degr or 79.0 Nm/radial;
- Static: 80 Nm/74 degr = 1.08 Nm/degr or 61.9 Nm/radial.

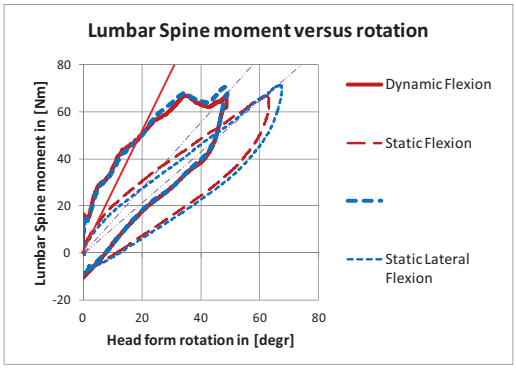


Figure 10: Lumbar spine stiffness (dynamic and static)

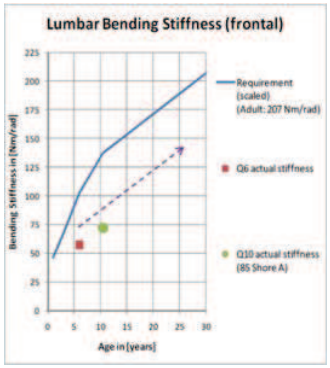


Figure 11: Q6 and Q10 lumbar stiffness compared to scaled adult requirement [8]

These stiffness values are significantly smaller than the scaled requirements (ANNEX C: Q10 DESIGN BRIEF); that is 137.1 Nm/rad for flexion and 142.8 Nm/rad for lateral flexion. The actual stiffness of a Q6 lumbar spine is about 50% of its scaled requirement (103 Nm/rad) (see Figure 11). During the performance tuning phase, it was decided by the EPOCh consortium, in line with Q6, to set the target stiffness of the Q10 lumbar spine to 50% of the scaled requirements (68.6 Nm/rad for flexion and 71.4 Nm/rad for lateral flexion, ANNEX D: Q10 VALIDATION REPORT). This approach may be justified by the consideration that the abdomens in the Q-dummies contribute to torso bending stiffness, in contradiction to those of the Hybrid III dummies. The lumbar spine stiffness with this approach complies with the requirement.

Discussion and conclusion

The vertical compression of the abdomen was found to contribute about 50% of the stiffness of the lumbar region in Q3 testing (Beillas et al., 2012b) [31]. This seems to support the presented lumbar spine stiffness approach. However, in the onset of the dynamic test, up to about 20 degrees head form rotation, a stiffness of about 80 Nm/30 degr = 2.67 Nm/degr or 152.8 Nm/radial may be read from the graph in Figure 10 (see red straight line). This highlights the doubts around the judgment of an appropriate lumbar spine stiffness. In conclusion, EEVC WG12 has insufficient information to judge the lumbar spine performance.

Abdomen

ANNEX C: Q10 DESIGN BRIEF specifies a biofidelity target stiffness for the abdomen up to about 65 to 70 mm belt penetration in the 1 m/s belt penetration test (Beyond this penetration the abdomen stiffness for belt intrusion should increase significantly):

- Upper stiffness limit 1500/66.8 = 22.46 N/mm
- Lower stiffness limit 500/62.7 = 7.97 N/mm

The design brief indicates that extrapolation of the Q6 abdomen design is anticipated to be adequate. No specific validation data is available on the performance of the abdomen within EPOCh. For the Q10 production version, the abdomen performs in the certification corridor with an average stiffness of (8.05 kg*9.81 m/s^2) N/10.4 mm = 7.59 N/mm in a quasi-static plate loading component test (see paragraph on Certification in this Chapter). This certification condition is, however, very different from the biofidelity reference (static vs. 1m/s, plate vs. belt loading, isolated abdomen vs. in dummy) and it is difficult to conclude

solely based on this information. For further information on abdominal performance see Chapter 5.

SENSITIVITY

In this chapter, the Q10 dummy sensitivity performance for the head and thorax in frontal impacts is presented (ANNEX D: Q10 VALIDATION REPORT). In this Annex sensitivity to lateral impacts is also included for the head, shoulder, thorax and pelvis. The background to this testing is that a dummy should be sensitive to parameters that relate directly to injury mechanisms (e.g. impact speed), but should not be sensitive to parameters that do not correlate to injuries, such as temperature or small angle variations.

Head

For the head, the sensitivity to impact angle variation was investigated. In two impact conditions, the impact angle was varied ±10 degrees. In Figure 12 and Figure 13, the results are presented as the average measured peak resultant acceleration together with the maximum and minimum measured values. For the nominal impact direction, five (5) tests were completed and for the ±10 degrees impacts three (3) tests were completed.

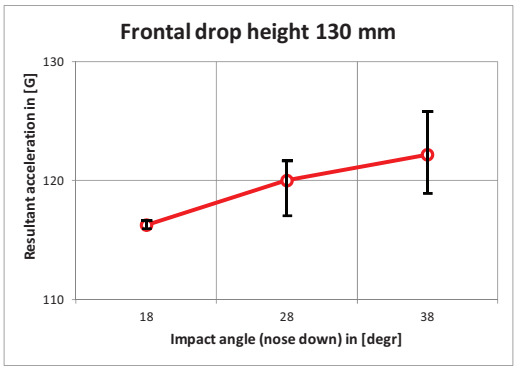


Figure 12: Frontal angle variation, 130 mm drop height

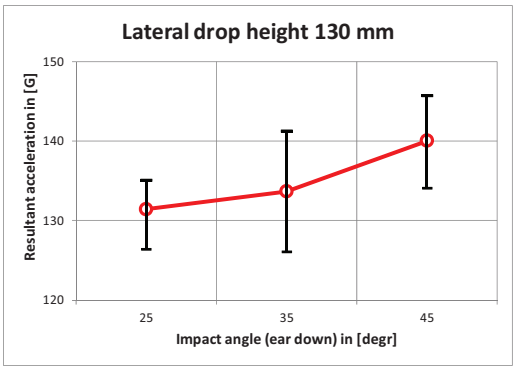


Figure 13: Lateral angle variation, 130 mm drop height

The small scatter at 18 degrees nose down impacts is not typical as a coefficient of variation of about 1 to 3% can be expected (see section on repeatability). From Figure 12 and Figure 13 it can be observed that the sensitivity found for ±10 degrees variation of impacts angle is in the same order as the variation that can be expected for repeated impact tests in a single test conditions. Compared to the variation that van be expected between two different dummies (frontal 138G±10% and lateral 143G±10%, see paragraph on Certification in this Chapter), the sensitivity is not large and is not considered to be significant. It can be concluded that the head response is not sensitive to small variations in the impact location.

Thorax

For the thorax, frontal impact sensitivity to impact speed and angular offset from the pure frontal were investigated. In Figure 14, the sensitivity of pendulum force and chest displacement (Dx) to impact speed is shown for impact speeds of 4.3, 5.5 and 6.7 m/s. For the angular offset sensitivity, the pure frontal impact test results at 4.3 m/s are compared with the results of impacts at the same speed with an angular off-set of 10, 20 and 30 degrees to the

left hand side (two tests for each offset direction). It is assumed that the sensitivity will be symmetrical for both sides. The results for the pendulum force are shown In Figure 15. In Figure 16, the results for the chest deflection are given. The small scatter found in some instances is not typical, a coefficient of variation (CoV) of about 1 to 3% can be expected (see section on repeatability). For chest deflection, the resultant displacement has been taken to allow for the combined X- (longitudinal) and Y- (lateral) displacement that can be calculated from the IR-TRACC and potentiometer signals. In Figure 17, the average 2-dimensional deflection trajectory of the sternum in X and Y direction is plotted for all four impact directions.

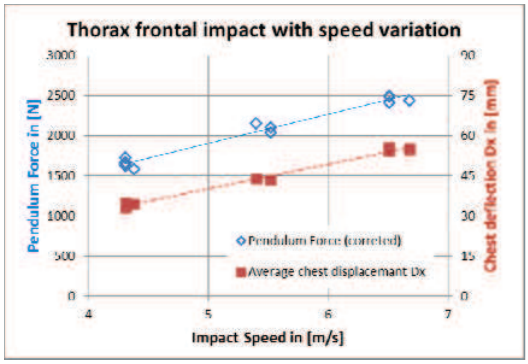


Figure 14: Thorax frontal impact results versus speed (total 12 tests)

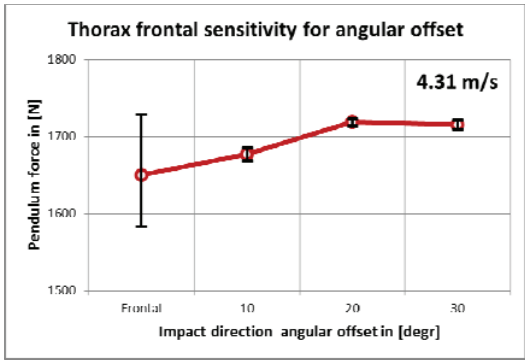


Figure 15: Pendulum force sensitivity for angular offset (total 11 tests)

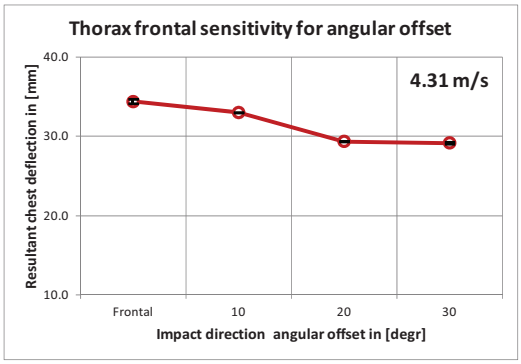


Figure 16: Chest resultant deflection sensitivity for angular offset (total 11 tests)

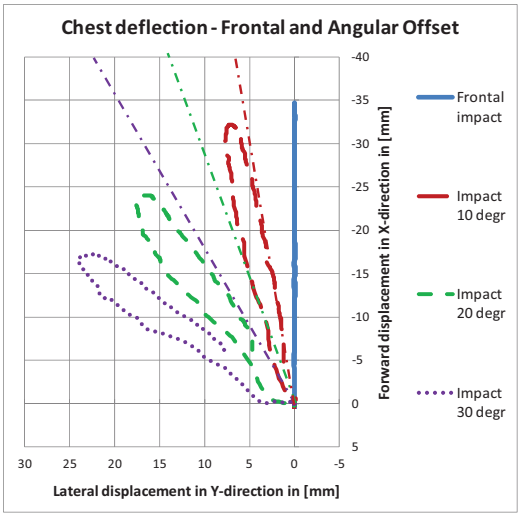


Figure 17: Chest sternum deflection in forward (X-) and lateral (Y-) direction for pure frontal and angular offset (straight lines indicate impact direction)

In Figure 14, the pendulum force and chest deflection show sensitivity to the impact speed, as desired (impact velocity would be expected to affect injury risk). For the angular offset sensitivity, the pendulum force increases slightly up to about 4% (Figure 15) whereas the resultant chest deflection decreases significantly up to about 15% (Figure 16). This may be because the 2D-IR-TRACC measures the displacement of the forward point of the chest, which is not optimal in the case of impacts with an angular offset. The X-Y displacement

plots given in Figure 17 clearly show that the pure frontal impact results in a pure longitudinal chest (X-direction) deflection. However, in the case of impact with angular offsets the lateral displacement measured at the forward 2D-IR-TRACC attachment points show an over proportional increase of the lateral sternum displacement. For 20 and 30 degrees angular offset, the 2D-IR-TRACC initially records a purely lateral chest displacement, later the deflection becomes an X-Y displacement. As a conservative approach, it is recommended to always assess the X-Y displacement to get the best possible indication of the chest deformation and to use the resultant deflection for injury assessment.

REPEATABILITY OF THE PROTOTYPE VERSION

The analysis below is performed on prototype version test data. The level of repeatability of dummy responses is often expressed as the Coefficient of Variation (CoV = Standard Deviation / Mean value). In component and full body impactor tests, that are considered to be highly repeatable, the number of variables involved is small. In those tests, the dummy, the impact pulse and the temperature of the setup are the main variables and a CoV of maximum 5% is considered to be acceptable [9]. For a proper statistically valid CoV, the minimum number of tests is six (6). The test series performed in this dummy validation exercise comprises, in general, a maximum of five (5) and a minimum of two (2) tests of the same test configuration, so the validity of the repeatability assessment would be limited. To overcome this limitation, an alternative approach is used: for each test configuration the results are normalised to the average result of the group. For any parameter, the CoV can be determined by calculating the standard deviation of all of the normalised results for that parameter. Below, per body region tables are presented that show the test configuration considered and the CoV values obtained per composed group. The associated number of tests in the (composed) group is given between brackets. If the number of tests is smaller than six (6), the CoV value is not statistically reliable. For an assessment of the Q10 production version dummy repeatability and reproducibility performance, see the paragraph on Certification at the end of this chapter.

Table 4: Head impact repeatability

Test configuration	Head Acc
Frontal impact 130 mm	1.59% (11)
18 degrees	2.83% (3)
28 degrees	1.53% (5)
38 degrees	0.31% (3)
Lateral impact 130 mm	2.50% (22)
25 degrees LH- and RH- side	1.29% (6)
35 degrees LH- and RH- side	3.59% (10)
45 degrees LH- and RH- side	1.19% (6)
Lateral impact 200 mm	2.65% (20)
25 degrees LH- and RH- side	2.11% (5)
35 degrees LH- and RH- side	2.24% (10)
45 degrees LH- and RH- side	4.21% (5)
All tests together	**2.35% (53)**

Table 5: Neck bending repeatability

Test configuration	Upper neck moment	Head form rotation
Flexion	2.04% (11)	0.67% (11)
4.7 m/s	1.62% (3)	0.27% (3)
4.8 m/s	2.46% (5)	0.99% (5)
4.9 m/s	2.47% (3)	0.48% (3)
Extension	4.03% (11)	0.80% (11)
3.6 m/s	4.81% (3)	0.75% (3)
3.7 m/s	5.31% (5)	1.11% (5)
3.8 m/s	1.79% (3)	0.43% (3)
Lateral Flexion	1.59% (11)	1.10% (11)
3.6 m/s	1.71% (3)	1.01% (3)
3.7 m/s	2.15% (5)	1.36% (5)
3.8 m/s	0.67% (3)	0.48% (3)
All tests together	**2.67% (33)**	**0.87% (33)**

Table 6: Lumbar spine bending repeatability

Test configuration	Lower lumbar moment	Head form rotation
Flexion	1.15% (11)	2.52% (11)
4.3 m/s	1.20% (3)	0.49% (3)
4.4 m/s	0.52% (3)	1.00% (3)
4.5 m/s	1.57% (5)	3.76% (5)
Lateral Flexion	1.68% (11)	1.69% (11)
4.3 m/s	2.45% (3)	0.21% (3)
4.4 m/s	1.55% (5)	2.63% (5)
4.5 m/s	1.81% (3)	0.55% (3)
All tests together	**1.40% (22)**	**2.11% (22)**

Table 7: Thorax impact repeatability

Test configuration	Pendulum force	Sternum deflection (X-direction)
Frontal impact		
4.3 m/s	3.26% (5)	0.66% (5)
5.5 m/s	2.79% (3)	0.80% (3)
6.7 m/s	1.67% (4)	0.84% (4)
4.3 m/s, fwd 10 degr	0.70% (2)	0.54% (2)
4.3 m/s, fwd 20 degr	0.40% (2)	2.58% (2)
4.3 m/s, fwd 30 degr	0.50% (2)	5.10% (2)
6.7 m/s, fwd 10 degr	1.01% (2)	2.21% (2)
4.3 m/s, tilt 12 degr	0.80% (2)	1.04% (2)
6.7 m/s tilt 12 degr	1.03% (2)	1.97% (2)
All tests together	**1.90% (24)**	**1.50 (24)**

For the frontal test, as shown in the tables above, none of the test configurations are considered to be outliers (CoV>7%). The results presented in Table 4 to Table 7 show good repeatability of the dummy (prototype). Nearly all combined CoV values remain below 2.5%. All of the coefficients of variation are within the required 5%. Overall, it is concluded that the Q10 dummy can be used as a repeatable tool.

MEASUREMENT CAPABILITIES

The Q10 dummy facilitates a large number of instrumentation options. In Figure 18, an overview of the available instrumentation options is given. In ANNEX E: Q-DUMMY a more extensive description of the possible instrumentation channels is given.

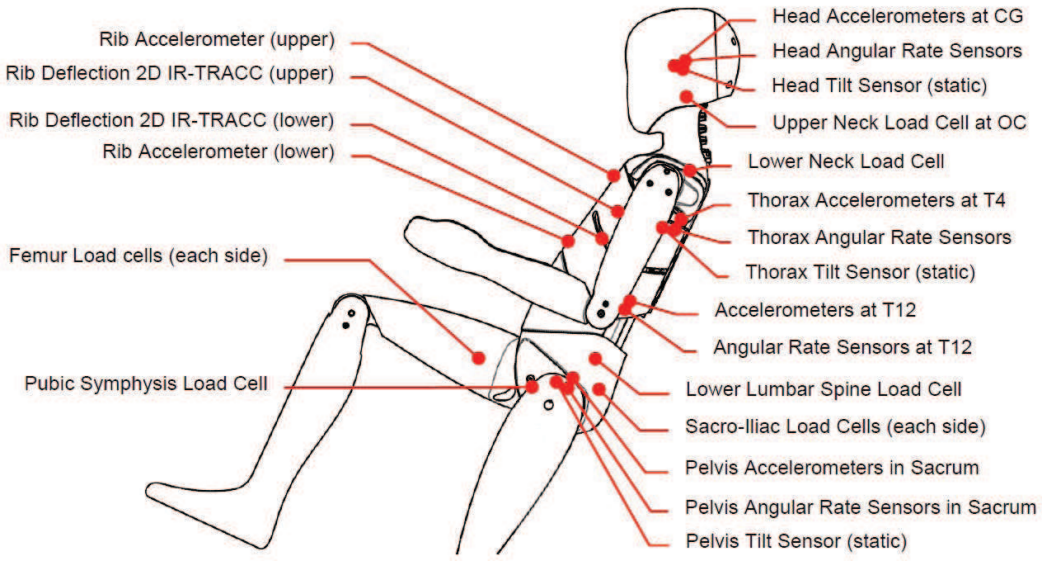


Figure 18: Q10 Overview of instrumentation options

DURABILITY

The 254 tests of the validation test program were performed in a dummy laboratory environment. The evaluation of the Q10 dummy under UN Regulation 44 and NPACS test conditions revealed some durability related issues on the neck, torso, lower legs and suit. Improvements related to these issues were implemented during the EPOCh project and found to be adequate. In addition to the EPOCh testing, the two prototype dummies have been exposed to numerous sled and full-scale tests since February 2012 (see Chapter 4). Although no major issues were found, some recommendations for updates were given and implemented in the production version of the dummy. See ANNEX F: UPDATES FROM PROTOTYPE TO PRODUCTION.

CERTIFICATION

The purpose of dummy certification is to safeguard consistent dummy performance in production and during operation of the dummy. Certification tests are often based on biofidelity tests. In October 2011, provisional certification procedures and corridors, based on the prototype performance, were set for internal use by Humanetics. The first production batches were tested to comply with these internal requirement. After collecting data from 18 production version dummies delivered to the market, final procedures and corridors were proposed in February 2014. There are no significant differences between the prototype performance and the production corridors. In this chapter, the final certification procedures and corridors are summarised. The lateral tests on shoulder, thorax and pelvis are not mentioned in the main text because these are not relevant for frontal impact. The corridor is according to engineering judgment proposed as: average value ±10%, which for the tests concerns generally appears to be about 2.4 times the Standard Deviation of the measured values. The corridor width is set larger for the abdomen, which is in line with the performance

corridors for the abdomens of the other Q-dummies. Using the 18 data sets, the repeatability and reproducibility of the production version dummy is assessed and reported.

Head

The head certification test set-up consists of a complete head including the accelerometer mounting hardware. Additional to the head, a half steel upper neck load cell replacement (mass 0.15 kg, part number TE-010-1007) should be mounted to the lower side of the head base plate. The head should be equipped to record the X, Y and Z accelerations filtered at CFC1000. From these results the resultant head acceleration should be calculated. The following certification test impacts should be performed:

Frontal

With the head tilted 28 ± 2 degrees nose down (from pure facial impact) and a drop height of 130 mm (as standard for Q-dummies), the corridors are:

- Maximum resultant acceleration shall be between 151.8 and 124.2 G
- Maximum lateral acceleration (Ay) shall be between +10 and -10 G

Lateral

With the head tilted 35 ± 2 degrees ear down (from pure lateral impact) and a drop height of 130 mm (as standard for Q-dummies), the corridors are:

- Maximum resultant acceleration shall be between 157.3 and 128.7 G
- Maximum frontal acceleration (Ax) shall be between +20 and -20 G

Neck

The necks must be certified with the standard Part 572 neck pendulum with a head form that replaces the actual head. Between the pendulum base and the neck lower plate a special interface ring should be used (part number TE-010-2015). Between the upper neck plate and the head form, the high capacity upper neck load cell (IF-217-HC) should be mounted. In the tests the pendulum acceleration (CFC180), the head form rotation obtained with the pendulum and head potentiometers (CFC600) and the upper neck moments Mx (lateral bending) and My (forward bending) (CFC600) should be recorded. Six inch honeycomb is used for the deceleration of the pendulum. The certification test procedures to be followed are:

Flexion

For the neck certification flexion test the pulse should be between the following boundaries:

- Pendulum speed: between 4.7 and 4.9 m/s
  - @ 10 ms: 1.0 – 2.0 m/s;
  - @ 20 ms: 2.3 – 3.4 m/s; and
  - @ 30 ms: 3.6 – 4.8 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 19.

The corridors are:

- Maximum upper neck moment (My) shall be between 28.80 and 35.20 Nm
- Maximum head form rotation shall be between 50.4 and 61.6 degrees

Extension

For the neck certification extension test, the pulse should be between the following boundaries:

- Pendulum speed: between 3.6 and 3.8 m/s
  - @ 10 ms: 0.7 – 1.7 m/s;
  - @ 20 ms: 1.7 – 2.8 m/s; and

- @ 30 ms: 2.8 – 4.0 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 20.
The corridors are:

- Maximum upper neck moment (My) shall be between -12.96 and -15.84 Nm
- Maximum head form rotation shall be between 56.7 and 69.3 degrees

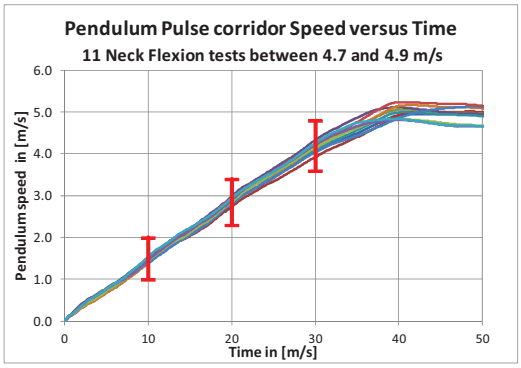


Figure 19: Pendulum pulse for neck flexion test

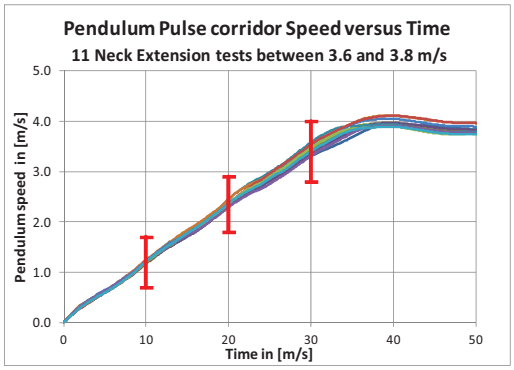


Figure 20: Pendulum pulse for neck extension test

Lateral flexion

For the neck certification lateral flexion test, the pulse should be between the following boundaries:

- Pendulum speed: between 3.6 and 3.8 m/s
  - @ 10 ms: 0.7 – 1.7 m/s;
  - @ 20 ms: 1.7 – 2.8 m/s; and
  - @ 30 ms: 2.8 – 4.0 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 21.
The corridors are:

- Maximum upper neck moment (Mx) shall be between 14.85 and 18.15 Nm
- Maximum head form rotation shall be between 45.9 and 56.1 degrees

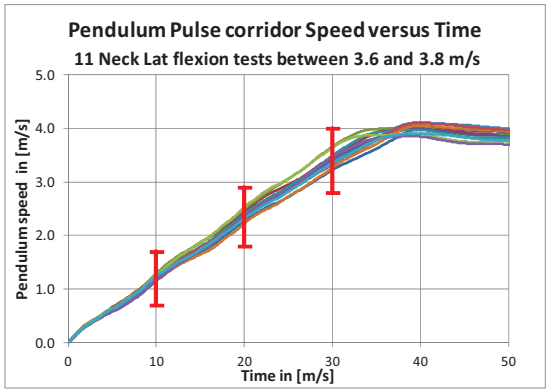


Figure 21: Pendulum pulse for neck lateral flexion test

Thorax

For the thorax certification, a full body frontal impact test should be performed with a six wire suspended pendulum (mass of 8.76 kg and an impact plate diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be purely frontal with

the pendulum centreline in the middle between the two IR-TRACCs to ribcage attachment screws. The dummy should be sitting with the thoracic spine vertical and the legs stretched forward on two sheets of PTFE (Teflon) to minimise the friction. In the frontal test the upper arms should be along the thorax sides. The pendulum acceleration (CFC180) and chest deflection from both 2D IR-TRACCs (IR-TRACCs and potentiometers at CFC600) should be recorded.
The corridors are:
Frontal

- Maximum pendulum force shall be between 1530 and 1870 N
- Maximum average IR-TRACC deflection shall be between 31.95 and 39.05 mm

Abdomen
The abdomen test is a component semi-static compression test. The abdomen should be removed from the dummy. The abdomen test compresses the abdomen between a Q10 abdomen certification support block that matches the shape of the rear side of the abdomen (Part number TE-010-9910) and a flat plate. The support is placed on a horizontal surface, and the abdomen is placed on the block with the front outer surface facing up. A guided flat plate should be placed parallel to the horizontal base plate (300 x 250 mm, 2.05 ± 0.05 kg) on top of the abdomen. The performance of the dummy abdomen is tested with an "Additional weight" (8.05 ± 0.05 kg) applied on the top plate and the additional flat plate intrusion is measured after 2 minutes ± 10 seconds. The only instrumentation necessary to perform this test is a calliper rule or dial test indicator to measure the distance difference between the two plate heights before and after application of the additional mass.
The corridor is:

- Additional intrusion shall be between 8.4 and 12.4 mm

Lumbar spine
The lumbar spine must be certified with the standard Part 572 neck pendulum with a head form mounted to the upper lumbar spine interface. A special head form central block (part number TE-2651-14) that allows for the offset in the upper lumbar spine mount should be used. Between the pendulum and the lumbar spine lower mount a steel load cell replacement of high capacity load cell (IF-217-HC) should be used. In the tests the pendulum acceleration (CFC180) and the head form rotation with the pendulum and head potentiometers (CFC600) should be recorded. The certification test procedures to be followed are:
For the lumbar spine certification flexion test the pulse should be between the following boundaries:

- Pendulum speed: between 4.3 and 4.5 m/s
  - @ 10 ms: 0.9 – 1.9 m/s;
  - @ 20 ms: 2.3 – 3.4 m/s; and
  - @ 30 ms: 3.4 – 4.6 m/s.

The pulse corridor and the pulses of the 11 flexion tests performed are shown in Figure 22 and 11 lateral flexion tests performed are shown Figure 23.
The corridors for both flexion and lateral flexion are:

- Maximum head form rotation shall be between 45.9 and 56.1 degrees
- Time of maximum head form rotation shall be between 60.30 and 73.70 ms

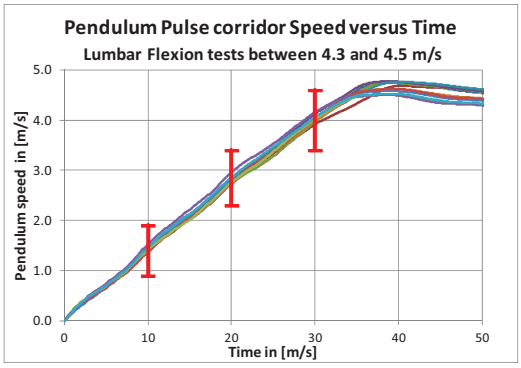


Figure 22: Pendulum pulse for lumbar flexion

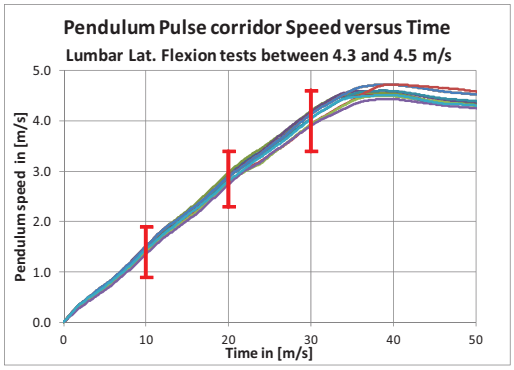


Figure 23: Pendulum pulse for lumbar lateral flexion

Repeatability and Reproducibility of production version dummy

Based on data sets obtained from the certifications of the 18 production version dummies, the repeatability and reproducibility of the Q10 dummy is assessed. The CoV values obtained for each composed group are provided in Table 8. The composed groups are detailed below. Between brackets the associated number of tests in the (composed) group is given. In general, there are two tests (one repeated test) per test mode per dummy available (2 tests * 18 dummies = 36 tests). For lateral tests, LHS and RHS can be combined and 72 tests are available.

For the Repeatability

- The two tests per test mode per dummy are grouped (18 groups of 2 tests).
- The results are normalized with the average of the group.
- The standard deviation of the normalized results is the coefficient of variation for repeatability.

For the Reproducibility

- All first tests per test mode are grouped and the second test are grouped (frontal: 2 groups of 18 tests or lateral: 4 groups of 18 tests)
- The results are normalized with the average of the group.
- The standard deviation of the normalized results is the coefficient of variation for reproducibility.

Table 8: Repeatability and Reproducibility of production version in certification tests

Test configuration Mode	Parameter	Repeatability CoV = StDev / Mean	Reproducibility CoV = StDev / Mean
Head impact			
Frontal	Max Resultant acceleration	0.40% (36)	2.29% (36)
Lateral	Max Resultant acceleration	1.39% (72)	3.76% (72)
Neck pendulum test			
Flexion	Max D-Plane Rotation	1.50% (36)	4.16% (36)
	Max Occipital Moment	2.20% (36)	3.74% (36)
Extension	Max D-Plane Rotation	1.51% (36)	2.83% (36)
	Max Occipital Moment	3.51% (36)	5.16% (36)
Lat. flexion	Max D-Plane Rotation	1.45% (72)	2.49% (72)
	Max Occipital Moment	0.91% (72)	1.72% (72)
Thorax frontal impact (full body)			
Frontal	Max Pendulum Force	1.70% (36)	3.32% (36)
	Max Sternum Deflection	1.14% (36)	5.15% (36)
Lumbar pendulum test			
Flexion	Max D-Plane Rotation	1.82% (36)	3.56% (36)
	Time at Max Rotation	1.33% (36)	2.97% (36)
Lat. Flexion	Max D-Plane Rotation	1.48% (72)	3.58% (72)
	Time at Max Rotation	1.58% (72)	2.67% (72)
Abdomen test (static intrusion)			(see note)
	Deflection at 10.1 kg	*No repeated tests available*	11.11% (18); (10.10% (17))
All modes together		**1.61% (684)**	**(3.64% (701))**

Note: First value: all 18 tests - Second value: all tests that comply with final certification corridor

All the coefficients of variation are well within the required 5% for repeatability and 10% for reproducibility. Overall it is concluded that the Q10 production version dummy can be used as a repeatable and reproducible tool.

SUMMARY AND CONCLUSIONS

Two prototype Q10 dummies were extensively evaluated for anthropometry, biomechanical performance, sensitivity, repeatability and durability to impact loading in head drop, neck pendulum and full body wire pendulum tests. Moreover, certification procedures were developed. Later, the certification test results of 18 production version dummies were used to set final certification corridors and to assess repeatability and reproducibility.

Biofidelity

For frontal loading conditions, it can be stated that the Q10 dummy meets most of the biomechanical targets specified in the design brief developed in the EPOCh project (ANNEX C: Q10 DESIGN BRIEF). In line with the Q dummy methodology, these biofidelity requirements are mainly based on scaled adult data in component and certification-type of tests. For the abdomen, no biofidelity evaluation testing was done in EPOCh, however limited testing performed on a prototype dummy within CASPER suggests that the abdomen response is likely to be within the biofidelity corridor defined within EPOCh (see Chapter 5 and corresponding ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT concerning the abdominal response and instrumentation). EEVC recommends to evaluate the Q10 dummy, preferably side by side with other dummies of the same size, in other conditions

that are relevant for the dynamic performance of CRS and restraint conditions on a bench or in vehicles, and in particular, evaluation in the following tests is suggested:

- Comparisons with tests from (Kallieris 1976) [10], which have been reproduced with HIII 10yo dummies (Ash, et al, 2009, ESV) [11].
- Comparisons with additional regional response (e.g. Ouyang et al., 2006 [12], Kent et al., 2011 [13], Chamouard et al., 1996[14])
- Characterisation of contribution of the abdomen vertical compression to the flexion response of the lumbar region.

Sensitivity

Sensitivity studies show that the dummy is sensitive to variations in impact speeds, impact direction and alignments as desired with regards to injury risk assessment.

Repeatability and Reproducibility

Repeated tests conducted on the prototype version show generally small variations in response of less than 2.5%. All the coefficients of variation are within the required 5%. Repeated tests on 18 production version dummies show generally small variations in response: less than 2.0% for repeatability and less than 5% for reproducibility. It is concluded that the Q10 dummy can be used as a repeatable and reproducible tool.

Durability

Some initial durability issues were found and successfully solved during the prototype testing. Some further recommendations for updates were implemented in the production version dummy.

Certification

The purpose of dummy certification is to safeguard consistent dummy performance in production and during operation of the dummy. The first production batches were tested to comply with internal requirement based on the prototype performance. After collecting data from 18 dummies delivered to the market, the final procedures and corridors were proposed in February 2014. There are no significant differences between the prototype performance and the production certification corridors.

4 EPOCh AND THIRD PARTY EVALUATION

Within the EPOCh project [2], sled tests according to the NPACS-protocol (task 3.1) and UN Regulation 44 (task 3.2) were performed to assess the ability of the Q10 dummy as a measurement tool. After The EC-EPOCh project, the two prototype dummies were used in a third party evaluation test program. In two meetings with third party testing participants, the results of their testing were discussed and recommendations and feedback were compiled. Recommendations and feedback from the EPOCh evaluation as well as from third party testing participants was addressed in the design of the Q10 dummy production version, see ANNEX F: UPDATES FROM PROTOTYPE TO PRODUCTION VERSION. In this chapter the results of these test series are summarised.

TEST PROGRAM

EC-EPOCh sled test according NPACS Protocol

Both prototype Q10 dummies were used in an extensive test program at IDIADA (Spain) and TRL (UK) (see ANNEX G: EPOCh EVALUATION TESTS):

- IDIADA and TRL performed 115 tests (in general three repeats) to investigate:
  - Q10 sensitivity to restraint loading from variation in test setup
  - Q10 sensitivity to differences in child restraint design
  - Q10 durability

EC-EPOCh sled test according UN R44

Both prototype Q10 dummies were used in an extensive test program DOREL (France) and TRL (UK) (see ANNEX G: EPOCh EVALUATION TESTS):

- DOREL preformed 64 tests (in general three repeats) to investigate:
  - Q10 sensitivity to restraint loading from variations in test setup
  - Q10 sensitivity to differences in child restraint design
  - Q10 durability
  - Q10 ability to recover between tests
- TRL performed 50 tests comparing Q10 and P10 (four of these with Hybrid III 10yo) to investigate:
  - Relation of loading measured by the Q10 to the kinematics of the dummy.
  - Ability to detect differences in loading when the test set-up is varied with respect to dummy positioning.
  - Ability to picking up differences in child restraint design with regards to kinematics and measured loading.
  - Durability and maintenance aspect of long term dummy operation compared to P10 operation.
  - Comparison of Q10 and P10 with regards to kinematics and measured loading.

Third party evaluation test program

After completion of the EPOCh project evaluation testing in September 2011, the two prototype dummies entered a third party evaluation program. Many parties from Japan, America and Europe borrowed the dummies to examine a large variety of operational aspects such as belt and airbag interaction, comparison with other dummy types, repeatability and reproducibility, robustness and sensitivity to restrain system features, including pre-tensioners

and load-limiters. The results of the third party tests are globally mentioned here. For some studies, more details are given because these are considered to complement the data reported in Chapter 3, DUMMY DEVELOPMENT AND EVALUATION IN CERTIFICATION TYPE TESTING

RESULTS

EC-EPOCh sled test according NPACS Protocol

The following summary was derived from EC-EPOCh testing according to the NPACS-protocol (for detailed results, see the EPOCh Project Dissemination (POCC 2011) [17]):

- The Q10 displayed different dummy readings when the installation of the dummy was altered. As an example, Figure 24 shows the pelvis acceleration versus time in NPACS tests with a belt tension of 100 N compared to baseline tests with 50 N belt pretension. The signals show, in the case of increased belt pretension, an earlier onset and a lower maximum pelvis acceleration (100N: 59 G instead of 50N: 68 G). The results of both test setups show good repeatability.

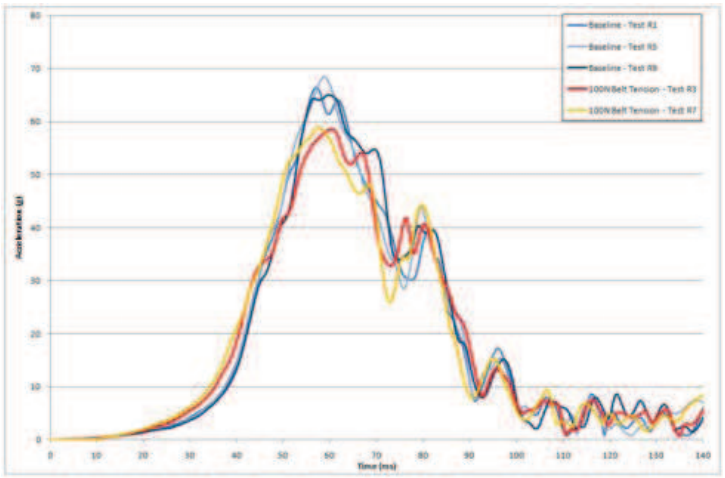


Figure 24: Pelvis acceleration in NPACS tests with belt pretension variation Blue: Baseline pretension (50 N) Red and Yellow: Increased pretension (100 N)

- The main objective of the sensitivity to child restraint design testing was to assess whether the Q10 dummy was capable of picking up differences between child restraints. From the analysis of the results, it was concluded that the dummy produced different results, depending on the particular child restraint tested. Figure 25 highlights differences seen in the head accelerations measured by the Q10 in front impact tests to investigate sensitivity of the Q10 to child restraint design. These differences demonstrate that the Q10 dummy was sensitive to child restraint design.

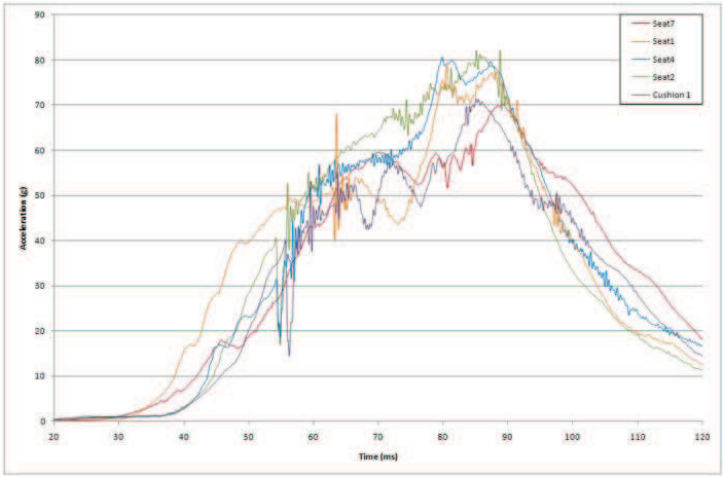


Figure 25: Head resultant acceleration in NPACS tests with five CRS types
Seat 7: Red, Seat 1: green, Seat 4: blue, Seat 2 orange and Cushion 1: purple

- The results from the NPACS durability frontal impact testing generally showed good repeatability. This was consistent with the repeatability found in the restraint loading and sensitivity to CRS design frontal impact testing. Overall, the durability of the Q10 dummy was good in the front impact testing. There were a few parts that required improved durability. Design improvements of these parts were incorporated into the production version. Some design updates to reduce the number of maintenance checks are recommended (see for the Q10 design updates ANNEX F: UPDATES FROM PROTOTYPE TO PRODUCTION VERSION).
- Base on test series with test intervals of 30 minutes and shorter, it is recommended to maintain a minimum 30 minutes time interval between subsequent tests that loads the same area. If this recovery time is maintained, repeatable results can be expected.

EC-EPOCh sled test according UN R44

The following summary was derived from EC-EPOCh testing according to UN Regulation 44. (For detailed results, see the EPOCh Project Dissemination (POCC 2011) [17]):

- General Observations
  - The abdomen foam insert seemed to balloon and pop out of its position. This was attributed to limited air venting to cope with volume change resulting from torso flection. This phenomenon was also reported by one of the third party test participants. In the production version, six additional vent holes were applied.
  - The lap belt became trapped between the pelvis and upper leg in some tests. Patches on the suit were introduced to mitigate this effect. Hip shield were introduced later.
  - The diagonal belt became trapped in the slot between the upper and lower part at the side of the ribcage in some tests. This was observed in very few instances. Several measures were considered to prevent this; however, the application of a Cordura cover at the front of the suit jacket appeared to be sufficient.

  - On durability and maintenance, the following summary of problems reported and final countermeasure was given:
    - The suit torn under the arms - Stitching improved
    - Rubbing wear of the suit - Cordura front on suit jacket
    - Feet were found too flexible - Tibia extended into the foot
    - Knee stops failed - Use of threaded inserts
    - Cable bay cover cracked - Material changed (higher strength)
    - Cracks in ribcage - Material changed (higher strength)
    - Some screw became loose easily - Use of self-locking Helicoils
- Sensitivity to variation in dummy installation
  - Unexpectedly, the presence or removal of the spacer used for belt tightening did not make a significant difference. This was attributed to the fact that the Q10, like the other Q-dummies, has a rigid thoracic spine. As a result, the Q-dummies remain more upright than P10 and other P-dummies (see Figure 31 and Figure 32 for illustration of this effect).
  - A clear difference between tests with 50 N (standard for UN R44) and 100 N belt pretension was exhibited with respect to Head excursion (Comparing the means of three tests at 50 N: 362 mm, and of three tests at 100 N: 340 mm), Chest X acceleration (High pretension results in earlier and higher peak values), Pelvis X acceleration (High pretension results in earlier onset of the pelvis acceleration) and Upper Neck My (50 N: 14 Nm 100 N: 11 Nm)
  - Different arm positions resulted in significant differences in Chest X acceleration at 60 to 72 ms (Hands on lap: peak 31 G, Lower arms up or arms stretched to knee: peak 37 G).
- Sensitivity to child restrain design (four different CRS designs)
  - Head excursion: Horizontal and vertical head excursion seemed to be related to the particular CRS that was tested (Figure 26): Seat 1 and 4 showed repeatable results. Seat 7 tests were less repeatable but the tests showed consistently the largest vertical excursion, as expected as this seat had the tallest base-pan. Cushion 1 tests showed more variable horizontal excursion and the smallest vertical excursion similar to Seat 4. This was expected because Cushion 1 and Seat 4 had the slimmest seat-pans. Therefore, the Q10 demonstrated sensitivity to differences in the design of CRS with regards to head excursion.

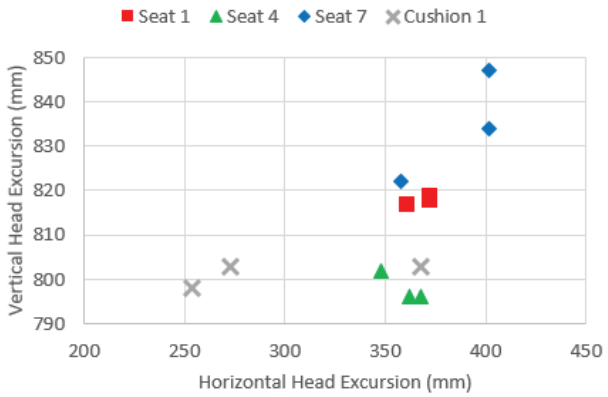


Figure 26: Vertical versus horizontal head excursion for four CRS types

- Head acceleration

  The head X-acceleration time histories showed a character that was specific to the particular CRS that was tested (Figure 27, top): The cushion-type CRS reached the maximum head acceleration earliest, as expected. The Seat 7 tests showed three remarkable phenomena compared to the other CRS: an acceleration plateau between 65 and 80 ms, flattened peak and early contact with head rest padding. The character of the signals of Seat 1 and 4 were similar.

  The Head Z-acceleration time histories also showed characteristics that were specific to the CRS that was tested (Figure 27, mid): The cushion-type CRS reached the maximum head acceleration earliest, as expected. The Seat 7 tests show a domed peak during the period of time that their X-accelerations show a plateau (between 65 and 80 ms), flattened peak and early contact with head rest padding. The peaks for Seat 1 and 4 occurred relatively late while the character of those two was similar.

  The CRS specific characters of the X- and Z-acceleration history show up in the Head Resultant acceleration with less or more pronounced double peaks.

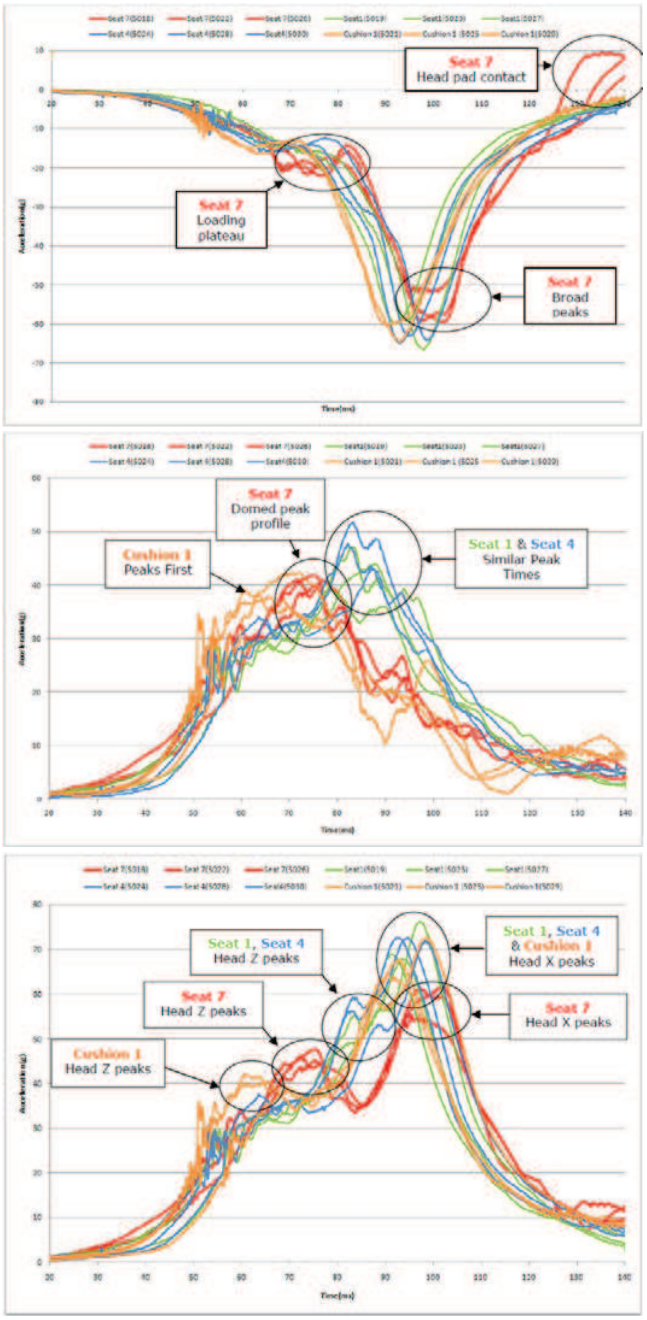


Figure 27: Head acceleration history for four CRS types
Top: Head X-acc, Mid: Head Z-acc, Bottom: Head resultant acc
Seat 1: green, Seat 7: Red, Seat 4: blue and Cushion 1: orange

- Neck force and moment

  The general shape of the Upper neck Fz signal was almost the same for all CRSs with small differences in timing and level: The peaks for Cushion 1 occurred first (3000-3400 N) followed by Seat 1 (3400-3900 N) and Seat 4 (3500 N) and finally Seat 7 (2500-3050 N).

  The character of the Lower neck My signal was almost the same for all CRSs tested with small differences in timing and level: The peak for Cushion 1

occurred first (190-200 Nm) followed by Seat 1 and 4 (230-250 Nm) and finally the peaks of Seat 7 (165-200 Nm) occurred.

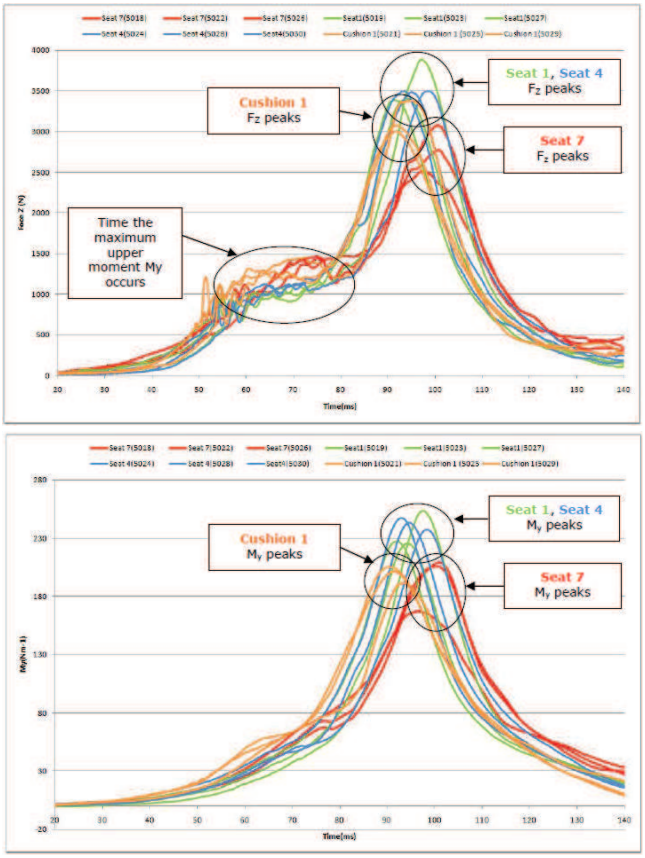


Figure 28: Neck load history for four CRS types
Top: Upper neck Fz, Bottom: Lower Neck My
Seat 1: green, Seat 7: Red, Seat 4: blue and Cushion 1: orange

- Chest acceleration

  The general shape of the chest acceleration history did not show much difference between the CRSs (Figure 29): Extra peaks were observed for Seat 7 and Cushion 1 and one of the tests with Seat 4 had a lower acceleration in the period 50-80 ms than all other tests. The values for the Chest acceleration 3ms were: Seat 1 and 4: 35 g (one Seat 4 test: 31 g), Seat 7: 34 g and Cushion 1: 37 g. This followed a trend whereby this CRS had the smallest head excursion compared with the others, which meant that the chest was decelerated over a shorter distance and therefore the decelerations were higher.

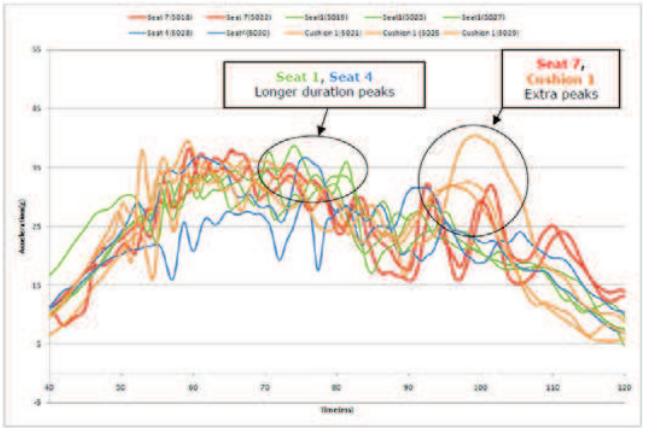


Figure 29: Chest resultant acceleration history for four CRS types
Seat 1: green, Seat 7: Red, Seat 4: blue and Cushion 1: yellow

- Pelvis acceleration

  The Pelvis X acceleration history showed CRS specific details for all four CRSs (Figure 30): Distinct groups for the peak Pelvis X-acceleration were observed for Seat 7 and Cushion 1. The three seat-type CRSs displayed a secondary peak whereas the cushion-type did not show this trend. Seat 7 exhibited a positive acceleration in the rebound phase. These findings show that the Q10 was affected by the design of CRS in the pelvis region.

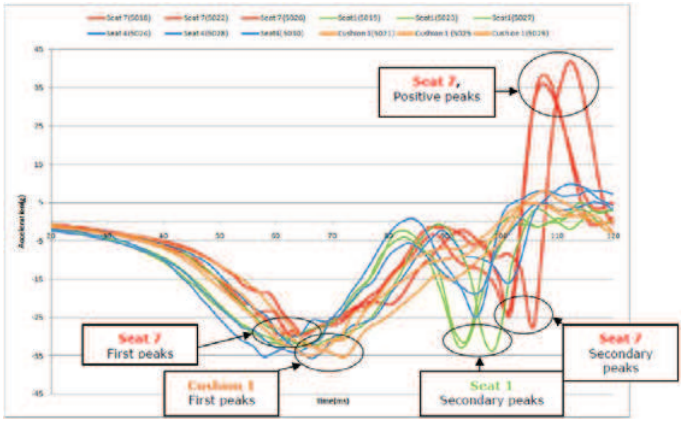


Figure 30: Pelvis X-acceleration history for four CRS types
Seat 1: green, Seat 7: Red, Seat 4: blue and Cushion 1: yellow

- Seat belt loading

  The diagonal belt force versus time for all three Seat 1 tests were grouped together, separate from the loading obtained for the other three CRS's at 55 to 80 ms. The lap belt load for all three Seat 1 tests started the loading curve at 20 to 47 ms before the other three CRS's. This showed that the seat belt loads were sensitive to the particular child restraint.

  Overall, variations between repeat tests were sometimes of a similar amplitude as those between different CRSs, but the shape of the signal seemed consistent for a given CRS and studying the repeatability of the setup was not the objective of the study.

- Comparison of P10 and Q10
    - Figure 31 shows typical differences observed in Q10 and P10 dummy kinematics at the moment of maximum head excursion. The head excursion was smaller with the Q10 than the P10, and differences in upper thorax kinematics are visible on the figure. The EPOCh consortium concluded that this will require the current UN R44 limits to be adjusted to provide an equivalent assessment with the new dummy. This phenomenon seems similar to the observation reported by Sherwood et al. (2003) [15] who compared the response of a dummy with a rigid thoracic spine (HIII) with a paediatric cadaver as shown in Figure 32.

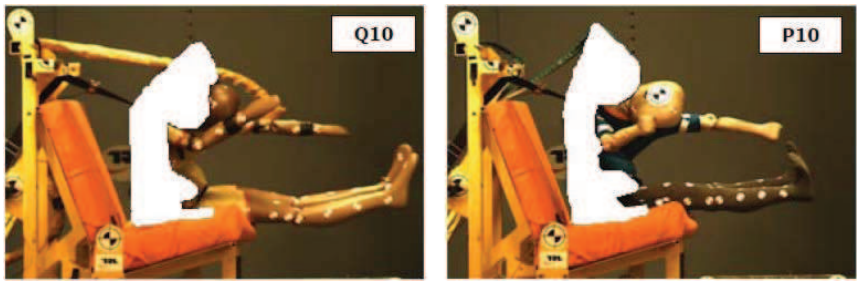


Figure 31: Q10 and P10 position at moment of maximum head excursion

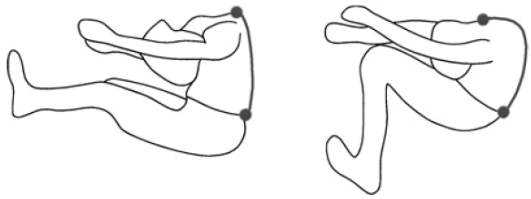


Figure 4 Schematic of face contact in dummy (left) and cadaver (right) in three-point belt tests. The highlighted spine segment represents the spine from T1 to midlumbar.

Figure 32: Dummy versus cadaver torso flexion in 3-point harness (illustration from Sherwood et al., 2003) [15]

Third party evaluation test program

Following the EPOCh evaluations, two instrumented Q10 prototype dummies were made available to third parties for further evaluation testing. A wide variety of tests were performed by research labs, restraint manufacturers, OEMs and consumer organisations world-wide to investigate the dummy performance in a range of conditions. The tests included sled tests on a body-in-white as well as full-scale crash tests. In two meetings (May and September 2012) third party testing participants presented the results of their testing. The results were discussed and recommendations and feedback were compiled and taken on board in the definition of the production version dummy. In Figure 33 two cross plots of maximum prototype dummy results from EPOCh project and third party testing up to September 2012 are given [16]:

- Maximum Head A3ms versus Maximum Chest A3ms
- Maximum Head A3ms versus Maximum Upper neck My.

The results are normalised to the performance criterion values recommended by EPOCh for UN R44 testing [17]. The data points are distinguished by type of testing:

- Grey data points: EPOCh and UN R44 sled testing
- 4: Consumer organisation, sled tests
- 5: OEM, Full scale offset barrier tests with dummy in left and right rear seat
- 6: OEM, Body-in-White (BIW) tests with Z-rotation
- 7: OEM, BIW sled tests
- 8: CRS manufacturer and Consumer organisation, UN R44 and BIW tests with Abdomen Pressure Twin Sensors
- 9: Restraint supplier, BIW side-by-side repeatability and reproducibility tests
- 10: Restraint supplier, BIW tests with pre-tensioner and load-limiter

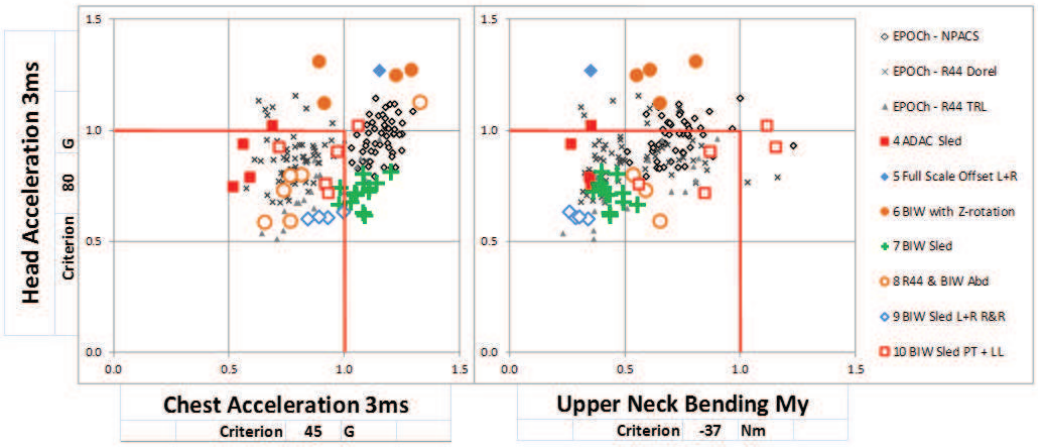
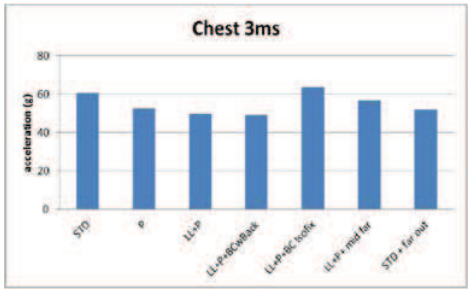


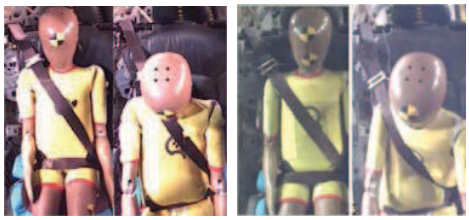
Figure 33: Cross plots of prototype dummy test results (up to September 2012)
Maximum values normalized to criterion limits recommended by EC-EPOCh for UN R44 testing

Figure 33 shows that NPACS test conditions resulted in higher load levels, as expected considering the severity of the pulse. Results for full scale vehicle tests or sled tests representing full scale vehicle impacts generally fell somewhere in between the outcome of NPACS and UN Regulation 44. The high head acceleration 3 ms results found in some tests was also attributed to rebound impacts.

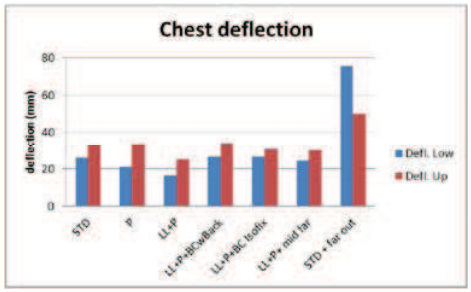
The following studies reported in conferences are briefly summarised:

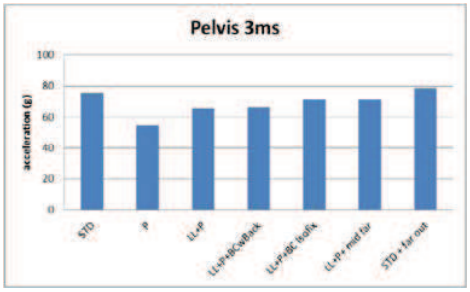
- Bohman and Sunnevang (POCC 2012) [18]
  In seven (7) frontal impact Body-in-White sled tests, the effect of several restraint system variations such as pre-tensioner, load-limiter, shoulder belt position, CRS (booster cushion, booster cushion with back rest and inflatable cushion) were explored using the Q10 prototype. In Figure 34, some results for frontal impact for restraint feature variations are given.





Left: STD and right: STD+ far out at 0 and 110 ms





Abbreviations

STD	Booster cushion (BC) only, Shoulder belt (SB) mid
P	BC+ Pre-tensioner (P), SB mid
LL+P	BC+ Load limiter (LL) + P SB mid
LL+P+BC w B	BC with Backrest + LL + P SB mid
LL+P+BC ISOfix	BC ISOfix + LL+ P SB mid far
LL+P+ mid far	BC+ LL+ P SB mid far
STD + far out	BC, SB far out

Figure 34: Side and frontal impact results for restraint feature variations

The authors concluded that the Q10 was sensitive to various countermeasures in frontal sled tests, although belt geometry was found to be the most important parameter affecting the chest deflection. Although the belt moved towards the neck resulting in low chest deflection in most cases, it stayed more in the centre of the chest when the "far out" belt anchor was used, and the lower part of the belt got stuck below the lower rib. Such sensitivity to belt routing is commonly observed in frontal impact dummies. It results from the dummy design, measurement locations used and injury criteria applied. See e.g. Kent, R., Patrie, J. and Benson, N. (2003) [19]. A benefit of the Q10 in this respect is that it has two 2-D IR-TRACCs. One located in the upper chest, one located in the lower chest. The entrapment of the lap belt into the gap between thigh and pelvis was also described in the paper and suggested to be more prominent with a pre-tensioner. The dummy was equipped with lap patches that were later replaced with a shield.

- TRL table top testing [20]
  In test series performed parallel to the work done in the EC-project THORAX, the Q10 was subjected to table top tests. This work was an extension of the usual biofidelity assessment. The table test work was carried out with the Q10 to investigate the thoracic biofidelity in more detail, and in particular, the regional thoracic stiffness under diagonal belt loading in comparison with adult requirements. The results for the Q10 are reported in the EPOCh project [20]. Figure 35 shows the Q10 prototype dummy in the table top test set-up at TRL.

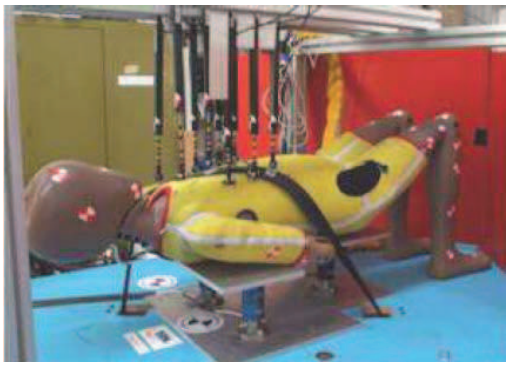


Figure 35: Q10 dummy in TRL table top test

Figure 36 presents the chest deflections relative to the displacement of point 1 on eight thorax points in belt loading table top tests compared with THORAX-project requirements and Hybrid III results. The THORAX-project requirements [21] for table top diagonal belt tests are based on work of Cesari and Bouquet (1994) [22].

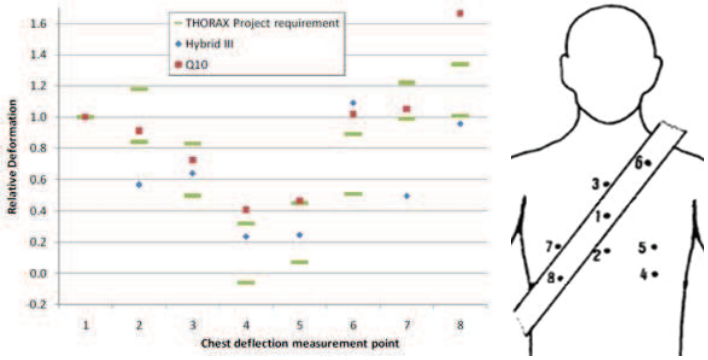


Figure 36: Chest relative deflections on eight thorax points in belt loading table top test compared with THORAX-project requirements and Hybrid III results.

TRL observed that the Q10 chest meets the requirements with the exception of points 4, 5, 6 and 8. For each of these points, the dummy allowed too much displacement. These points related to the lower left of the thorax (away from the diagonal belt), the belt-loaded left clavicle and the point below the belt to the lower right of the thorax. From the results, it seems that the Q10 response showed similar trends to the responses obtained previously with adult PMHS, and in this regard, demonstrated good biofidelity. It is impossible to comment on the biofidelity of the Q10 in relation to other older child dummies as the Hybrid III 10yo and the P10 have not been evaluated under the same test conditions.

EEVC WG12 observations on table top test results

EEVC considers that the Q10 ribcage has a continuous bending stiffness all over the rib bow from spine to spine whereas the human has a significant lower bending stiffness in the sternum region. This may contribute to the overestimation of the deflection of point 4, 5, 6 and 8. The P10 dummy would not give meaningful results in table top tests because its chest is not deformable. In conclusion, it can be stated that the Q10 shows a humanlike trend, which is not at all represented in the P10 dummy. In line with the other

Q-dummies, the lack of reduced sternum bending stiffness leads to slightly overestimated deflection on 4 of the 8 points. Also, a recent study on the Q6 (Beillas et al., IRCOBI 2014) [23] suggests that the upper ribcage of the Q6 dummy is softer than the centre region in quasi-static loading (a trend that was not found in human models), which may also explain some of the overestimation on the edge of the ribcage.

- Arbogast et al. (IRCOBI 2013) Q10 belt interaction comparison with volunteer data
  Arbogast et al. [24] performed a series of male child human volunteer sled tests. Three of the children matched the size of the Q10 and were used to compare the shoulder belt response of the Q10 with child dummy response. The crash pulse was based on amusement park bumper car impacts. Occupant delta-V in the tests was 2.58 m/s and peak acceleration level was 4.3 g. Subjects were restrained using an automotive three-point belt system. In the volunteer tests, it was found that the shoulder belt moved laterally toward the neck and then away from the neck (sometimes moving back beyond the starting (base) point). This response was also observed in the Q10, but the absolute movement to the neck of the belt in the Q10 was greater in comparison to the volunteer tests. Tests were also carried out with the Hybrid III 10 year child dummy and the heavier and taller 5th percentile small female adult Hybrid III dummy. In these two dummies, the lateral shoulder belt motion to the neck was smaller than that observed with the Q10. The return to the starting (base) point was less in the Hybrid III 10 year old and not present at all in the Hybrid III 5th percentile small female. The authors concluded that, qualitatively, the Q10 best mimics the shoulder belt motion but that the lateral motion of the shoulder belt in all tested ATDs may underestimate the chest deflection, due to the principal loading being away from the chest deflection sensor.

- Croatto and Masuda, Toyota and JAMA (ESV 2013) [25]
  This paper compares the sensitivity of the Q10 and Hybrid III-10yo ATDs to pre-tensioner and force-limiter equipped 3-point belts, and to high back booster CRS. The Body-in-White sled tests were performed with a uniaxial (no pitch and yaw representation) compact car 64 km/h ODB acceleration pulse under 4 different test situations: Without and with pre-tensioner and force limiter seat belt and without and with CRS. The Q10 was, in addition to its standard instrumentation, equipped with abdomen pressure sensors described in Chapter 5 and ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT. In line with the results of the present study, belt sliding to abdomen and neck have been reported for HIII 10yo to be less common when using CRS and chest deflection was reported to be higher when using a CRS. In this study, differences in the chest deflection sensitivity to restraint systems were observed between the Q10 and HIII 10yo dummies. These differences presumably originated from the difference in behaviour of the shoulder belt on the dummies' chest. In all tests, the Q10 exhibited a sliding up of the shoulder belt towards the neck, whereas no sliding of the shoulder belt was observed for the HIII. For both dummies, the chest deflection was decreasing as the lap belt was sliding up towards the abdomen.

It cannot be concluded whether these belt sliding phenomena represent human characteristics or if it is a dummy artefact. The phenomenon of belt migration towards the neck for Q10 was reported by Bohman and Sunnevang, (POCC 2012) [18]. Further investigation is needed. The authors recommend using the abdomen pressure sensor when assessing restraint system performance as it seems to be able to identify differences in the phenomenon of lap belt migration.

- TRW study on rear seat protection for all occupant sizes (POCC 2013) [26]
  This study utilised the Q10 dummy on the rear seat, as proposed for the EuroNCAP protocol in 2016. The effectiveness of several occupant protection measures for frontal impact such as belt pre-tensioner and load limiter, inflatable belt and airbags (in several design concepts) were evaluated. Figure 37 shows the summary of the results obtained with the Q6 and Q10. The reference values used to normalise the results were the FMVSS 208 OOP reference values.

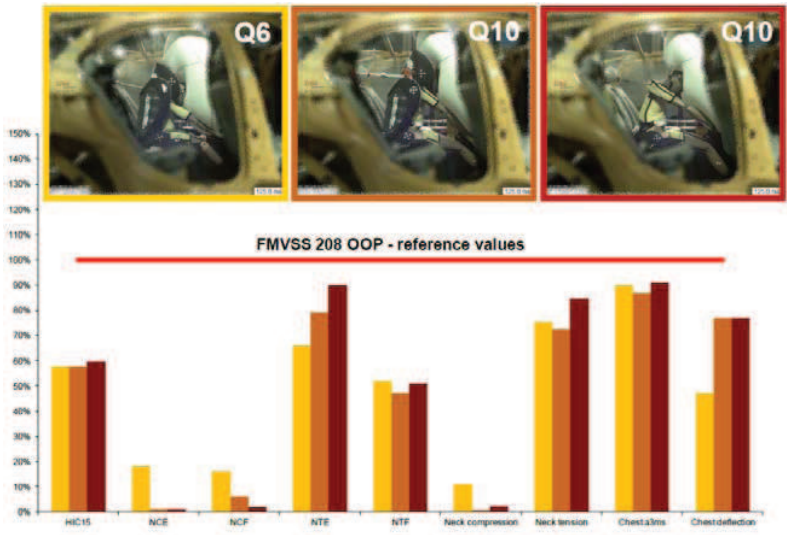


Figure 37: Q6 and Q10 dummy loads and kinematics in EuroNCAP 64 km/h sled tests Left: Q6 in "full size" group 2-3 ISOfix CRS (yellow), Mid: Q10 in "full size" group 2-3 ISOfix CRS (light brown), Right: Q10 on ISOfix booster cushion only (dark brown)

EEVC concludes that the Q10 is sensitive to differences in restraint system characteristics. Moreover, no specific issues in terms of dummy response, damage or permanent deformation were reported as a result of the interaction of the Q10 with the tested airbag systems.

- Lap belt interaction experiences at ADAC, Transport Canada and BASt
  The following gives information on non-published results. These results are included because of their relevance for lap belt interaction, as referred to in Chapter 5 of this report.
  With the Q10 on the UN R44 bench without booster cushion, the lap belt routing is not optimal and it may be possible that submarining occurs. This could be desirable behaviour for a test designed to evaluate the protection provided by a booster CRS as

such CRS have been shown to reduce the risk of abdominal injury. However, in several tests with the Q10 prototype in this condition no submarining was observed (one setup is described in ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT). Some test results relevant for the issue of submarining are mentioned here (unfortunately these results are not published yet):

- ADAC tested the Q10 prototype with APTS and hip shields on the rear seat (without the seat in front) in a body-in-white. One test without and one with booster seat with backrest. Figure 38 shows stills from the video of both test conditions at 100 ms. It can be observed that in the test without booster seat, the lap belt shifts over the ASIS-points (Anterior Superior Iliac Spine) of the dummy pelvis. These tests are also described in ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT.

Figure 38: ADAC Q10 prototype tests on the rear seat without seat in front in a BIW, without (left) and with booster cushion (right) (Stills from videos at 100 ms)

- Transport Canada conducted paired comparison tests with the Q10 and Hybrid III 10yo seated in the outboard positions of the rear in five full width full scale tests in 2013/2014. The hip shields were not used. In these tests it was observed that the upper leg flesh shifted forward 15 to 30 mm at the level of the knee. The trochanter appeared to protrude from the flesh by approximately 60 to 80 mm. In Figure 39 the shift of the upper leg flesh during one of the tests is illustrated. As a result, the gap between the pelvis and the thigh flesh opens up, exacerbating the lap belt intrusion and contact with the upper femur hardware. In the Q10 production version, a plug to restrain the upper leg flesh to the femur is introduced in the upper femur region as shown in Figure 40. Transport Canada will repeat these tests in the future to evaluate the effect of the femur modification and hip shields.

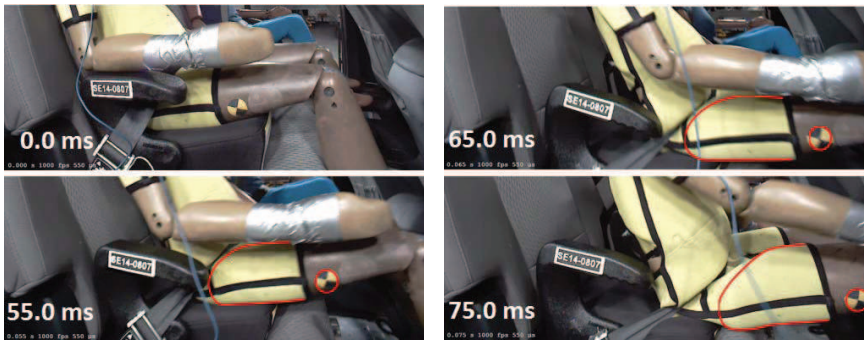


Figure 39: Q10 prototype version – Upper leg flesh shift along the femur

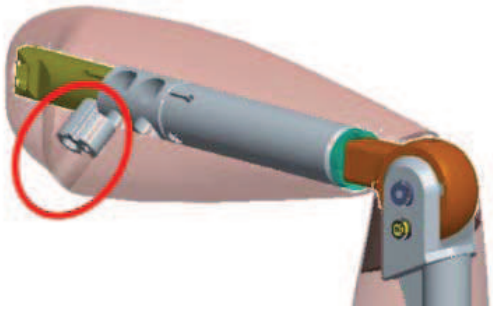


Figure 40: Q10 production version upper leg flesh restraint plug

- BASt front seat sled tests (with footrest) with the Q10 production version dummy with adult belt only.
  The belt was equipped with a pre-tensioner and load limiter of about 5 kN. Figure 41 shows two stills from the video of one of the tests at 90 and 150 ms. It can be observed that the belt is clearly shifted over the ASIS points. This effect was also observed in a repeated test in the same configuration. Moreover, these tests show that in the production version, the upper leg flesh does not shift over the femur as observed in tests with the Q10 prototype version. This suggests that the upper leg flesh restraint plugs (Figure 40), along with the hip shield are effective. A large motion of the hip shield is visible towards the end of the test (as in the ADAC rear seat test discussed before). It is unclear if this motion could be an issue in some configurations.

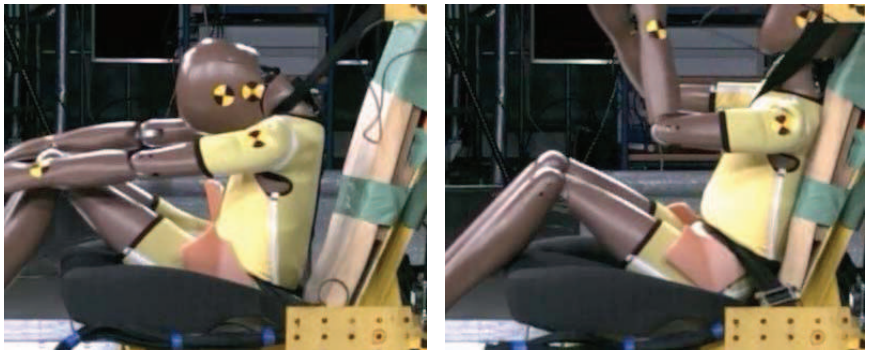


Figure 41: Q10 production version tests in a car front seat with footrest at BASt

- Takata Japan
  Takata Japan was the first third party that performed tests with the hip shields, in 2012. Based on their results the final stiffness for the hip shields was selected. Lemmen, P., et al. (ESV 2013) [16] reported a comparison of the Q10 performance without and with hip shields as shown in Figure 42. This comparison shows small changes in dummy readings when using the hip shields. This was explained by small changes in the dummy kinematics when using the shields.

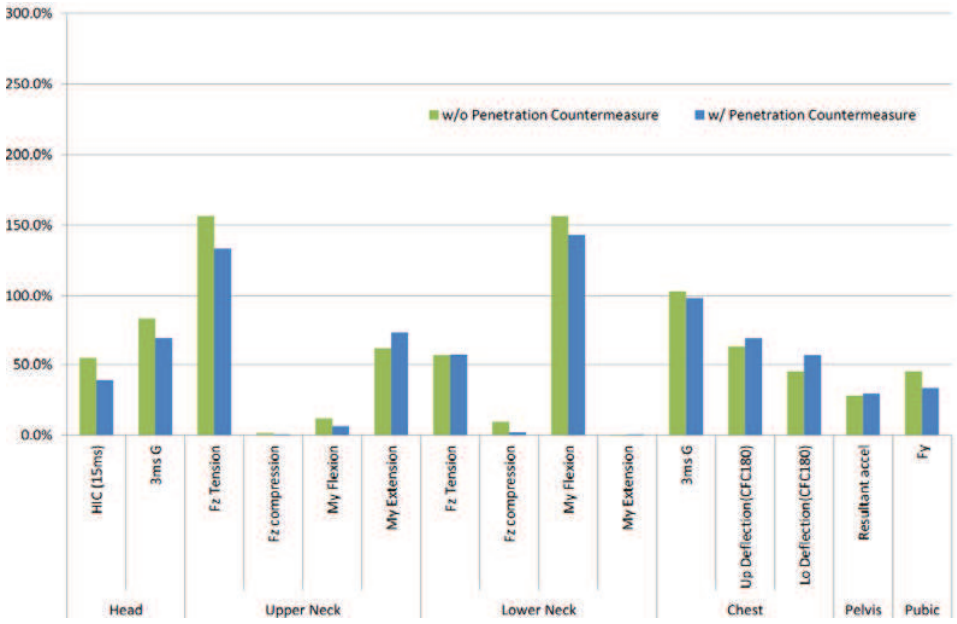
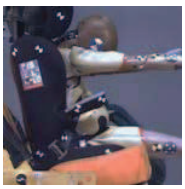


Figure 42: Peak dummy reading comparison for without (green) and with (blue) hip shields [16]

- TRL study for the European Commission (DG Enterprise)
  Visvikis et al. (2014) undertook a program of experiments to inform discussions about the assessment of abdominal loading in non-integral child restraint systems in Phase 2 of UN Regulation 129. The study was not intended to evaluate the Q10; instead the focus was on the regulatory test procedure (of which the dummy is just one component). Nevertheless, the results are summarized here (and within Chapter 5/Annex G) to add to the evidence-base on its use, particularly in the regulatory test environment. The Q10 was equipped with the prototype abdominal sensors described in Chapter 5. It was restrained in non-integral ISOFIX child restraints under various different conditions (derived primarily from UN Regulation 129). The key findings from the study, particularly with respect to the behaviour of the dummy are summarized below.
  - Effect of abdominal sensors on dummy response
    The sensors had marginal effects on the response of the Q10 in a non-integral ISOFIX child restraint system. Lumbar spine flexion (observed from the posture of the dummy in Figure 1) and peak head excursion may have reduced when the sensors were fitted, but the evidence for a trend was fairly weak.

No sensor



With sensor

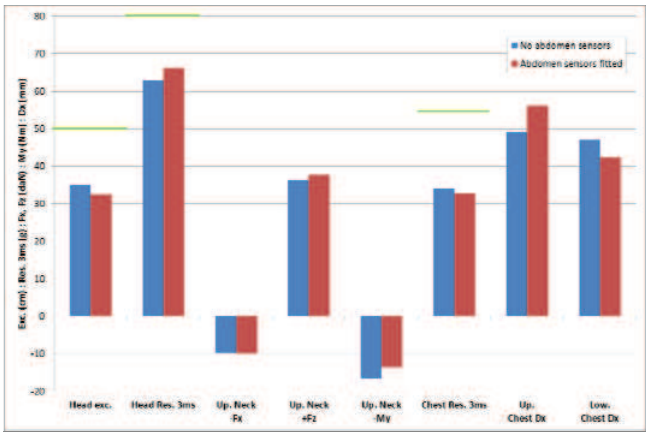


Figure 43: Effects of abdominal sensors on Q10 belt interaction and other sensor measurements

- Effect of hip shields to prevent lap belt intrusion on dummy response

  Belt intrusion was less pronounced with the Q10 (than that observed with other Q Series dummies); nevertheless, the belt was higher on the pelvis (with much less abdominal expansion) when hip shields were used. This is illustrated in Figure 2, which also shows that the dummy measurements tended to increase when the hip shields were used. It was unclear why they might have such an effect; no additional slack was introduced into the belt, for instance.

No hip shields

With hip shields

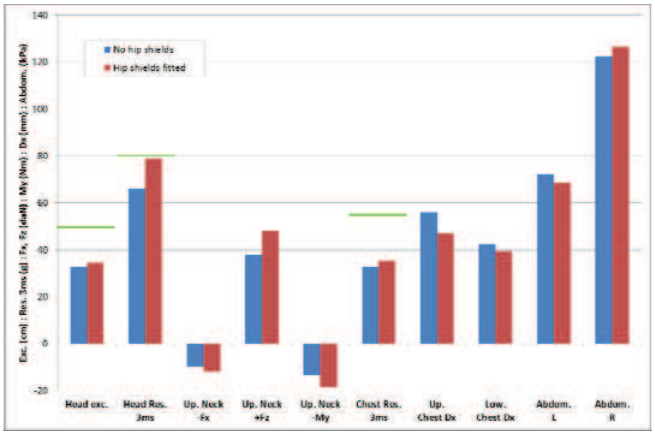


Figure 44: Effect of abdomen sensors and hip shields on Q10 kinematics and belt interaction

- Other findings

  Other findings of potential interest were that the (draft) front impact test procedure in UN Regulation 129 did not distinguish between two non-integral child restraints with seemingly different characteristics for abdominal protection. However, it was difficult to separate the performance of the dummy in this regard from the broader test procedure (such as the severity, anchorage positions, cushion characteristics and belt tensions). It seems likely that further work will be needed to understand this phenomenon.

DISCUSSION AND CONCLUSIONS

Tests have been carried out on two prototype dummies to assess the ability of the Q10 dummy as a measurement tool in laboratory as well real world crash conditions. A large variety of aspects were evaluated, such as belt and airbag interaction, comparison with other dummy types, repeatability and reproducibility and sensitivity to restraint system features, including pre-tensioners and load-limiters, etc.. The tests included:

- Table top test
- Low severity child volunteer sled tests
- Sled tests under UN R44 and NPACS test conditions
- Body-in-white sled tests as well as full-scale crash tests

Sled tests (EPOCh) according to the NPACS protocol found that the Q10 dummy was sensitive to the way it was positioned and installed in the CRS. Due to this sensitivity, EEVC recommends that a seating procedure is developed for future use in sled and full-scale testing. In these tests, the Q dummy readings was affected by child restrain design. The repeatability of the dummy in NPACS testing was good (CoV smaller than 3%).

UN R44 sled tests (EPOCh) confirmed the sensitivity of the Q10 dummy to initial positioning/installation. Furthermore, UN R44 tests with four different restraint systems showed that the dummy readings and head excursions were influenced by the particular CRS being tested. Comparison of the Q10 with the P10 in UN R44 testing (EPOCh) showed that the kinematics of both dummies are significantly different. Due to the thorax and shoulder design of the Q10, the interaction with the adult belt is different from the P10 dummy, which has a tendency to slide out of the belt. This results in a difference in measured loading between the two dummies. Therefore, revised limits were proposed for the Q10, for use in UN R44 testing.

A large number of tests including sled and full scale tests were carried out with the two Q10 prototypes by third parties in order to evaluate the dummy performance in a vehicle environment. The severity of most of these tests, considering the dummy readings, was in the range between UN R44 (less severe tests) and NPACS tests (most severe tests). Based on these tests (as well as the earlier EPOCh tests), recommendations were made to further improve the durability of the dummy, which were incorporated in the production version dummy.

In 3rd party testing by Bohman and Sunnevang [27], the sensitivity of the Q10 to differences in the characteristics of primarily adult restraint systems was confirmed. Vehicle belt geometry was found to be the most important parameter affecting the chest deflection.

In TRL table top biofidelity tests that evaluated thorax regional biofidelity (stiffness) under diagonal belt loading, the Q10 dummy was compared with requirements defined from scaled adult PMHS tests. Thorax deflection was compared at 8 thorax locations. For four locations, the thorax deflection of the Q10 was within the requirements, but for four other locations a larger deflection was noted. Note that the P10 dummy thorax is almost rigid so would have shown almost no deflection in this tests. For the HIII 10yo, no test results were available.

In low severity child volunteer sled tests carried out by Arbogast at al. it was shown that the shoulder belt moves laterally toward the neck and then away from the neck. This response was also observed in the Q10, but the absolute movement to the neck of the belt in the Q10 was larger in comparison to the volunteer tests. Similar tests were carried out with the HIII 10 year and the HIII 5th percentile small female adult. It was concluded that qualitatively the Q10 best mimics the volunteer shoulder belt motion, but that the lateral motion of the shoulder belt in all tested ATDs may underestimate the chest deflection due to the belt being away from the chest deflection sensor.

In a comparison study (Croatto and Masuda) of Q10 and H III 10 year in a rear seat body-in-white sled tests (64 km/h ODB acceleration pulse) with four different restraint conditions, differences in the chest deflection sensitivity to restraint systems were observed between both dummies. In these tests, the Q10 exhibited a sliding up of the shoulder belt towards the neck, whereas no sliding of the shoulder belt was observed for the HIII. It was also observed for both dummies that the chest deflection was decreasing when the lap belt was sliding up towards the abdomen.

From tests carried out by TRW in a rear seat car environment, with EuroNCAP pulse, the sensitivity of the Q10 to differences in vehicle-based occupant protection measures was confirmed. No specific issues in terms of dummy response, damage or permanent deformation were reported as the result of the interaction of the Q10 with the tested airbag systems. In these tests no signs of damage or permanent deformation were noted.

The production version dummy has provisions to prevent the lap belt from sliding into the gap between pelvis and femur flesh. Unpublished tests in sled configurations with realistic crash pulses show promising results concerning the effectiveness of these design improvements. Apart from avoidance of the belt grabbing in the pelvis region, penetration of the belt into the abdomen is also observed in these tests. In view of these findings EEVC WG12 recommends to conduct tests on the UN R129 bench using the production version Q10 dummy to further evaluate these dummy improvements.

Although not intended to evaluate the Q10 dummy specifically, research carried out by TRL for the European Commission provided further experience of its use in the regulatory test environment (as proposed for Phase 2 of UN Regulation 129). The key findings from this study were that while the dummy could be equipped with abdominal sensors, and with hip shields to prevent the lap belt from becoming trapped in the gap between the legs and the pelvis, the frontal impact test procedure in UN Regulation 129 was unable to distinguish between two non-integral child restraint systems with seemingly different features for abdominal protection. Although the dummy is a key component of the procedure, other components such as the severity of the pulse, the anchorage positions, cushion characteristics and seat belt tensions are also likely to play a role. All of these components should be investigated fully.

5 ABDOMEN PRESSURE TWIN SENSORS (APTS) DEVELOPMENT

BACKGROUND

Numerous abdominal injury criteria have been proposed in the past (as reviewed by Kent et al., 2008 [28]). For example, based on tests performed on a porcine specimen selected to represent a 6 years old (YO) paediatric population, they found that peak belt force, mechanical work up to maximum compression and abdominal penetration were the best injury discriminators. More recently, based on ex-vivo liver tests and full body PMHS tests, Kremer et al. (2011) [29] found that pressure related variables such as vascular pressure velocity, maximum vascular pressure and their product were correlated with liver injury risk. Most of these criteria cannot be used with a dummy without specific instrumentation. This chapter focuses on the introduction of Abdominal Pressure Twin sensors (APTS) in the Q10.

APTS AND ABDOMEN

APTS were developed for Q-dummies during the CHILD EC project and improved during the CASPER EC and Proetech projects. They are two soft cylindrical polyurethane bladders closed by aluminium caps and filled with liquid. The pressure in the fluid is measured by a pressure cell implanted in the cap. Three versions (V1, V2 and V3**)** were developed successively. APTS V1 were retired in 2011. Only APTS V2 were used in the Q10 up to now. Transitioning to V3 (evolution affecting mainly non-deformable components) is ongoing. The same APTS (V2 or V3, 50mm nominal diameter) can be used with the Q3, Q6, Q10 and THOR dummies (Hanen et al., 2012 [30]). A smaller APTS V3 is also available for the Q1.5. An illustration of the APTS and the Q10 abdomen is shown in Figure 45 below.

Figure 45: APTS and Q10 abdomen. Left: APTS V2 or V3 are available in 50 mm diameter for Q3, Q6 and Q10. Right: APTS inserted into the Q10 abdomen A1.

APTS are positioned in two vertical holes in the dummy abdomen (cap down). The pressure measured in the bladder is directly related to the pressure applied by the belt through the abdominal foam. In principle, forces applied to the pelvis skin or to the thorax are only marginally transmitted to the foam (and bladder), thereby resulting in lower pressures (Beillas et al., 2012b [31], Beillas et al., 2013 [32] for Q3 and Q6, respectively). Attached to the abdomen by the bottom, the APTS can slide against the sides of the holes to prevent pressure from building up in the case of abdomen vertical compression by the ribcage during lumbar flexion (Beillas et al., 2012b [31] for Q3 and APTS V1).

Until now, two abdomens (designated in this report: Q10_A1, used in early testing, and Q10_A2, used more recently) were prepared by drilling. A new abdomen prototype from Humanetics (Q10_B1) has not been tested yet but evolutions in the manufacturing process are expected.

TEST PROGRAM

Tests with prototypes of the Q10 with APTS were performed by Ifsttar and third parties (i.e. DOREL, JAMA, TRL, ADAC and Autoliv Research) to check the working principles, observe the response for various restraint configurations, etc.. The tests are described in detail in ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT.

RESULTS OVERVIEW, DISCUSSION AND CONCLUSIONS

DURABILITY

No failure of the APTS V2 was reported in the Q10 tests (or with other Q dummy tests). A 3 bar peak pressure was reached in one test but the 7 bar reached in a Q6 test suggest that higher loading could be possible without damage or saturation. Minor issues reported with APTS V2 include small fluid leaks making the sensor greasy to the touch, and cable output damage requiring several repairs. APTS V3 were designed to solve these issues by providing a better cable attachment and sealing (production candidate). A possible contact between APTS V2 and thoracic components during torso flexion has been pointed by Humanetics based on simulation work. The effect on durability is not clear and should be further investigated.

EFFECT ON DUMMY BIOFIDELTY AND RESPONSE

APTS V2 were found to stiffen the abdominal response in belt compression, edging the limits of the biofidelity corridor with Q10_A1. Isolated tests with Q10_A2 suggested that the foam was lighter and relatively softer than Q10_A1. This affected the stiffness response with APTS V2, possibly bringing it towards the inside of the corridor, as well as the pressure compression relationship. It is not clear which abdomen is closer to the current production version. It is also not clear if the abdomen certification procedure currently used to monitor the abdomen foam (static plate loading) would be sufficient for an instrumented abdomen. Overall, it is suggested to repeat and expand the study on the effect of APTS on the dummy response (including biofidelity, sensitivity to flexion, effect on thorax stiffness, mass impact, repeatability, etc.) as soon as the production version Q10 is available. Currently, the sensitivity to lumbar flexion was only evaluated for the Q3 dummy equipped with APTS V1 and tested in a fixed pelvis configuration (Beillas et al., Stapp 2012) [31]. The effect of flexion on pressure was found to be limited in both static and dynamic testing. While the same design principles were used in the Q10, this result should be confirmed.

ABDOMINAL LOADING DETECTION

Similarly to results obtained in other dummies, the APTS V2 were found to detect direct belt abdominal loading in the Q10 with a higher sensitivity in the mid abdomen than in the thoracic and pelvic regions. See ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT for details. For the pelvic region, it is an important feature to ensure that appropriate restraint conditions with high belt loads transmitted to the pelvis are separated from the loading to the soft abdomen. For the thoracic region, the problem is biomechanically different as the lower ribcage includes some of the solid abdominal organs. However, as the thorax instrumentation already provides an assessment of the loading to the region, the lower sensitivity would seem acceptable.

In sled testing, trends can be observed by looking at dummy kinematics, interactions with the lap and shoulder belt, and corresponding abdominal pressures. Results and detailed analyses based on 23 sled tests and 5 static OOP tests are provided in ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT. Overall, these results suggest the APTS are able to detect abdominal loading when it visibly occurs in the lower or upper abdomen, and that it may be possible to separate visibly acceptable from unacceptable behaviours using a pressure threshold between 1 and 1.5 bar. This is not based on a Q10 injury risk curve but the range is similar to thresholds on Q3 and Q6 based on accident reconstructions and sled testing (Beillas et al., 2012b) [31]. This conclusion should be reinforced by further testing in more diverse environments and with a Q10 production dummy to test the robustness of a candidate threshold and by work ongoing on other dummies and scaling. In the midterm, accident reconstructions could be useful in attempting to build a risk curve.

DUMMY BEHAVIOUR AND PROCEDURES

In frontal impact, the lack of CRS use has been linked to an increased risk of abdominal injuries in epidemiological studies (e.g. Durbin et al., 2003 [33]). Boosters are believed to help protect children from abdominal injuries by, among others, reducing the risk of submarining or lap belt slippage. However, when observing the prototype Q10 responses, it appeared that (see ANNEX H: ABDOMEN PRESSURE TWIN SENSORS DEVELOPMENT for details):

- No CRS is required to restrain a Q10 on a UN R129 candidate bench and pulse (Study 2, no hip shield). Similar results were shown with Q6 tests and Q6 simulations (Beillas et al, 2014 [34]).

- Partial belt slippage into the abdomen visibly occurred in at least in one of the tests when no CRS was used (and is suspected in another one). However, abdominal loading seemed more clear with the HIII 10yo in the same test.

- No belt slippage into the abdomen occurred with an inflatable CRS used with Q10 (UN R129 candidate bench and pulse) while it did with P10 (UN R44 bench and pulse).

- Lap belt slippage into the abdomen occurred in ADAC testing without CRS (more severe pulse than UN R44). Similar behaviour was observed in the BASt tests performed on a generic vehicle seat as described in Chapter 4.

It must be noted that each of these observations was made in single tests (no repetition) with the prototype dummy. The findings need to be evaluated for the production version of the Q10 dummy, which has means to prevent the intrusion of the belt in between the femur and pelvis flesh. In general, the effects of the changes made on the production need to be evaluated as most data presented in this report (including in other sections) is based on prototype dummies.

Overall, while these observations are based on a limited number of tests using prototype Q10 dummies by different parties and should be considered cautiously, they suggest that, with regards to abdominal protection, the Q10 coupled with the procedure currently considered for the future regulation:

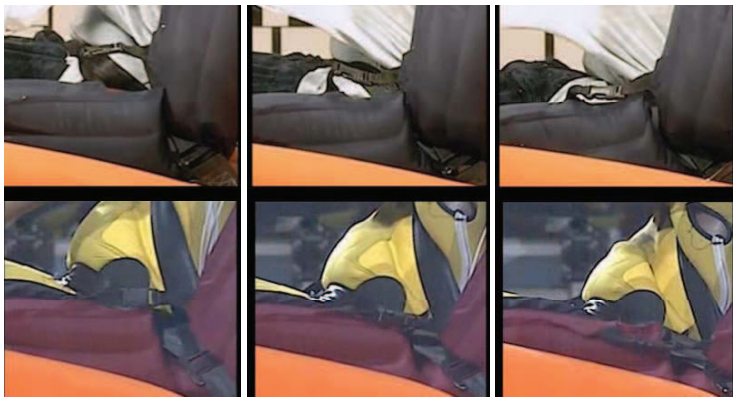
- Could be less challenging than some other dummies (e.g. HIII 10yo) or test environments (in particular Body-in-white with harder pulses)

- May not detect future product designs that may not behave appropriately in real life. In particular, paper thin boosters without effective belt guides (equivalent to no CRS) could be used to pass a frontal impact requirement based on the UN R129 candidate bench and pulse. Also, it is unclear if very soft designs (that could let the pelvis pass under the belt in real life) could be detected in testing.

EEVC recommends that the possible consequences of such observations on future products and protection strategies should be considered.

a) No CRS seems required to obtain an apparently appropriate restraint kinemetics on the UN R129 bench / UN R44 pulse (Study 2)

b) In the same test condition (no CRS, no P/T F/L, Body-in-white, Study 3), while the abdomen is possibly (not clear) loaded by the lap belt in the test with Q10, the belt seems to slip more visibly in the abdomen with the HIII 10yo dummy



c) UN R44 pulse sled tests on inflatable booster seats: P10/UN R44 bench (top) and Q10/NPACS (bottom). The zoom in the lap belt region shows submarining/belt sliding into the abdomen for the P10 and appropriate restraint kinematics for the Q10.

Figure 46: Kinematic results from tests without CRS and comparison with other dummies

6 Q10 INJURY ASSESSMENT REFERENCE VALUES

INTRODUCTION

The first comprehensive proposals for Q-Series injury assessment reference values (IARVs) in front impact were prepared by EEVC Working Groups 12 (Biomechanics) and 18 (Child Safety). They were derived from injury risk curves that were developed using accident reconstruction, supplemented with scaling (see Wismans et al., 2008 [1]). The accident reconstruction data came from a European Framework Programme project: CHILD (CHild Injury Led Design, 2002-2006). The IARVs were selected for a 20% and a 50% risk of AIS≥3 injury as this bracketed the range typically used in regulations. They were derived for the Q0, Q1, Q1.5, Q3 and Q6 dummies only; the Q10 had not been developed at the time.

More recently, two further European Framework projects have contributed to the evidence-base for Q-Series IARVs:

- CASPER (Child Advanced Safety Project for European Roads), carried out further accident reconstructions to support the development of injury criteria and reference values for the Q-Series (see Johannsen et al., 2012) [35].
- EPOCh (Enabling Protection for Older Children) developed the Q10 dummy and proposed injury criteria and thresholds for use in regulatory test conditions (see Hynd et al., 2011) [17].

The CASPER project performed further accident reconstruction experiments with the Q-Series dummies (to enhance the injury risk curves derived by the CHILD project). The Q10 was not used because its development was being led by the EPOCh project. However, accident reconstructions with the newly-developed Q10 were beyond the scope of EPOCh. As an alternative, EPOCh scaled published Hybrid III adult dummy injury risk curves to make them applicable for the Q10. For further confidence, EPOCh also scaled Q3 injury risk curves developed by EEVC Working Groups 12 and 18. By way of further background, their work is presented in ANNEX I: Q-DUMMIES FRONTAL INJURY CRITERIA.

METHOD DESCRIPTION

The EPOCh project proposed a series of indicative thresholds for use with the Q10 under regulatory conditions for child restraint systems. These thresholds were essentially a pragmatic solution that took account of their results from ‘scaling down’ the Hybrid III injury risk curves, ‘scaling up’ the Q3 injury risk curves, balanced with the results from a program of sled experiments with common child restraints.

The setting of performance thresholds is usually considered to be a matter for regulators. In completing this new report, we have used the EPOCh data (in ANNEX I: Q-DUMMIES FRONTAL INJURY CRITERIA) to derive (where possible) Q10 IARVs for a 20% and a 50% risk of AIS≥3 injury as examples. This provides consistency with the previous EEVC report

on Q-Series dummies and allows regulators to set thresholds as needed to target any specific priorities for improving child restraint performance.

INJURY CRITERIA

The injury criteria for which IARVs are derived for the Q10 are: head acceleration exceeded for a cumulative duration of 3 ms (Head A3ms), upper neck tension (Fz), upper neck bending moment in flexion (My) and chest deflection (Dchest). These are consistent with those derived by EEVC Working Groups 12 and 18 for the other Q-Series dummies, with the exception of the Head Injury Criterion (HIC). The EPOCh project did not attempt to scale HIC for the Q10 and hence no data are available in ANNEX I: Q-DUMMIES FRONTAL INJURY CRITERIA. As noted above, where possible, IARVs have been derived for a 20% and a 50% risk of AIS≥3 injury as this encompasses the range typically used in regulations and is consistent with the previous report.

Q10 INJURY ASSESSMENT REFERENCE VALUES

The Q10 dummy IARVs are given in Table 9. These are based on scaling down from the adult Hybrid III injury risk curves and scaling up from the Q3 injury risk curves developed by Wismans et al., (2008) on behalf of EEVC Working groups 12 and 18 [1]. The principal work was undertaken in the EPOCh project, as presented in ANNEX I: Q-DUMMIES FRONTAL INJURY CRITERIA. These values were extracted from EPOCh data.

Many authors have published techniques for scaling biomechanical measurements to different sizes of subject. Although the general principles underpinning scaling are usually applied consistently, material properties can vary leading to different outcomes. Where different options were available for the scaling in Table 9, the properties used by Wismans et al. in the previous EEVC report [1] were adopted.

Table 9: Examples (at 20% and 50%) of IARV's for Q10 dummy by scaling method

		Unit	Scaled down from Hybrid III		Scaled up from Q3	
			20% AIS≥3	**50% AIS≥3**	**20% AIS≥3**	**50% AIS≥3**
Head Acceleration 3 ms	A_{3ms}	*g*	126*	212*	138	169
Upper neck tension force	F_z	N	2,241 [3% AIS≥3]		2,590	2,840
Upper neck flexion moment	M_y	Nm	123 [3-5% AIS≥3]		157	191
Thorax chest deflection	D_{chest}	mm	28	56	23	37

* Peak acceleration (not 3ms) available only. Represents a risk of skull fracture, applicable to contact mechanisms only

EPOCh also suggested a threshold for chest acceleration of 45 *g*. However, this was not derived from an injury risk curve. Instead, it was based on the results of sled experiments comparing the Q10 with the P10, and the observation that the Q10 tended to record lower chest acceleration than the P10 in the same child restraint system. Chest acceleration provides a general indication of how well a restraint system allows the occupant to "ride down", or absorb the collision force in a manner that might avoid some injury mechanisms. However, it would not detect concentrated loading through improper restraint design and was not included in the original EEVC Working Group 12 and 18 report. Furthermore, the CASPER project found that chest acceleration was unable to predict the risk of AIS≥3 injury from their accident reconstruction data (Johannsen et al., 2012) [35].

DISCUSSION AND CONCLUSION

The injury criteria and IARVs in **Table 9** allow assessments to be made in the head, neck and chest of the dummy. Abdomen injury criteria and IARVs were not developed during the EPOCh project because tools for the measurement of abdominal loads in the Q-Series were still being developed (in the CASPER project) as was discussed in Chapter 5

These Q10 IARVs reflect the information that was available at the time of the EPOCh project. For instance, the 'scaled up' IARVs were derived with accident reconstruction data collected during the CHILD project. However, new reconstruction data are now available from the CASPER project (as well as new injury risk curves for the Q3, excluding the chest). In addition, the consensus regarding appropriate statistical methods for deriving injury risk curves has changed since CHILD. This explains some of the differences in the risk curves developed by CASPER, EPOCh and CHILD and implies that some of the previous EEVC Working Group 12 and 18 proposals for IARVs may also need to be updated. In the case of the Q10, updating the analysis in ANNEX I: Q-DUMMIES FRONTAL INJURY CRITERIA would enable these latest data and curves to be used.

In considering further work to refine these data, it should be noted that a group of interested experts has formed a Q-Series Chest and Abdomen Injury Criteria Task Force. The task force is aiming to derive injury risk curves for chest deflection and abdomen pressure by repeating accident reconstructions from the CASPER project, or by performing new reconstructions (with the Q10, for example). It might be worthwhile, therefore, to wait for this group to report its findings (expected end of 2014), before further analyses are carried out (at least for the chest).

7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

Each year, 700 children are killed on European roads and 80,000 are injured [1]. This represents an unacceptably high burden on Europe's society and economy. Although it is not known exactly how many of these deaths and injuries occur in ECE approved CRSs (Child Restraint Systems), it is considered that there is significant scope for improvement in the design of CRSs.

In the European regulation, UN Regulation 44, CRSs are homologated through testing with P-dummies that were developed in the 1970s by TNO. The dummies were mainly designed to act as a loading device with appropriate dimensions and mass distribution, but with limited measurement capability. The anatomy and behaviour of the internal structures of the body are not represented, which is one of the fundamental shortcomings of these dummies. In addition, the method used to detect abdomen loading (a clay insert between the lumbar spine and abdomen) is somewhat subjective and does not allow for a complete assessment of injury risk.

In 1993 the development of the Q-series of child dummies started as successors to the P-series. Initially the Q-Series comprised Q0, Q1, Q1.5, Q3 and Q6 dummies only; there was no dummy to represent older children in the highest mass group specified in UN Regulation 44. In 2007, the UN Informal Group on child restraint systems was established (by the UN Working Party on Passive Safety (GRSP) to develop a new UN Regulation on the approval of "Enhanced Child Restraint Systems". The first phase of the new Regulation was completed in 2011 and sets out performance requirements and test methods for integral ISOFIX child restraints and includes the new family of child dummies (the Q-Series). It was adopted by the World Forum for Harmonisation of Vehicle Regulations (WP.29) during its 158th Session held in Geneva in November 2012 and came into force in July 2013. The UN Informal Group based many of its decisions regarding the use of the Q-Series in UN Regulation 129 on the work carried out by EEVC Working Groups 12 and 18 [514 document].

The prototype Q10 was developed within the EPOCh project (Enabling Protection for Older Children, 2009-2011) and was intended to provide the "upper limit" dummy for the new Regulation (Age 10.5 years old, Stature 1443 mm, Body mass 35.5 kg). A production version of the Q10, was released in 2013. An extensive evaluation program using prototype dummies was carried out within the EPOCh project and by third parties. With the introduction of this new dummy, the UN Informal Group on child restraint systems asked EEVC to provide a recommendation on its use in legislative testing. This recommendation is given in this report which should be considered as continuation of the 2008 report [1]. Most findings are based on testing with prototype versions of the Q10 dummy.

Accident and injury causation for older children

Injuries to older children in front impact collisions tend to occur in the head, chest, abdomen and extremities. Contact with the vehicle interior appears to be the principal mechanism for

head and extremity injuries, whereas the chest and abdomen are injured by loading from the adult seat belt. Injuries to the neck appear to be particularly rare, even accounting for limitations in the availability of representative data. It should be noted that there is very limited representative data with enough depth to identify (with any statistical confidence) needs and priorities for improving the performance of child restraint systems for specific age groups.

Q10 dummy design and EPOCh evaluation

The design of the Q10 is rather similar to that of the other Q-dummy family members except for the pelvis structure, which is similar to the design of the WordSID dummies. The design of the head, the neck, the shoulder, the clavicle, the thorax, the lumbar spine, the abdomen and the extremities attempt to represent the main features of human anatomy. Compared to the US-developed Hybrid III 10yo child dummy, the Q10 is based on a different design approach, using plastics and high density foams. The Q10 has been primarily designed for frontal UN R44 (succeeded by UN R129) and future side impact testing, while the US child dummies are developed for FMVSS 208 (to evaluate the risk of out of position airbag deployment) and FMVSS 213.

Two prototype Q10 dummies were extensively evaluated on anthropometry, biofidelity, sensitivity, repeatability and durability to impact loading in head drop, neck pendulum and full body wire pendulum tests. Concerning *biofidelity* the dummy meets most of the biomechanical targets specified in the design brief developed in the EPOCh project. However, it should be noted that these requirements did not include targets for kinematic behaviour, biofidelity of the lumbar region, among others. The dummy is *sensitive* to variations in impact speeds, impact direction and alignments, as desired, with regards to injury risk assessment. Concerning *repeatability and reproducibility,* it is concluded that the dummy meets the usual requirements in this field. Some initial *durability* issues were found and successfully solved during the prototype testing. Some recommendations for updates were proposed and implemented in the production version dummy. Also tests with production version dummies were carried out to evaluate reproducibility and *certification* procedures. After collecting data from 18 dummies delivered to the market, the final certification procedures and corridors were proposed in February 2014. There were no significant differences between the prototype performance and the production certification corridors.

Q10 evaluation in laboratory, sled and car crash tests

Tests within EPOCh as well as by third parties were carried out on 2 prototype dummies to assess the ability of the Q10 dummy to be used as a measurement tool in sled and full-scale crash conditions. A large variety of aspects were evaluated such as belt and airbag interaction, comparison with other dummy types, repeatability and reproducibility, and the sensitivity to restraint system features, including pre-tensioners and load-limiters, etc. Tests included table top biofidelity tests, low severity child volunteer sled tests, sled tests under UN R44 and NPACS test conditions and Body-in-White sled tests as well as full-scale crash tests. The severity of most of these sled and full-scale tests varied in the range between UN R44 (less severe tests) and NPACS tests (most severe tests).

In biofidelity table top tests (TRL) with diagonal belt loading, the Q10 dummy performance was compared with requirements defined in the THORAX project on the basis of scaled adult PMHS tests. Thorax deflection was compared at 8 locations. For 4 locations the thorax deflection of the Q10 was within the requirements and for 4 locations a larger deflection was noted. The P10 dummy thorax, which is almost rigid, would have shown almost no deflection in these tests.

In different test programmes it was shown that the Q10 dummy response was affected by CRS design. The Q10 dummy was also shown to be sensitive for initial dummy positioning, indicating the need for a dummy seating procedure. Some durability issues were noted in the tests with the prototype dummies which has resulted in design improvements in the production version dummy.

Comparison of the Q10 with the P10 in UN R44 testing (EPOCh) showed that the kinematics of both dummies is significantly different. Due to the thorax and shoulder design of the Q10 the interaction with the adult belt is different from the P10 dummy, which has a tendency to slide out of the belt. This results in a difference in measured loading between the two dummies. Therefore different limits for head excursion were proposed for the Q10.

In low severity child volunteer sled test conditions as well as tests under real world crash conditions it was observed that the shoulder belt in a Q10 dummy slides into the direction of the neck. This behaviour, which is not usually observed with the HIII child dummy, reduces the thorax deflection. In child volunteer tests this belt sliding to the neck was also observed but to a less extent than in the Q10 tests. In this respect, the Q10 dummy appeared to be more realistic than the HIII for these low severity tests. The biofidelity of this phenomenon for higher pulse is however not known.

Some durability issues were observed in the extensive prototype tests which resulted in some changes in the production version dummy. The production version dummy has provisions to prevent the lap belt from sliding into the gap between pelvis and femur flesh. Unpublished tests in sled configurations with realistic crash pulses show promising results concerning the effectiveness of these design improvements.

APTS development and abdominal injury criteria

Despite the presence of abdominal injuries, the standard Q-dummies do not include abdominal instrumentation. Instrumentation efforts have been conducted by third parties on smaller Q-dummies. One effort has yielded promising results including an accident reconstruction based risk curves for Q3 and Q6 dummies in the CASPER project. The same instrumentation was applied to the Q10. Abdominal Pressure Twin sensors (APTS) are two soft cylindrical polyurethane bladders closed by aluminium caps and filled with liquid. The pressure in the fluid is measured by a pressure cell implanted in the cap. APTS are positioned in two vertical holes in the dummy abdomen. The pressure measured in each bladder is assumed to be directly related to the pressure applied by the belt through the abdominal foam. Until now, two prototype abdomens were prepared by drilling holes in them. Overall, the test results suggest that the APTS are capable of detecting abdominal loading when it visibly

occurs in the lower or upper abdomen, and that it may be possible to separate visibly acceptable from unacceptable behaviours using a pressure threshold between 1 and 1.5 bar. This finding, which seems in line with results already available for other dummies, should be confirmed by further testing in more diverse environments and with a Q10 production dummy to test the robustness of the candidate threshold. In the midterm, planned accident reconstructions could be useful to attempt building a risk curve.

For the abdomen, no biofidelity evaluation testing was carried out in EPOCh. However, in subsequent research, the APTS was found to effect the abdomen biofidelity performance. Initial testing in the CASPER project suggested that by proper selection of the abdomen material the performance of the abdomen can be kept within the EPOCh biofidelity corridor. There could also be some small effect of the APTS on the kinematics observed in prototype testing but the evidence was weak.

Overall, the APTS show good potential for the detection of abdominal loading (which is currently evaluated using video analysis and clay in UN R44 with P dummies) and for the evaluation of the injury risk (which is currently not evaluated). Future work should be focused in priority on APTS integration and evaluation in production dummies, and on the determination of possible limits for detection and injury risk. These limits could be based on observation of real tests and injury risk curves.

An interesting observation was made in one of the APTS sled tests: using the UN R129 bench and pulse (which is derived from UN Regulation 44), it was possible to meet the regulatory requirements without a CRS; the dummy was restrained by a regular seat belt only. If confirmed, the consequence of such a result for a regulatory test evaluating the protection provided by CRS could be very significant. This may be attributed to various factors including the poor lap belt interaction with the Q10 prototype and the test conditions. This belt interaction is significantly improved in the production version by the introduction of the upper leg flesh restraint plugs and the lap belt hip shields.

Other test conditions including the ADAC setup (hip shield, prototype dummy), the BASt setup (hip shield, production dummy), and to some extent the JAMA study (no hip shield, prototype dummy) have led to inappropriate restraint conditions including some abdominal loading when no CRS was used, and no abdominal loading by the lap belt with a CRS. However, these setups were all performed using actual car seats (front seat for BASt, rear bench for ADAC and JAMA) instead of a bench, with pulses harder than UN R44/R129. Considering the presence of abdominal injuries in the field and the positive role expected from booster seats, it may also be that the UN R129 bench and associated pulse do not represent a configuration that is challenging enough from a safety standpoint.
This should be further investigated by analysing the restraint conditions and repeating some of the tests with a Q10 dummy, possibly equipped with abdominal sensors to help in assessing the loading.

Injury Assessment Reference Values (IARVs)

It is not the role of this group to select target risk (e.g. 20% or 50%) and injury severity levels (e.g. AIS2 or AIS3). However, injury criteria and IARVs are provided for the head, neck, and chest in Table 9 of Chapter 6 to assist the decision. The Q10 IARVs reflect the information that was available at the time of the EPOCh project. New reconstruction data are available from the CASPER project. These new data and risk curves were not taken into account in the IARVs in Table 1 because they were not available at the time of the principal work being carried out. Updating the analysis in ANNEX H: Q-DUMMIES FRONTAL INJURY CRITERIA would enable these latest data and curves to be used. In considering further work to refine these data, it should be noted that a group of interested experts has formed a Q Series Chest and Abdomen Injury Criteria Task Force. The task force is aiming to derive injury risk curves for chest deflection and abdomen pressure by repeating accident reconstructions from the CASPER project, or by performing new reconstructions. It might be worthwhile, therefore, to wait for this group to report its findings, before further analyses are carried out (at least for the chest).

EEVC WG12 recommendations

The Q10 dummy described and evaluated in this report shows a significant improvement with respect to the P10 dummy currently used in UN R44 frontal impact tests. The Q10 dummy is better adapted to recent child anthropometry data and the performance is tuned to comply with more recent biofidelity requirements and introducing possibilities to measure neck loads, chest deflections as well as potentially also abdomen loading. Based on the extensive evaluation and validation results described in this report, EEVC recommends that the Q10 dummy is used in child restraint homologation tests (UN R129). It is recommended to implement initially 5 injury criteria: Head acc. (3ms), Upper Neck tension (Fz) and Upper Neck flexion and extension bending moment (My) and Chest deflection complementary to the UN R129 excursion limits. Concerning the abdomen, it is recommended that, upon completion of the work initiated on the APTS, an additional requirement on abdominal pressure is introduced. Concerning chest deflection it is recommended to review the work of the Q Series Chest and Abdomen Injury Criteria Task Force as soon as completed (expected end of 2014). These recommendations are largely based on the results of Q10 prototype testing and therefore have to be confirmed for the Q10 production version dummy. The changes between production version and prototype dummy seem however limited as described in ANNEX F: UPDATES FROM PROTOTYPE TO PRODUCTION VERSION and these changes did not affect certification test result. The use of hip shields to prevent the lap belt from becoming trapped in the gap between the legs and the pelvis appears to be beneficial; nevertheless, the frontal impact test procedure in UN Regulation 129 may not encourage features that keep the belt low on the pelvis (such as a raised seating position and/or lap belt guides). Although it was outside the scope of this Q10 report to investigate this issue in-depth, EEVC recommends that every effort is made to ensure that UN Regulation 129 makes a robust assessment of abdomen protection in non-integral child restraint systems.

In summary, it is recommended to:

- Complete the work initiated on APTS by focusing, as a priority, on their integration in the Q10 production version dummy, their evaluation under various conditions (including EPOCh defined abdomen biofidelity requirements), and the finalisation of the development of an abdominal injury risk curve to assist in the selection of limits.

- Evaluate the Q10 dummy, preferably side by side with other dummies of the same size, in additional biofidelity test conditions as suggested in Chapter 3
- Develop a seating procedure for the Q10 dummy
- Review the results of the work done by the Q Series Chest and Abdomen Injury Criteria Task Force as soon as available (expected end of 2014)
- Evaluate the changes made in the production version Q10 dummy concerning prevention of lap belt sliding into the gap between pelvis and femur flesh
- Check if the test conditions to be used in the future UN R129 regulation are sufficiently challenging for the evaluation of the protection provided by CRS with a Q10 dummy. This could include testing the Q10 production version with and without CRS and comparing with other test configurations where inappropriate restrain conditions (e.g. submarining) have been observed, including gaining knowledge on the parameters, that may promote the submarining.

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ANNEX A: CHILD INJURY CAUSATION STUDY

INTRODUCTION

The EPOCh project investigated the injuries received by older children in collisions as part of the process for specifying the measurement capabilities of the Q10 dummy. The work was described by Visvikis et al. (2009) and was published on the project web-site (see www.EPOChfp7.org). The intention of the work was to draw primarily from previous large-scale European collision studies, such as those analysed by EEVC Working Groups 12 and 18 for their Q-dummies report (see Wismans et al., 2008 [1]). However, while these studies highlighted overall trends and priorities for the protection of children in general, it was impossible to separate the experiences of older children.

In an effort to gain more detailed information on older children, the EPOCh partners performed a new analysis of the United Kingdom Cooperative Crash Injury Study (for the period 1998 – 2008). This work was outside of the original scope of the project and hence a Europe-wide analysis of representative data was not feasible. Nevertheless, these UK data provided a useful insight into the types of injuries and mechanisms experienced by older children (aged 6 to 12 years). The remainder of this annex comprises sections from the EPOCh report (Visvikis et al., 2009).

COLLISION DATA ANALYSIS

OVERVIEW

The European Road Safety Observatory (www.erso.eu) is a pilot web site established during the SafetyNet project (an integrated project funded by the European Commission). The web site includes basic traffic safety facts, which are delivered in a series of fact sheets. The fact sheets are based on data from the CARE (Community database on Accidents on the Road in Europe) database. Table 10 shows that 735 older children were killed in police-reported collisions across the European Union (EU-19) in 2006 (ERSO, 2008).

Table 10: Fatalities by gender and age in EU-19 in 2006 (reproduced from ERSO, 2008)

Age (years)	Female	Male	Both sexes
5 – 9	102	155	257
10 – 14	164	314	478
Totals	**266**	**469**	**735**

While the CARE data presents European-wide information, more detailed analysis is impossible. The information was supplemented, therefore, with data from the UK. Table 11 shows that shows that there were 4,193 older child casualties reported to the police in Great Britain in 2007 and the killed or seriously injured casualties amounted to 157. All of these children were car passengers. The data were obtained from Road Casualties Great Britain 2007: Annual Report (DfT, 2008). While it is likely that very few, if any, fatal accidents are

not reported to the police, research shows that a significant proportion of non-fatal injury accidents are not reported (Ward et al., 2006). In addition, police may underestimate the severity of injury due to the difficulty in distinguishing severity at the collision scene (DfT, 2008). Nevertheless, Table 11 provides an overview of the involvement of older children in personal injury road accidents in a typical country in (western) Europe.

Table 11: Older child casualties by age band and severity in 2007

Age (years)	Killed	Seriously injured	Slight	All severities
5 – 7	6	60	1,443	1,509
8 – 11	6	97	2,581	2,684
Totals	**12**	**157**	**4,024**	**4,193**

In order to gain more detailed information about older children and their injury patterns, accident cases involving children aged from 6 to 12 years were obtained from the United Kingdom Cooperative Crash Injury Study (UK CCIS) database. The data span the years from mid-1998 to mid-2008. There were 277 children involved in a front impact collision for all restraint types and injury levels. Figure 47 shows the distribution of restraint type for these children.

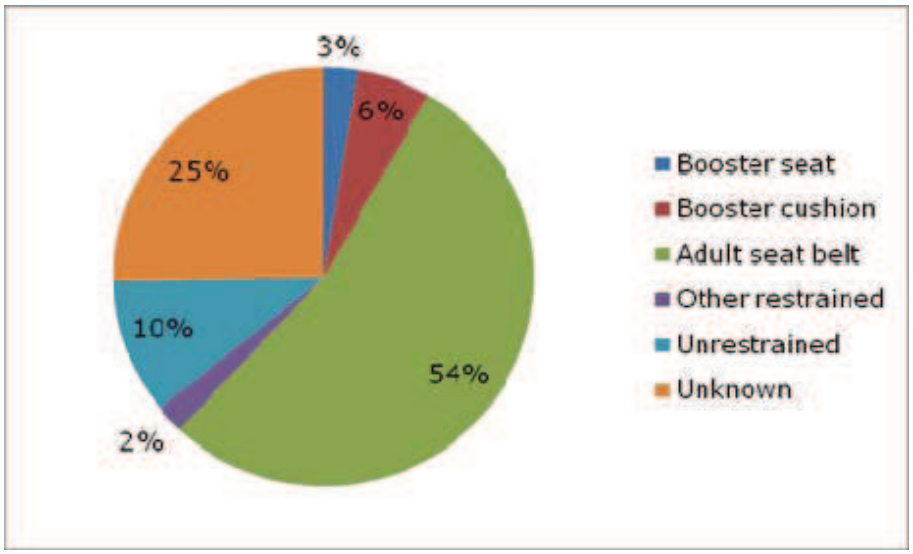

Figure 47: Restraint type for children aged 6 to 12 years in front impacts (n=277)

There were 127 children involved in a side impact for all restraint types and injury levels. Figure 48 shows the distribution of restraint type for these children.

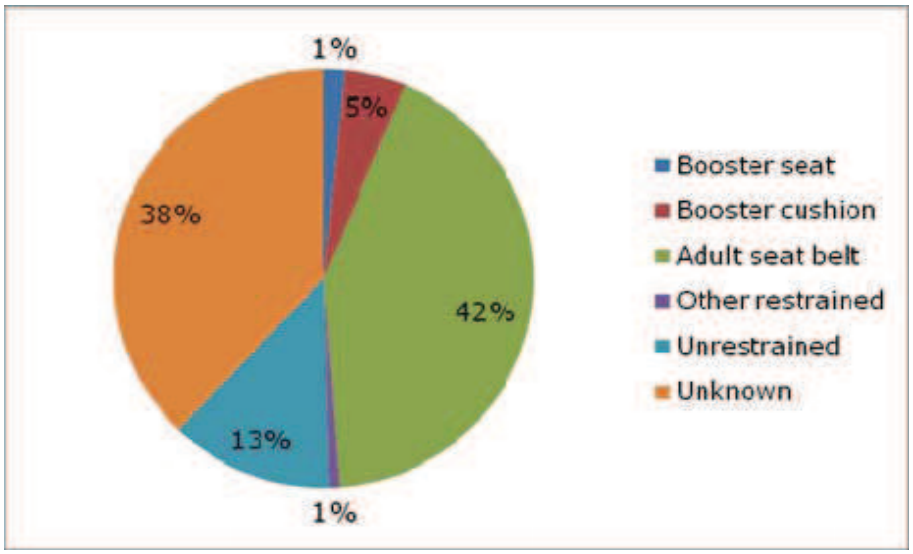

Figure 48: Restraint type for children aged 6 to 12 years in side impacts (n=127)

There is a large proportion of unknown restraint use in the CCIS database, which could affect any conclusions drawn from these data. Figure 47 and Figure 48 show that during this ten year period, which was mostly prior to amendments made to the seat belt wearing directive coming into force in the UK, the adult seat belt was the most common type of restraint for children aged six to twelve years, and there were a greater proportion of children unrestrained than there were using child restraint systems.

Injury patterns for older children in front impact

Table 12 shows the injury distribution with respect to restraint type for the older children in the CCIS database that were involved in a front impact. The adult seat belt was the most common type of restraint system for these children. Unfortunately, there were too few cases involving children in booster seats and booster cushions to comment on the performance of these devices in comparison with the adult seat belt. It is interesting to note, however that there were no AIS>2 injuries to the children restrained in booster seats.

Table 12: Injury distribution with respect to restraint type for children aged 6 to 12 years (front impact)

Restraint type	Total	MAIS0		MAIS1		MAIS2		MAIS≥3		Unknown	
		n	%	n	%	n	%	n	%	n	%
Booster seat	7	1	14.3	5	71.4	0	0.0	0	0.0	1	14.3
Booster cushion	16	1	6.3	8	50.0	1	6.3	2	12.5	4	25.0
Adult seat belt	149	20	13.4	107	71.8	8	5.4	5	2.7	9	6.0
Other restrained	6	1	16.7	2	33.3	0	0.0	1	16.7	2	33.3
Unrestrained	29	6	20.7	15	51.7	4	13.8	3	10.3	1	3.4
Unknown	70	17	24.3	36	51.4	4	5.7	3	4.3	10	14.3
Total	**277**	**46**	**16.6**	**173**	**62.5**	**17**	**6.1**	**14**	**5.1**	**27**	**9.7**

Fifteen restrained children (aged 6 to 12 years) received AIS≥2 injuries. Details about these children are shown in Table 13. The average age of the injured children was 9.3 ± 2.0 years. Where reported, the average velocity change (Δv) was 48 km/h, indicating that the collisions

were moderate to severe in severity. Six children were seated in the front passenger seat and 9 children were seated in the rear outboard seats.

Table 13: Cases of AIS≥2 injury in restrained children aged 6 to 12 years (front impact)

Case	Age	Restraint type	Seating position	MAIS (Body region)	PDOF/Δv (km/h)	Object hit
1	9	Adult seat belt	Rear nearside	2 (Head)	12/44	Car
2	10	Adult seat belt	Front seat	2 (Head)	12/Unknown	Car
3	7	Adult seat belt	Front seat	2 (Upper extremity)	12/47	Car
4	10	Adult seat belt	Rear offside	2 (Upper extremity)	1/32	Car
5	11	Adult seat belt	Rear nearside	2 (Upper extremity)	1/50	Car
6	12	Adult seat belt	Rear nearside	2 (Abdomen)	12/Severe	Car
7	11	Adult seat belt	Rear nearside	2 (Abdomen)	1/50	Car
8	7	Adult seat belt	Front seat	2 (Abdomen)	12/43	Car
9	10	Adult seat belt	Front seat	3 (Upper extremity, lower extremity)	12/Unknown	MPV or LGV
10	12	Adult seat belt	Front seat	3 (Thorax)	12/Unknown	Car
11	6	Adult seat belt	Rear nearside	3 (Abdomen)	1/53	Car
12	11	Adult seat belt	Front seat	3 (Abdomen)	12/79	Car
13	8	Booster cushion	Rear nearside	2 (Head)	12/31	Car
14	8	Booster cushion	Rear nearside	4 (Head)	12/Unknown	Car
15	7	Booster cushion	Rear nearside	4 (Neck)	12/Unknown	Wide object (>41cm)

There were 18 AIS≥2 injuries among the 15 children. The distribution of injuries is shown in Figure 49. Most injuries occurred in the head (n=4), upper extremities (n=4) or the abdomen (n=6).

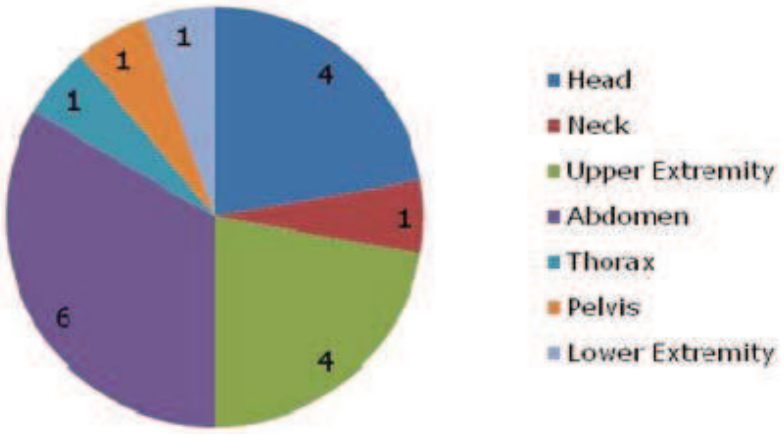

Figure 49: Distribution of AIS≥2 injuries (n=18) among restrained children (front impact)

While the number of children receiving an AIS≥2 injury was low in the CCIS sample, similar findings have been reported in the literature. García-España and Durbin (2008) analysed a sample of 761 children aged 8 to 12 years with AIS≥2 injuries. They found that head injury was the most common injury (60%), followed by injury to the face (9%), upper extremity

(9%) and abdomen (9%). However, the study relied on driver reports for information on injury and restraint use, etc., and did not distinguish between front and side impact.

Factors affecting injury of older children in front impact

The velocity change of the case vehicle is often associated with a greater injury severity for the occupants. Unfortunately, the velocity change was unknown for most of the children in Table 13 with serious injuries and greater (i.e. AIS≥3). For example, in Cases 14 and 15, the child received an AIS4 injury but the velocity change of their car was unknown. In Case 15, it seems likely that the collision was severe since their car struck a wide object (>41cm). This could have been a tree, a building or a piece of roadside furniture.

Intrusion into the seating position is also associated with greater injury severity. In Case 9, the child was seated in the front passenger seat of a car involved in a collision with a multi-purpose or light goods vehicle. The child received serious injuries to their extremities, which seem likely to have resulted from intrusion of the facia and footwell. Another factor associated with greater injury severity is misuse of the restraint system. Unfortunately, no information was available on the presence of misuse in the sample of cases.

Factors affecting the performance of CRS's for older children in front impact

The CCIS sample comprised 277 children aged 6 to 12 years and included all restraint types and injury levels. Twenty-three of these children were known to be using a child restraint system: 7 were in a booster seat, while 16 were on a booster cushion. Table 13 reveals that none of the children in booster seats received AIS≥2 injuries, while three children on booster cushions were injured at that level. Unfortunately, there were too few cases of children using child restraint systems to establish any clear associations or contributory factors related to the performance of the devices.

MECHANISMS OF INJURY IN OLDER CHILDREN

Injury mechanisms by body region for older children in front impact

Many studies of child injury mechanisms in front impact collisions include older children in the sample. However, very few studies describe in detail the types of injuries received by older children specifically. The previous section revealed the importance of head, abdomen and extremity injuries. While the evidence is limited, it appears that most head injuries in older children result from direct contact with the interior of the vehicle (Agran et al., 1987). This causes the skull to deform with the risk of fracture and/or local brain injury. Head contact can also induce relative motion of the brain with respect to the skull. Contact can occur for a variety of reasons. These include vehicle intrusion into the child's seating position or excessive head excursion due to incorrect or inappropriate restraint use. Non-contact head injuries are rare in older children. Nevertheless, in high severity collisions, acceleration (or deceleration) of the head can result in inertial loading that leads to brain injury. Similarly, the risk of basilar skull fracture with neck injury, which has been reported extensively in the literature for younger children, does not seem to be found in older children (Jakobsen et al., 2005).

The most common abdomen injury mechanism in older children is (adult) seat belt loading directly at the site of the injured organ (Arbogast et al., 2007). This can result from submarining (where the pelvis slips under the lap part of the seat belt) and/or from an initial misplacement of the belt, for instance, due to a slouched posture. Injuries to the lumbar spine seem to be rare in older children, particularly when the diagonal part of the seat belt is used correctly. Individual cases were discussed by Brown and Bilston (2007) and were associated with "high severity" collisions.

Injuries to the extremities of older children are likely to result from interaction with parts of the vehicle interior. Jermakian et al. (2007) described the lower extremity injuries in a sample of children in forward facing child restraints. Although the oldest child was only 5 years old, some of the key mechanisms are likely to be the same for older children. Jermakian found that a loose child restraint attachment and/or intrusion of the vehicle seat back in front of the child were important contributing factors. The main injury mechanism is loading applied to the extremity from the vehicle interior resulting in fracture.

CONCLUSIONS

Limited information was available on the types of injuries experienced by older children. Traditional collision studies tend to focus on the differences in injury patterns across child restraint types and although older children tend to use certain types only, they are often also used in significant numbers by younger children. The review of representative collision data from the UK provided some information on the specific experiences of older children, but the number of cases was very low.

Nevertheless, head injury resulting from contact with the interior of the vehicle appeared to be the most common mechanism of injury for older children in both front and side impact collisions. Injuries to the abdomen were observed in front impact collisions and resulted from loading from the lap part of the seat belt.

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ANNEX B: INJURIES TO OLDER CHILDREN IN FRANCE

There is lack of representative European data providing sufficient detail about the restraint and accident configuration as well as injury patterns as a function of age. A query of the Rhône Registry Injury Database in France covering the period 1996 – 2012 provided 77,608 car occupants sustaining all levels of injuries. Of these, 18 children aged 8 to 12 years received an injury at the AIS≥3 level. The distribution of injuries is shown in Figure 50. Most injuries occurred in the head (44%), Thorax (39%) or the abdomen (22%).

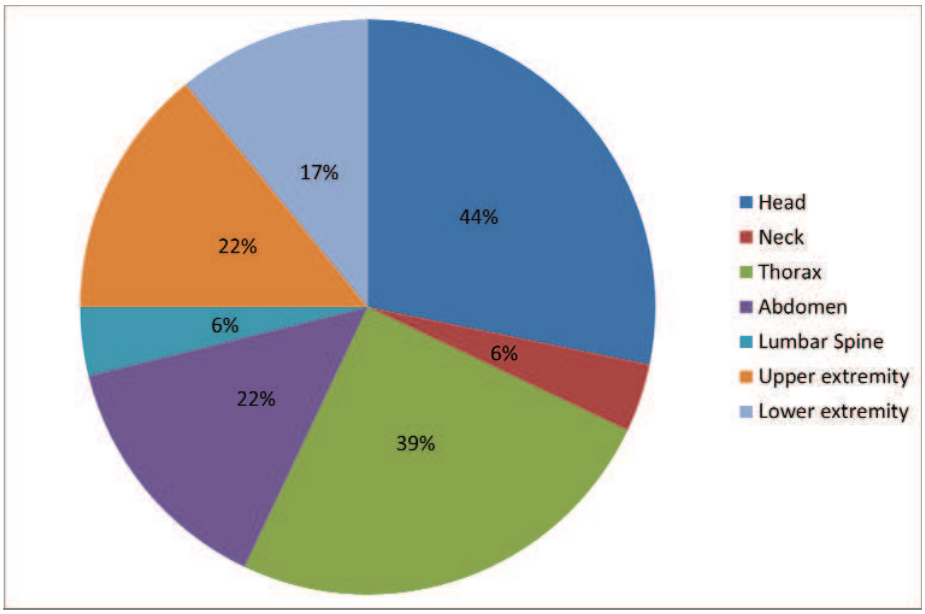

Figure 50: Distribution of AIS≥3 injuries (n=18) among children aged 8 – 12 (front impact, all restraint conditions) Data derived from the Rhône Registry, described by Laumon et al., 1997

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ANNEX C: Q10 DESIGN BRIEF

EPOCh Deliverable D1.2

Biomechanical Requirements and Design Brief (public version)

This deliverable is published September 17, 2009

67 pages

Enabling Protection for Older Children

SEVENTH FRAMEWORK PROGRAMME
THEME 7
Transport (including AERONAUTICS)

EPOCh 218744

DRAFT PROJECT REPORT

Work Package 1
Task 1.2
D1.2 - Biomechanical Requirements and Design Brief

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D1.2 - Biomechanical Requirements and Design Brief

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by Kees Waagmeester, Mark Burleigh and Paul Lemmen
(First Technology Safety Systems)

This is a public version of a confidential report.

The confidential information is omitted.

Where this is done it is indicated with yellow shading.

The layout and paragraph and page numbering are unchanged.

	Name	Date Approved
Administrative coordinator	Maria McGrath	17/09/2009
Technical coordinator	Marianne Hynd	17/09/2009

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Executive Summary

The EPOCh project will develop extended procedures and a measurement tool for impact testing of Child Restraint Systems (CRSs) designed to provide protection for older and larger children [ref. EPOCh project Description of Work]. As such the project will:

- Develop a prototype older Q dummy, representing the largest children that make use of CRSs.
- Enable the extension the NPACS testing and rating protocols to include assessments of child restraints for older children
- Make proposals that will allow the assessment of child restraints in ECE Regulation 44 if the Q series dummies replace the P series in the future

This draft report presents biofidelity, instrumentation and functional requirements of the dummy. It is the outcome of Task 1.2: "Development of biomechanical requirements" and will form the basis for the dummy design under WP2.

In this task all of the dummy requirements have been brought together in a comprehensive specification. The following task components have been addressed:

I. An important aspect for Task 1.2 was to contribute to the knowledge that would inform the decision on the child size to be represented by the dummy: 10 or 12 year old (Q10 or Q12 dummy). Recommendations from this task, along with task 1.1, were disseminated to stakeholders and their feedback was taken into consideration during a requirements review meeting before making the final decision on dummy size. As such, this report provides design requirements and targets for both the Q10 and the Q12 dummy. The Anthropometric data of CANDAT, that have been the basis of all Q dummy family members, were used to provide data for this task.

II. Biofidelity requirements (frontal and side) have been defined based on scaling in line with the procedures common for Q dummies.

III. Instrumentation requirements have been defined based on task 1.1 results (injury priorities and loading conditions).

IV. Functional requirements have been set in this task with regards to Biofidelity, Repeatability, Durability, Functionality (resonance, posture, etc.) Handling and Preliminary calibration / verification.

V. Means to show compliance with the biofidelity requirements including evaluation test matrices have been defined.

This Design Brief document concludes the work for task 1.2

An important aspect for Task 1.2 is the decision on the child size to be represented by the dummy: 10 or 12 year old (Q10 or Q12 dummy). To facility a fare size selection discussion and decision this report provides design requirements and target for both the Q10 and the Q12 dummy. The EPOCh consortium initially recommended to select the Q12 dummy (11.6 year old 50%ile anthropometry: mass 40.0 kg and stature 1500 mm) inline with the maximum size of children that should make use of an appropriate CRS (up to 150 cm stature according to Directive 2003-20-EC). All background information gathered by the EPOCh team to make the recommendation is given in the report. After a stakeholder forum discussion held on July 10, 2009 and the gathering of other stakeholder feedback, the EPOCh team decided to proceed with the development of the Q10 (10.5 year old 50%ile anthropometry: mass 35.5 kg and stature 1443 mm). This size is generally considered to be an appropriate representation of older children including the children with the maximum size that use a CRS (stature 1500 mm). The report summarise the stakeholder feedback that initiate the final decision.

1 Introduction

Within the EPOCh project a dummy designed to represent older children in crash test environments will be developed. The dummy should complete the Q-dummy family to enable Child Restraint System (CRS) safety assessment over its full range of application. In the subsequent section the design requirements for that dummy are reported.

1.1 Background

Across most of Europe, the law requires children less than 3 years to use the child restraint appropriate for their weight in any vehicle (including vans and other goods vehicles). Recent seat belt wearing laws in Europe changed with the submission of European Directive 2003/20/EC (published September 10, 2007). In vehicles where seat belts are fitted, the law now also requires children up to the age of 12 years and less than 150 cm in height to use an appropriate child restraint. Child restraints sold in the EU must comply with UN-ECE Regulation 44 (R44). This regulation currently relies on the P series child dummies as restraint loading devices. In previous Framework Projects CREST and CHILD new, more advanced dummies, representing 0, 1, 1.5, 3 and 6 YO children, were developed (ref. [i] CREST-project and [ii] CHILD-project). In comparison to the P-series these so-called "Q" series dummies stand out by:

- Accurate anatomical representation of relevant body parts;
- Use of advanced, deformable materials such as plastics and high dense foams to provide more realistic biomechanical response;
- Interchangeable (modular) instrumentation relevant to the injuries observed with children;
- Usable in both front and side impact testing.

An Informal Group on CRS testing was established in January 2008, by the UNECE Working Party on Passive Safety (GRSP). GRSP stands for Global Road Safety Partnership. This group is likely to recommend the use of the Q series dummies in a new Regulation for the assessment of CRSs. Consumer testing programmes have already opted to use the current Q dummy family dummy. The NPACS research resulted in test procedures that specify use of the Q dummies. Future (Euro)NCAP-test procedures under development are also likely to use Q-dummies in the rear seat of cars in full scale crash tests.

The current Q series of dummies represents children up to the age of six only. As such, the consumer testing programmes already using the Q series and future regulatory procedures which may adopt the Q series cannot evaluate the CRSs for use by children older than six years. This all means that the Q series that currently ends at the six year old needs to be extended to represent the full range of children that use CRSs. For this reason the EPOCh project aims to complete the Q series by providing a dummy representing the largest children that use a CRS when transported in cars in the age up to 12 years old and with a stature of less than 1500 mm and to develop proposals that will extend of the test procedures of NPACS and ECE R44 to include assessment with the older Q dummy.

1.2 Current Q-dummies and running developments

The current Q series are designed as omni-directional dummies; however, they are optimised for frontal tests with the intention to make them suitable to replace the P-dummies in UNECE R44. The extensive development, validation and evaluation efforts performed with the current European primarily frontal Q-dummies Q0, Q1, Q1.5, Q3 and Q6 is described in [iii]. At the moment it is unlikely that the Q series will replace the P-dummies under the current regulation as new regulations, that will include side impact testing, are under development within the new GRSP Informal Working Group on CRS testing. Consumer test programs have selected the Q series as developed in Europe in their test protocols for both frontal and side impact tests. In America special side impact versions of Q3 and Q6 called Q3s and Q6s are developed. Currently those two dummies are under evaluation at NHTSA, Transport Canada and the OSRP (Occupant Safety Research Partnership in the USA). These Q-dummies dedicated for side impact do not receive significant support in Europe where there are seen as American dummies.

1.3 Q-dummy family design

The dummy to be developed shall be like a Q-dummy to maintain a physical link to the current Q-dummy range and thus appear as part of that group. The performance of the dummy to be developed shall also fit in the characteristics of the smaller sized members of the series. By doing so, the research results for the existing Q series, obtained in the almost 15 year development period, can be used through performance and criteria scaling. Although the development of a side impact version of the dummy is outside the scope of the EPOCh project, potential design commonality between frontal and side impact versions of the new dummy will be explored and were possible implemented.

2 Objectives

This draft document presents results of EPOCh Task 1.2: "Development of biomechanical requirements and design brief". The objectives of this task are to

- Define biomechanical targets and functional requirements for the development of the prototype dummy (development in WP2).
- Define assessment methods to evaluate the dummy's biomechanical and functional performance against the targets and requirements defined (evaluation in WP2).

The design targets and requirements should be suitable for a dummy that represents either a 10 or 12 year old child in CRS crash test conditions, with the exact age or size to be based on consideration of regulatory requirements in Europe. For both the Q10 and Q12 the design targets and requirements will be presented as well as discussions on the size selection and biomechanical harmonisation issues.

3 Method

3.1 Approach

According to the Description of Work the dummy requirements will be specified as follows:

I. The Anthropometric data of CANDAT [iv], that has been the basis of all Q dummy family members, will be used to define the anthropometry of the dummy.
A decision will be taken to build a dummy representing 10 or 12 years old Q10 or Q12 dummy [referred to in this report as the 'older child dummy'] and will be justified based on regulatory requirements in Europe.

II. Biofidelity requirements (frontal and side) will be defined based on scaling in line with the procedures common for Q dummies.

III. Instrumentation requirements will be defined based on EPOCh Task 1.1 results (injury priorities and loading conditions).

IV. Functional requirements will be set with regards to Repeatability, Durability, Functionality (resonance, posture, etc). Handling and preliminary calibration / verification.
Additional application related requirements input will come from EPOCh Task 3.1 and 3.2.

V. Means to show compliance with the requirements including evaluation test matrices will be defined.

This approach ensures that the new dummy remains "in-line" with the other members of the Q series. It must be noted here that Task 1.3 dealing with injury criteria will consider scaling of injury risk functions based on recent developments for EEVC. During first project meetings it was decided that a comparison will be made between the scaling of the biomechanical requirements and the injury risk functions in order to ensure compatibility. As such some modifications to the biomechanical requirements might be expected when the results of Task 1.3 are available. It should be noted the consistency with methods used for the Q dummy family remains important.

The requirements definition depends on the decision to build an older child dummy representing a suitable age of child to fit with legislation in Europe (and expected to be in the range 10 to 12 years old). This report considers both sizes to facilitate the recommendation and decision making process within EPOCh. In view of the link between the size selection and the requirements this document also includes relevant information with respect to the size selection and the recommendation from the EPOCh consortium on the size selection.

3.2 Contents

Chapter 4 provides dummy design requirements and targets. A complete set of Anthropometry and Biofidelity targets as well as Functional and Instrumentation requirements is provided together with indications for methods to show compliance. Information is provided for both the Q10 and the Q12 dummy.

Chapter 5 provides relevant background information regarding the dummy size selection and Biofidelity requirements harmonisations issues. This chapter includes a recommendation from the EPOCh consortium on the size selection to be discussed with stakeholders in month 6 of the project. The final decision on the size selection will take onboard the views of the stakeholders and will be included in the final version of this report.

4 Dummy Design Requirements and Targets

4.1 Anthropometry for a 10 and 12 Year Old dummy

The dummy size discussion needs to be based on:

- Regulatory requirement in Europe
- Anthropometric data from CANDAT

These aspects will be outlined in this section of the document and discussed in chapter 5 under the heading Discussion.

4.1.1 Regulatory requirements in Europe

It is not yet clear what the size of the largest child dummy will be. At least two options are open at the moment:

1. A Q10 to replace the current P10 dummy as specified in UNECE Regulation 44. If this regulation will stay in place for years this occupant size may be driving for the requirements.
2. Q12 to represent the child with a stature of 1500 mm. In Europe Directive 2003-20-EC requires adult seat belt use with an appropriate CRS up to a stature of 1500 mm. Countries are allowed to reduce this limit to 1350 mm, as derogation. So far many European countries (Sweden, Germany, Austria, Italy, Luxembourg, Ireland, Greece, Hungary, Poland, Portugal and Switzerland) enforced the 1500 mm rule. It is essential to know the reasons behind the selection of a certain maximum occupant size. This issue is under consideration by the GRSP informal group on CRSs

Further information with respect to the dummy size selection as well as a recommendation on the size from the EPOCh consortium can be found under chapter 5 under the heading Discussion. The following chapter provides requirements for both options.

4.1.2 Q10 age definition

For a dummy representing the 50 percentile anthropometry of 10 year old children there is an unofficial TNO report (dated 17 March 2006) that specifies the anthropometry targets as developed in April-May 2000 [v]. This report defines the Q10 anthropometry targets presented below. With regard to the age of the child that is represented by the data, the CANDAT report states on page 5:

> *ECE-Group III ranges from 22 to 36 kilograms. A CRS designed for this group should be tested with two dummies, one for each end of the range. At the low end, the 23 kg Q6 dummy is used. At the high end, a dummy should be used with a mass close to, not necessarily equal to, 36 kilograms. The CANDAT database indicates that a 10.5 year old has a body weight of 35.5 kg, while a 10.75 year old has a body weight of 36.5 kg. The 10.5 child should therefore be used.* ***The dummy based on the anthropometric parameters of the 10.5 year old child from CANDAT will be the basis for the Q10 dummy.***

Note: If necessary the CANDAT-data can be interpolated between 10.5 and 11.0 years old to tune the total body mass to exactly 36 kg.

4.1.3 Q12 age definition

The anthropometry values for Q12 are determined through linear interpolation of the CANDAT data. The stature of 1500 mm as required in European Directive 2003-20-EC (see paragraph 4.1.1) requires the anthropometry for a Q12. According to linear interpolation of stature in CANDAT between 11.5 and 12 year old children (1494.3 mm and 1518.8 mm respectively) the stature of 1500 mm is reached at an age of 11.62 year.

Formula: age = 11.5 + (1500 – 1494.3) / (1518.8- 1494.3) * (12.0 – 11.5)

The 50th percentile mass associated with a stature of 1500 mm is about 40kg, so Group III products approved under ECE R44 will not be appropriate for most children with a stature of 1500 mm.

4.1.4 Anthropometry data from CANDAT for Q10 and Q12

4.1.4.1 Design targets used for Q0, Q1, Q1.5, Q3 and Q6

For the Q dummies developed so far (Q0, Q1, Q1.5, Q3 and Q6) the CANDAT database is used to obtain suitable anthropometry requirements. For each dummy there are official TNO reports that specified numerous target dimensional and mass properties of the 50th percentile child size that they should represent.

- Q0 dummy with a mass of 3.4 kg represents a new born child of 6 weeks old. Its design targets are specified in TNO report: 03.OR.BV.003.1/KDJ [vi]
- Q1 dummy with a mass of 9.7 kg represents a child of 1 year old. Its design targets are specified in TNO report: 99.OR.BV.014.1/DT and Addendum page 16 [vii]
- Q1.5 dummy with a mass of 11.0 kg represents a child of 1.5 year old. Its design targets are specified in TNO report: 99.OR.BV.014.1/DT [vii]
- Q3 dummy with a mass of 14.5 kg represents a child of 3 year old. Its design targets are specified in TNO report: 95.OR.BV.047.1/DT [viii] and 96.OR.BV.027.2/MSC [ix]
- Q6 dummy with a mass of 23.0 kg represents a child of 6 year old. Its design targets are specified in report 98.OR.BV.022.1/DT [x].
  The target mass of the 6 year old dummy has been increased from 21.3 for to 23.0 that corresponds with a 50 percentile at 6.75 year old. On page 11 the TNO report gives the following rationale:

  > *ECE-Group II ranges from 15 to 25 kg and Group III from 22 to 36 kg. The dummy would therefore not fit properly in the one of the ECE groups. It is therefore advisable to make the dummy heavier than the 22 which is the lower boundary of ECE group III. It is proposed to make the dummy slightly heavier than the 21.3 kg indicated by CANDAT and the 21.3 of the Jensen regressions. 23 kg appears to be a good value as this weight is compatible with ECE regulation groups.*

  The Q6 dummy dimensions remained unchanged and are therefore representative of a 50th percentile 6 year old child.

4.1.4.2 Q10 and Q12 dummy anthropometry definition

External Dimensional Requirements

In Table 1 all dimensions available for Q10 (10.5 year old) and Q12 (11.62 year old) are specified. The definition of the dimensions is given in ref. [xi]. The validity of CANDAT results, according to the description in [iv], is limited to children up to 10 years of age; beyond that limit the accuracy of the CANDAT results decreases and differences between sexes becomes apparent.

The dummy dimensions should not deviate by more than five percent from the target dimensions indicated as priority 1 in Table 1. Other dimensions should be used as guideline indications.

Means of Compliance

A Computer Aided Design "Stickman" layout shall be made to establish anatomical landmarks and joints. With the "Stickman the compatibility of the data can be checked and adjusted if necessary. In case target dimensions are in conflict with each other a deliberated choice that gives priority to the dimensions important for CRS and belt interaction will be documented as justification. This "Stickman" will be used as overlay reference in the design. Care must be observed as to the definition of these interfaces to avoid any problems when fleshing the dummy to ensure anthropometric requirements are met.

Internal Dimensional Requirements

With regards to internal dimensions there are a number of body regions that need detailed definition to establish design boundaries. The main points are listed below.

1. Head-neck (OC and CG location)
2. Neck-shoulder

3. Rib cage lower edge shape.
4. Pelvis bone shape
5. Positions of OC, C7/T1, T12/L1, L5/S1
6. Joint positions and ROM's

Note: see under means of compliance for a reference to additional data on the pelvis and lumbar spine landmark positions

It is essential to define human like bone interaction and load paths for CRS elements like harness straps and shields as well as intruding parts during impacts.

Means of Compliance

The internal dimensions are to be established from averaged human body 3D bone scans, if available, and other geometry definition sources that are available in literature. Data from scans and other geometrical definitions, if available, will be put into CAD format and used as a base template to ensure suitable dummy pelvis geometry. For the pelvis reference [xii] defines the 3D position of 31 landmarks (left and right hand) in the pelvis and lumbar area. This paper may provide enough data to define sufficient representative internal pelvis geometry.

Table 1: Dimensions in [mm] for Q10 and Q12 (Q6 given for reference)

Description / **Age in years** / **Priority**		**CANDAT code**	**Q6**	**Q10**	**Q12**
			6	**10.5**	**11.62**
General					
total mass in [kg]		p1	21.3 (increased to 23.0)	35.5	40.0
stature	1	p2	1173	1442.5	1500.0
sitting height (to top of head)	1	p3			
eye height sitting	3	p4			
shoulder height sitting	1	p5			
elbow height sitting	3	p6			
Torso					
biacromial distance	1	p8			
shoulder breadth (maximum)	1	p9			
suprasternal height (standing)	3	p10			
torso height at axilla	3	p12			
torso breadth at axilla	2	p13			
torso circumference at axilla	2	p15			
torso depth at nipples	2	p18			
torso circumference at nipples	2	p19			
torso height at waist		p20			
torso breadth at waist	2	p21			
torso circumference at waist	2	p23			
Hip and Pelvis					
iliocristal height	3	p28			
iliospinal height	3	p29			
bispinious breadth	2	p30			
trochanter height	3	p31			
hip breadth (standing)	3	p32			
hip breadth seated	3	p33			

Description Age in years Priority	CANDAT code	Q6 6	Q10 10.5	Q12 11.62
Thigh				
thigh height (sitting) 1	p34			
buttock-knee length 1	p37			
buttock-popliteus length 1	p38			
buttock-foot (leg stretched) 1	p39			
Lower leg				
knee height 1	p40			
popliteal height 1	p41			
tibial height 3	p42			
maximum leg circumference 2	p43			
leg depth at maximum circumference 3	p45			
ankle circumference 3	p46			
ankle breadth 3	p47			
Foot (standing – wider than sitting				
foot length 3	p48			
foot breadth 3	p49			
Shoulder and upper arm				
shoulder-elbow distance 1	p51			
upper arm circumference at biceps 2	p52			
upper arm depth at biceps 2	p53			
elbow breadth 2	p54			
acromion radiale 1	p55			
Lower arm and hand				
lower arm and hand length 1	p56			
lower arm max circumference 2	p57			
lower arm depth at max circumference 2	p58			
radiale stylion 1	p59			
wrist breadth, minimum 3	p60			
wrist circumference 3	p62			
hand length 3	p63			
hand breadth at metacarpal III 3	p64			
hand depth at metacarpal III 3	p65			
Head and neck				
head length 1	p66			
head breadth 1	p67			
head circumference 1	p68			
menton-vertex 1	p69			
bitragional arc 3	p71			
pupillary distance 3	p72			
neck circumference 2	p73			
neck breadth 1	p74			
clavical-acromion length 2	p75			
lower face height 3	p78			
bizygomatic breadth 3	p79			

Description Age in years Priority		CANDAT code	Q6 6	Q10 10.5	Q12 11.62
bitragion breadth	3	p81			
tragion-vertex	3	p84			

Miscellaneous

shoulder height standing	3	p105			
CG standing (relative to floor)	3	p500			
CG sitting (relative to seat)	1	p501			

Derived dimensions

horz. distance from OC to menton	d1			
vert. distance from OC to menton	d2			
OC to vertex	d3			
OC to CG horizontal	d4			
OC to CG vertical	d5			
neck link length	d6			
maximum pelvis breadth	d8			
dist. between iliac crests (inside)	d9			
dist. between lowest points on pelvis	d10			
anterior posterior length of iliac wings	d11			
total height of pelvis	d12			

Table 2: Masses in [kg] for Q10 and Q12
(Q6 given for reference to justify the extrapolation for Q12)

Description Age in years	CANDAT code	Q6 6.75 (see note 1)	Q10 10.5	Q12 11.62 (see note 2)
Head	m1			
Neck	m2			
Upper Torso	m3			
Lower Torso	m4			
Torso Total	***m5***			
Upper Arm (each)	m6			
Lower Arm (each)	m7			
Hand (each)	m8			
Upper Leg (each)	m9			
Lower Leg (each)	m10			
Foot (each)	m11			
Total	***m12***	***23.00***	***35.50***	***40.00***

Note 1: The Q6 dummy is increased in mass corresponding with 6.75 year old while the dimensions correspond with 6 year old

Note 2: The Q12 mass distribution is extrapolated from Q6 (6.75 yo) and Q10 (10.5) so the total mass is 40.0 kg (CANDAT dimension p2). If the Q12 is selected a more accurate distribution can be obtained through application of the Jensen distribution regression.

4.2 Biofidelity Performance Targets

4.2.1 Introduction

Because of the different nature of responses under frontal and side loading the biofidelity performance targets are provided for each of these directions separately. This section starts with the frontal impact performance targets for relevant body parts followed by the side impact performance targets.

4.2.2 Frontal Impact

In line with the other members of the Q-family the frontal impact biofidelity will be based on scaling adult performance targets with geometrical and material property scaling factors. The geometry scaling is based on CANDAT (Child ANthropometry DATabase) dimensions. In consistency with this methodology Q10 and Q12 data is derived with help of the corresponding Q10 and Q12 dimensions given in Table 1.

Note: In EPOCh Task 1.3 "Specification of Injury Criteria" new, more advanced scaling methods may be used for the injury criteria development. This may result in a different view on biofidelity scaling. If this is the case both methods will be compared. Based on this comparison, actions will be defined by the EPOCh consortium.

4.2.2.1 Frontal Head Biofidelity Target

The head impact biofidelity corridor is scaled from that applicable for an adult dummy based on the Q10 and Q12 dimensions p66 (head length), p67 (head breadth) and p69 (menton to vertex) and the bone elastic modulus estimate ref. [xiii].

Performance Target

The head impact performance targets for Q10 and Q12, in a test with a drop height of 130 mm on a flat rigid face are defined in Table 3.

Means of Compliance

The Q10 and Q12 target performance limits for the head in frontal impact are very close to those applicable for adults. The performance tuning will be done through skin thickness or material mix variation.

Table 3: Q10 and Q12 Head frontal impact targets (Q6 and adult values are given for reference)

Description **Age in years**	**CANDAT code**	**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
head length in [mm]	p66				
head breadth in [mm]	p67				
menton-vertex in [mm]	p69				
bone young modulus in [Pa]	-				
Scale Factor		0.8747	**0.9663**	**0.9753**	1.00
Head peak acceleration between					
Upper limit in [G]		176	**194.2**	**196.0**	201
Lower limit in [G]		102	**113.1**	**114.1**	117

4.2.2.2 Frontal Neck Biofidelity Target

In accordance with the Q series methodology [iii], the neck flexion biofidelity corridor is scaled from that applicable for an adult dummy based on the Q10 and Q12 dimensions p74 (neck width), p91 (neck depth) and the tendon modulus. The value for p91 for Q6 is re-engineered based on the TNO neck biofidelity corridor data.

Performance Target

The neck performance targets for Q10 and Q12, in a neck flexion test are defined in Table 4 and Figure 1.

Means of Compliance

The compliance with this requirement must be seen in the light of the compliance shown by the other Q dummies as reported in ref. [iii]. The Q6s neck may well show the best compliance. A deliberated choice should be made between the Q3s and Q6s neck design with the best possible biofidelity performance [xiv] or use a current Q dummies neck design that fits in the Q dummies evaluated in Europe. In the later case the neck of the Q6 dummies may be compliant enough.

Table 4: Q10 and Q12 Neck forward flexion targets (Q6 and adult values are given for reference)

Description **Age in years**	**CANDAT code**	**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
neck breadth in [mm]	p74				
neck depth in [mm]	P91				
Tendon modulus in -	-				
Scale Factors					
Flexion angle		1.00	**1.00**	**1.00**	1.00
Upper neck moment		0.4964	**0.6621**	**0.7094**	1.00

Neck moment versus flexion

		Degr.	Nm	**degr.**	**Nm**	**degr.**	**Nm**	degr.	Nm
Upper limit		0	0.00	0	0.00	0	0.00	0	0
		15	30.3	15	40.4	15	43.3	15	61
		45	30.3	45	40.4	45	43.3	45	61
		66	43.7	66	58.3	66	62.4	66	88
		70	94.3	70	125.8	70	134.8	70	190
Lower limit		35	0.0	35	0.0	35	0.00	35	0
		55	13.4	55	17.9	55	19.2	55	27
		76	43.7	76	58.3	76	62.4	76	88
		80	94.3	80	125.8	80	134.8	80	190

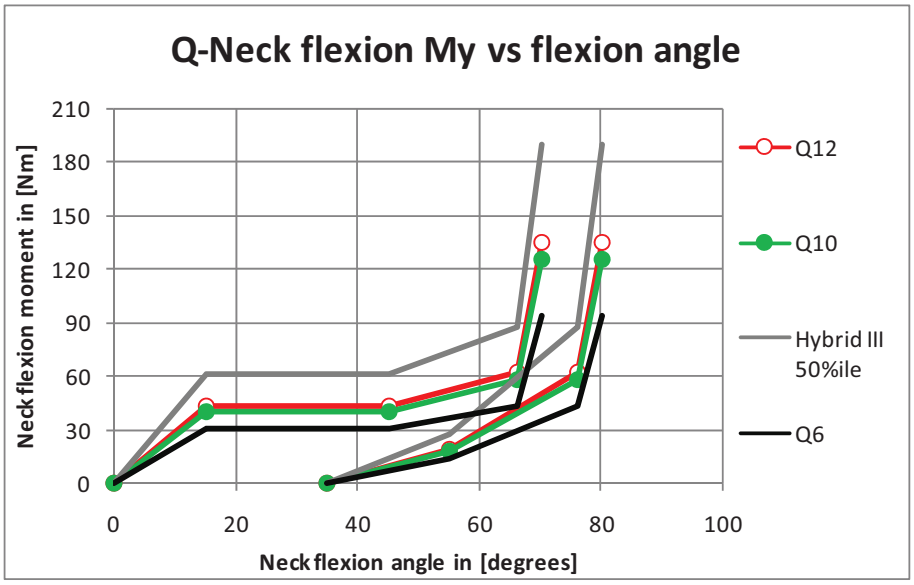

Figure 1: Neck flexion moment versus neck flexion angle biofidelity corridors

4.2.2.3 Frontal Thorax Biofidelity Targets

In accordance with the Q series methodology [iii], the frontal impact thorax biofidelity corridors are scaled from those applicable for an adult dummy based on the Q10 and Q12 dimensions p5 (shoulder height sitting), p13 (torso width at axilla), p14 (torso depth at axilla), p15 (circumference at axilla) and Eb (Young's modules rib (compact bone)). Dimension p14 and the young's modulus for the rib bone for Q6, Q10 and Q12 are not given in Table 1, the value for Q6 is obtained from the TNO biofidelity corridor scaling assessment and the Q10 and Q12 values are extrapolated from Q3 and Q6 values.

Performance Target

The thorax performance targets for Q10 and Q12, in a full body pendulum impactor tests at 4.27 and 6.71 m/s are defined in Table 4, Figure 2 and Figure 3. Note that the impactor masses for Q10 and Q12 are different.

Means of Compliance

The compliance with these requirements must be seen in the light of the compliance shown by the other Q dummies as reported in ref. [iii]. CAE simulations are recommended to evaluate design options.

Table 5: Q10 and Q12 Thorax impact targets
(Q6 and adult values are given for reference)

Description **Age in years**	**CANDAT code**	**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
shoulder height at axilla in [mm]	p5				
torso width at axilla in [mm]	p13				
torso depth at axilla in [mm]	p14				
circumference at axilla in [mm]	p15				
Young's modulus for rib bone Eb in [kN/mm^2]					
Scale Factors					
Mass		0.2255	**0.3742**	**0.4193**	1.00
Displacement		0.6802	**0.7459**	**0.7629**	1.00
Impact force		0.3315	**0.5016**	**0.5496**	1.00

Thorax impactor force versus deflection

Impactor mass in [kg]		5.28		**8.76**		**9.81**		23.4	
		mm	kN	**mm**	**kN**	**mm**	**kN**	mm	kN
4.27 m/s impact									
Upper limit		4.4	0.87	4.8	1.31	4.9	1.44	6.4	2.62
		17.3	0.81	18.9	1.22	19.4	1.34	25.4	2.44
		25.9	0.81	28.4	1.22	29.1	1.34	38.1	2.44
		36.3	0.96	39.8	1.45	40.7	1.59	53.3	2.89
		43.2	0.66	47.4	1.00	48.4	1.10	63.5	2.00
		39.7	0.07	43.6	0.11	44.6	0.12	58.4	0.22
Lower limit		4.4	0.60	4.8	0.91	4.9	1.00	6.4	1.82
		17.3	0.54	18.9	0.82	19.4	0.90	25.4	1.64
		25.9	0.54	28.4	0.82	29.1	0.90	38.1	1.64
		32.0	0.63	35.1	0.96	35.9	1.05	47	1.91
		29.4	0.07	32.2	0.11	33.0	0.12	43.2	0.22
6.71 m/s impact									
Upper limit		4.4	1.22	4.8	1.85	4.9	2.03	6.4	3.69
		17.3	1.28	18.9	1.94	19.4	2.13	25.4	3.87
		25.9	1.37	28.4	2.07	29.1	2.27	38.1	4.13
		42.3	1.58	46.4	2.39	47.5	2.62	62.2	4.76
		52.7	1.25	57.8	1.90	59.1	2.08	77.5	3.78
		56.2	0.81	61.6	1.22	63.0	1.34	82.6	2.44
		50.1	0.07	55.0	0.11	56.2	0.12	73.7	0.22
Lower limit		4.4	0.89	4.8	1.35	4.9	1.48	6.4	2.69
		17.3	0.90	18.9	1.36	19.4	1.49	25.4	2.71
		25.9	0.96	28.4	1.45	29.1	1.59	38.1	2.89
		39.7	1.10	43.6	1.67	44.6	1.83	58.4	3.33
		41.5	0.81	45.5	1.22	46.5	1.34	61.0	2.44
		35.4	0.07	38.9	0.11	39.7	0.12	52.1	0.22

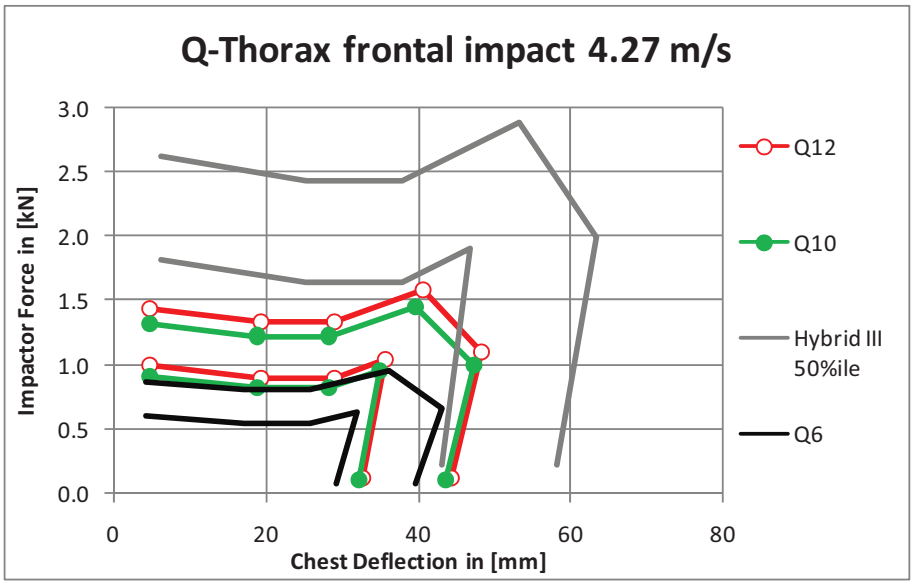

Figure 2: Thorax impactor force versus chest deflection biofidelity corridors for 4.27 m/s impact

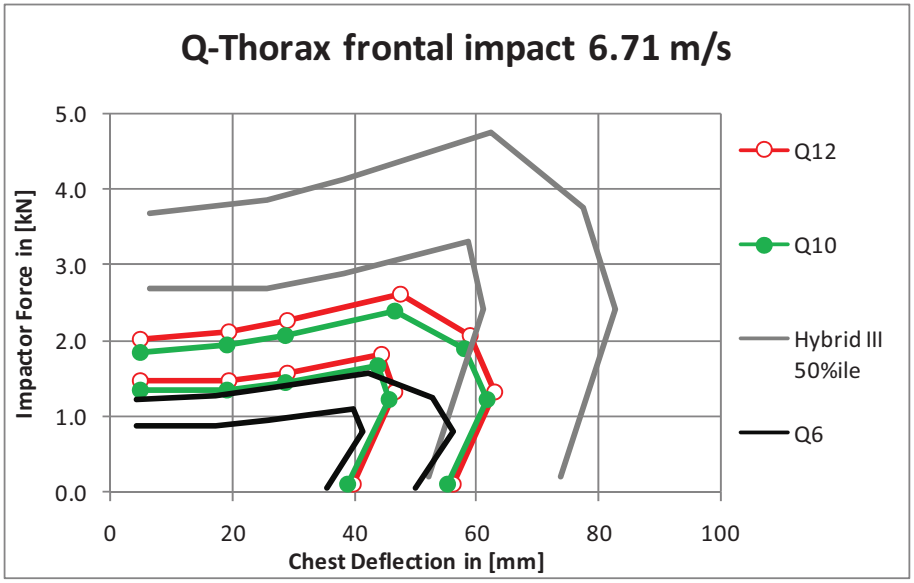

Figure 3: Thorax impactor force versus chest deflection biofidelity corridors for 6.71 m/s impact

4.2.2.4 Frontal Lumbar Spine biofidelity target

For Q6 lumbar spine a response target in forward bending is defined in ref. [xv].

Performance Target

The target specified in [xv] is scaled from the Hybrid III and the referenced report provides detailed information about the original data, the test set-up, the instrumentation and the static lateral stiffness performance target. This target doesn't fit in the method used for Q3 as reported in [xvi]. The scaling method used is based on the geometrical data of the human neck, assuming that the spinal cord development during the growth of a child is consistent over its complete length. In Table 6 the scaling factors, as well as the performance targets, for frontal lumbar static bending stiffness are specified. For reference the Q6 and adult values are specified as well.

Table 6: Q10 and Q12 Lumbar spine performance target (Q6 and adult values are given for reference)

Description **Age in years**		**Q6** **6.75**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
Scaling factor see Table 4		0.4964	**0.6621**	**0.7094**	1.00
Lateral bending stiffness in [Nm/rad]		102.8 (note)	**137.1**	**146.8**	207

Note: The value specified here deviates from the value in ref. [xv]: (62.1 Nm/rad). The value of 102.8 complies with scaling the methodology that is the basis of al the Q-dummy requirement (ref. [xvi]).

Means of Compliance

Because the same lumbar spine is used on Q1, Q1.5 and Q3 and the Q6 has a different one, it is anticipated that the Q6 spine can also be used on the Q10 or Q12. The relevance and the tolerance on the stiffness target are not yet established. In the design phase the targets will be further investigated to see whether the use of the Q6 spine on the Q10 or Q12 can be justified.

4.2.2.5 Frontal Abdominal biofidelity targets

The scaling methods used for the Q10/12 abdomen are based on those extensively reported in ref. [xvi] that specifies the Q3 response targets.

Performance Target

One of the performance targets specified in ref. [xv] and [xvi] is considered below. These reports provide detailed information about the original data, the test set-up, the instrumentation and the performance targets. The belt force versus penetration performance target corridors of Q10 and Q12 in pendulum tests are given in Table 7 and Figure 4. For reference the values for Q6 and Adults are given. The test according to Rouhana (1989) [xvii] penetrates a seat belt with a width of 30 to 35 mm into the abdomen at the L4 vertebrae with speed of 1.0 m/s up to a deflection of about 50% of the torso depth at waist.

Means of Compliance

This requirement issue is anticipated to be not critical for the design because the force deflection ratio below 70 mm penetration level is approximately the same for Q6 to Q12 dummy sizes. The increase of the stiffness occurs at a smaller penetration, this seems obvious because of the bottoming out effect of the belt when the penetration becomes larger than half the torso depth. Extrapolation of the current design is not anticipated to give any problem.

Table 7: Q10 and Q12 Abdomen performance targets
(Q6 and adult values are given for reference)

Description		**Q6**		**Q10**		**Q12**		**Adults**	
Age in years		**6.0**		**10.5**		**11.62**		**-**	
Scale Factors (extrapolated from Q3 and Q6 factors)									
Belt force		0.375		**0.515**		**0.550**		1.00	
Belt penetration		0.700		**0.836**		**0.869**		1.00	
		mm	kN	**mm**	**kN**	**mm**	**kN**	mm	kN
Upper limit		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		56.0	1.1	66.8	1.5	69.5	1.6	80.0	3.0
		66.5	1.9	79.4	2.6	82.6	2.7	95.0	5.0
		73.7	3.2	87.7	4.4	91.3	4.7	105.0	8.5
Lower limit		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		52.4	0.4	62.7	0.5	65.2	0.5	75.0	1.0
		70.0	0.9	83.6	1.3	86.9	1.4	100.0	2.5
		77.2	2.6	91.9	3.6	95.6	3.8	110.0	7.0

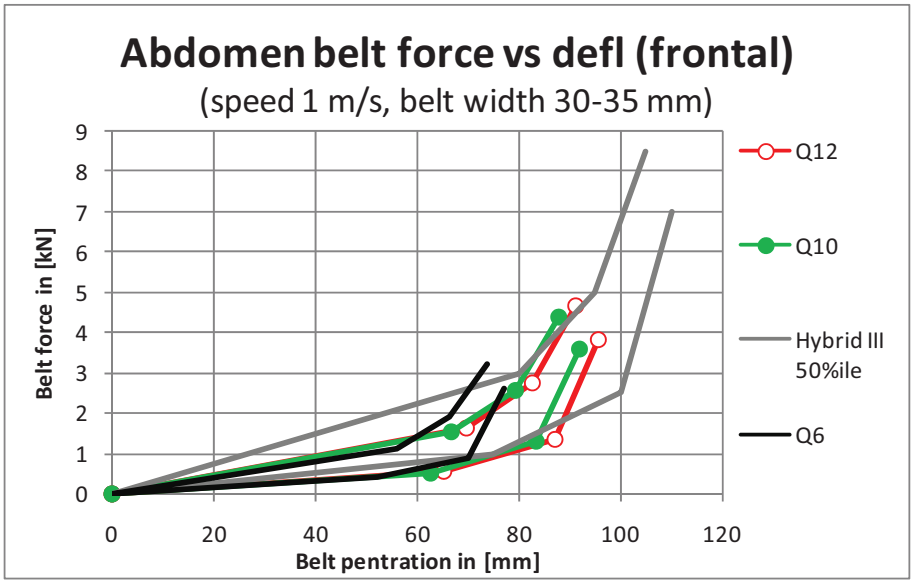

Figure 4: Abdomen biofidelity corridors

4.2.3 Side Impact

4.2.3.1 Introduction

The Q10 or Q12 development in EPOCh should result in a dummy that fits in Q-dummy family as known in Europe. The Q-family members are developed as omni-directional dummies. However, as it appears to be difficult to comply with both requirements the focus and the first priority is put on the frontal performance. Therefore the dummies are tuned to show optimal performance in frontal impact. So the requirements defined in this paragraph are of secondary importance, where possible the requirements will be taken onboard and in line with the other Q-series dummies.

Since 2004 side impact version of the Q dummies (Q3s and Q6s) are under development at FTSS in North America working with NHTSA, OSRP and Transport Canada. The Qs dummy is outside the scope of EPOCh, however on the design level, concepts used in the Q3s and Q6s to comply with the side impact performance targets will be facilitated where possible.

The side impact biofidelity of the Q dummies is based on scaling adult performance targets with geometrical and material property scaling factors. The geometry scaling is based on CANDAT (Child Anthropometry DATabase) dimensions as given. To remain consistent with this methodology Q10 and Q12 data is derived with help of the corresponding Q10 and Q12 dimensions given in Table 1.

For the development of the Q3s and Q6s in America the ISO/TR 9790 biofidelity data [xviii] is used to define the target values - this approach differs from the EEVC based European Q-series biofidelity targets. For interest only, the requirements for both the European and ISO approach are reported below. The European requirements are derived in line with the requirements definition for the other Q dummy family members.

4.2.3.2 Side Impact Head Biofidelity Target

In Europe the head biofidelity is based on brain injury, with skull fracture explicitly excluded whereas in America the requirements include skull fracture data points. For interest, both requirements are given in this paragraph.

Performance Targets

Q-series methodology based values

The head impact biofidelity corridor is scaled from that applicable for an adult dummy based on the Q10 and Q12 dimensions p66 (head length), p67 (head breadth) and p69 (menton to vertex) and the bone elastic modulus estimate ref. [xiii]. The primary head impact performance targets for Q10 and Q12, in a test with a drop height of 130 mm on a flat rigid face according to the European Q-series methodology are defined in Table 8. The values in this table are base on data sets that **exclude** skull fracture.

ISO/TR9790 based values (for interest)

The ISO/TR9790 based values obtained from ref. [xix] Table A1 applicable for tests with a drop height of 200 mm on a flat rigid face and with a drop height of 1200 mm on a padded surface are given in Table 9 and Table 10. The values in these tables are base on data sets that **include** skull fracture. The ISO 200 mm drop height performance targets in Table 9 should be considered as of secondary importance. With regards to ISO 1200 mm drop height performance targets are given for reference only because the specification of the padding used in the test is not clear.

Comparison of both corridors

In Appendix A the comparison of both corridors is discussed and conclusions are drawn.

Means of Compliance

The Q10 and Q12 target performance limits for the head in side impact are very close to those applicable for adults. It is recommended to follow the European Q-series methodology.

Table 8: Q10 and Q12 Head side impact primary targets,
Q-series methodology
Test: Impact on flat rigid face, drop height 130 mm,
(Q6 and adult values are given for reference)

Description **Age in years**	**CANDAT code**	**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
head length in [mm]	p66				
head breadth in [mm]	p67				
menton-vertex in [mm]	p69				
bone young modulus in [Pa]	-				
Scale Factor		0.9173	**0.9951**	**1.0014**	1.00
Head peak acceleration between					
Upper limit in [G]		184	**200.0**	**201.3**	201
Lower limit in [G]		107	**116.4**	**117.2**	117

Table 9: Q10 and Q12 Head side impact secondary targets,
ISO TR9790 method, ref. [xix]
Test: Impact on flat rigid face, drop height 200 mm,
(Q6 and adult values are given for reference)

Description **Age in years**		**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62 (see note)**	**Adults** **-**
Scale Factor		1.09	**1.07**	**1.07**	1.00
Head peak acceleration between					
Upper limit in [G]		164	**161**	**161**	150
Lower limit in [G]		109	**107**	**107**	100

Note: Q12 assumed to be equal to 10YO because ref. [xix] specifies same figures for 10YO and Small Female.

Table 10: Q10 and Q12 Head side impact targets (for reference), ISO TR9790 method, ref. [xix], Test: Impact on padded surface, drop height 1200 mm, (Q6 and adult values are given for reference)

Description		**Q6**	**Q10**	**Q12**	**Adults**
Age in years		**6.0**	**10.5**	**11.62 (see note)**	**-**
Scale Factor		1.09	**1.07**	**1.07**	1.00
Head peak acceleration between					
Upper limit in [G]		303	**297**	**297**	277
Lower limit in [G]		224	**220**	**220**	205

Note: Q12 assumed to be equal to 10YO because ref. [xix] specifies same figures for 10YO and Small Female.

4.2.3.3 Side Impact Neck Biofidelity targets

The neck flexion biofidelity corridor is scaled from that applicable for an adult dummy based on the Q10 and Q12 dimensions p74 (neck width), p91 (neck depth) and the tendon modulus. The value for p91 for Q6 is re-engineered based on the TNO neck biofidelity corridor data. Furthermore the ISO/TR9790 lateral impact neck performance corridor is given.

Performance Targets

Q-series methodology based values

The neck flexion target performance corridors of Q10 and Q12 according the Q-series methodology are given in Table 11 and Figure 5.

ISO/TR9790 based values (for interest)

The ISO/TR9790 ref. [xix] neck lateral impact scaling factors and biomechanical performance targets specifies in tables 8 and B1 are given in Table 12 and Figure 6.

Comparison of both corridors

In Appendix A the comparison of both corridors is discussed and conclusions are drawn.

Means of Compliance

It is recommended to follow the European Q-series methodology.

Table 11: Q10 and Q12 Neck lateral flexion targets, Q-series methodology (Q6 and adult values are given for reference)

Description Age in years	CANDAT code	Q6 6.0	Q10 10.5	Q12 11.62	Adults -
neck breadth in [mm]	p74				
neck depth in [mm]	P91				
Tendon modulus in -	-				
Scale Factors					
Flexion angle		1.00	**1.00**	**1.00**	1.00
Upper neck moment		0.3710	**0.5082**	**0.5406**	1.00

Neck moment versus flexion

		Degr.	Nm	**degr.**	**Nm**	**degr.**	**Nm**	degr.	Nm
Upper limit		0	5.2	**0**	**7.1**	**0**	**7.6**	0	14.0
		10	15.2	**10**	**20.8**	**10**	**22.2**	10	41.0
		35	15.2	**35**	**20.8**	**35**	**22.2**	35	41.0
		40	20.0	**40**	**27.4**	**40**	**29.2**	40	54.0
Lower limit		40	0.0	**40**	**0.0**	**40**	**0.0**	40	0.0
		50	20.0	**50**	**27.4**	**50**	**29.2**	50	54.0

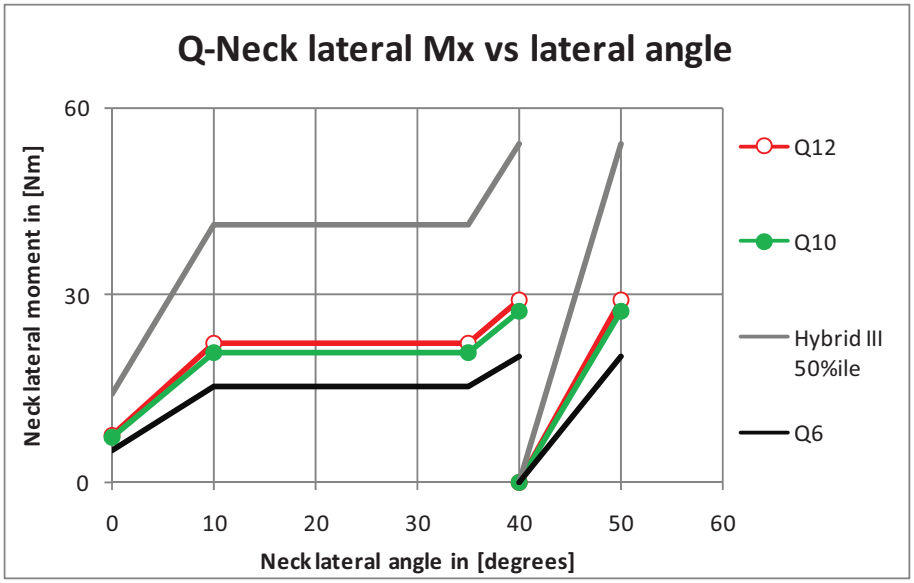

Figure 5: Neck lateral moment versus neck lateral angle biofidelity corridors

Table 12: Q10 and Q12 Neck lateral flexion targets, ISO TR9790, ref. [xix] (Q6 and adult values are given for reference)

Description Age in years	CANDAT code	Q6 6.0	Q10 10.5	Q12 11.62 (see note)	Adults -
Scale Factors					
Flexion angle		1.00	**1.00**	**1.00**	1.00
Upper neck moment		0.327	**0.420**	**0.501**	1.00

Neck moment versus flexion

		Degr.	Nm	**degr.**	**Nm**	**degr.**	**Nm**	degr.	Nm
Upper limit		0	5	**0**	**6**	**0**	**5**	0	10
		15	15	**15**	**19**	**15**	**23**	15	45
		40	15	**40**	**19**	**40**	**23**	40	45
		55	23	**55**	**29**	**55**	**35**	55	70
		75	43	**75**	**55**	**75**	**65**	75	130
Lower limit		50	0	**50**	**0**	**50**	**0**	50	0
		80	5	**80**	**6**	**80**	**8**	80	15
		90	43	**90**	**55**	**90**	**65**	90	130

Note: Q12 assumed to be equal to 10YO because ref. [xix] specifies same figures for 10YO and Small Female.

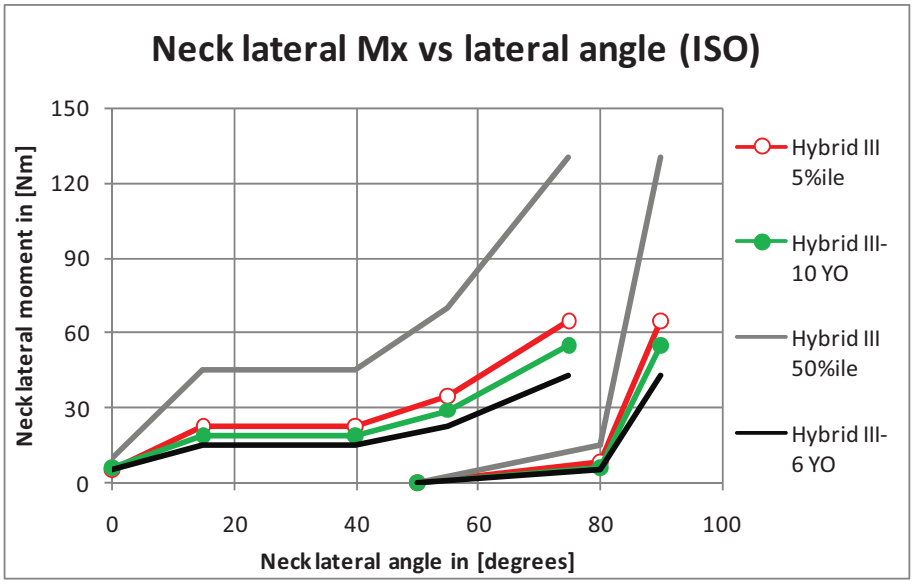

Figure 6: ISO Neck lateral moment versus neck lateral angle biofidelity corridors

4.2.3.4 Side Impact Thorax Biofidelity Targets

The frontal impact thorax biofidelity corridors are scaled from those applicable for an adult dummy based on the Q10 and Q12 dimensions p5 (shoulder height sitting), p13 (torso width at axilla), p14 (torso depth at axilla), p15 (circumference at axilla) and Eb (Young's modules rib (compact bone)). Dimension p14 and the young's modulus for the rib bone for Q6 Q10 and Q12 are not

given in Table 1, the value for Q6 is obtained from the TNO biofidelity corridor scaling assessment and the Q10 and Q12 values are extrapolated from Q3 and Q6 values.

Performance Target

Q-series methodology based values

The thorax side impact performance targets for Q10 and Q12, in a full body pendulum impactor tests at 4.27 and 6.71 m/s are defined in Table 13, Figure 7 and Figure 8. Note that the impactor masses for Q10 and Q12 are different.

ISO/TR9790 based values

With regards to the thorax biofidelity based on ISO/TR9790 ref. [xix] specifies corridors for several test conditions. The test conditions are listed below. In order to get a first indication of the Q12 ISO requirements the 5%ile small female data is taken, it should however be noted that the thorax dimensions and bone property of the small female deviates from those of the Q12.

1. Full body thorax pendulum impact at 4.3 m/s, ref. [xix] Table A6
   Pendulum force versus time corridor (see Table 14 and Figure 9)
   T1 Acc versus time corridor (see Table 14)
   The pendulum force requirement can be compared with the corresponding Q-series methodology target (see Figure 7). However, although the test configurations are similar for both requirements, the impactor masses are different: for Q-series methodology 8.7 kg and for ISO 6.9 kg.
2. Full body thorax pendulum impact at high speed 6.0 to 6.7 m/s, ref. [xix] Table A7
   Pendulum force versus time corridor (see Table 14 and Figure 10).
   This requirement can be compared with the Q-series target (see Figure 8). However, although the test configurations are similar for both requirements, the impactor masses are different: for Q-series methodology 8.7 kg and for ISO 6.9 kg.
3. Full body thorax drop from 1.0 meter height on a rigid surface, ref. [xix] Table A8
   Force versus time corridor (NOT FURTHER SPECIFIED)
   and
   Peak rib deflection (NOT FURTHER SPECIFIED)
4. Full body thorax drop from 2.0 meter height on a padded surface, ref. [xix] Table A9
   Force versus time corridor (NOT FURTHER SPECIFIED)
   and
   Peak rib deflection (NOT FURTHER SPECIFIED)
5. Full body thorax sled test at 6.8 m/s onto rigid surface, ref. [xix] Table A10
   Force versus time corridor (NOT FURTHER SPECIFIED)
   and
   Peak upper spine acceleration (NOT FURTHER SPECIFIED)
   and
   Peak lower spine acceleration (NOT FURTHER SPECIFIED)
   and
   Peak rib deflection (NOT FURTHER SPECIFIED)
   This test is very severe with peak rib deflection that are beyond the measurement capability of the dummies.
6. Full body shoulder and thorax sled test at 8.9 m/s onto a padded surface, ref. [xix] Table A11
   Force versus time corridor (NOT FURTHER SPECIFIED)
   and
   Peak lower spine acceleration (NOT FURTHER SPECIFIED)

Comparison of both corridors

In Appendix A the comparison of both corridors is discussed and conclusions are drawn.

Means of Compliance

It is recommended to follow the European Q-series methodology. The compliance with these requirements must be seen in the light of the compliance shown by the other Q dummies as reported in ref. [iii]. CAE simulations are recommended to evaluate design options.

Table 13: Q10 and Q12 Thorax lateral impact targets, Q-series methodology (Q6 and adult values are given for reference)

Description **Age in years**	**CANDAT code**	**Q6** **6.0**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
shoulder height at axilla in [mm]	p5				
torso width at axilla in [mm]	p13				
torso depth at axilla in [mm]	p14				
circumference at axilla in [mm]	p15				
Young's modulus for rib bone Eb in [kN/mm^2]					
Scale Factors					
Mass		0.2255	**0.3742**	**0.4193**	1.00
Displacement		0.8782	**0.9630**	**0.9849**	1.00
Impact force		0.2568	**0.3886**	**0.4257**	1.00

Thorax impactor force versus time

Impactor mass in [kg]		5.28		**8.76**		**9.81**		23.4	
		ms	kN	**ms**	**kN**	**ms**	**kN**	ms	kN
4.27 m/s impact									
Upper limit		0.0 8.8 26.3 39.5	0.26 0.80 0.80 0.33	**0.0** **9.6** **28.9** **43.3**	**0.39** **1.20** **1.20** **0.51**	**0.0** **9.8** **29.5** **44.3**	**0.43** **1.32** **1.32** **0.55**	0.0 10.0 30.0 45.0	1.00 3.10 3.10 1.30
Lower limit		4.4 8.8 26.3 30.7	0.00 0.26 0.26 0.00	**4.8** **9.6** **28.9** **33.7**	**0.00** **0.39** **0.39** **0.0**	**4.9** **9.8** **29.5** **34.5**	**0.00** **0.43** **0.43** **0.0**	5.0 10.0 30.0 35.0	0.00 1.00 1.00 0.00
6.71 m/s impact									
Upper limit		0.0 4.4 22.0 39.5	0.10 1.16 1.16 0.46	**0.0** **4.8** **24.1** **43.3**	**0.16** **1.75** **1.75** **0.70**	**0.0** **4.9** **24.6** **44.3**	**0.17** **1.92** **1.92** **0.77**	0.0 5.0 25.0 45.0	0.40 4.50 4.50 1.80
Lower limit		4.4 13.2 22.0 35.1 39.5	0.00 0.67 0.67 0.00 0.00	**4.8** **14.4** **24.1** **38.5** **43.3**	**0.00** **1.01** **1.01** **0.0** **0.0**	**4.9** **14.8** **24.6** **39.4** **44.3**	**0.00** **1.11** **1.11** **0.0** **0.0**	5.0 15.0 25.0 40.0 45.0	0.00 2.60 2.60 0.00 0.00

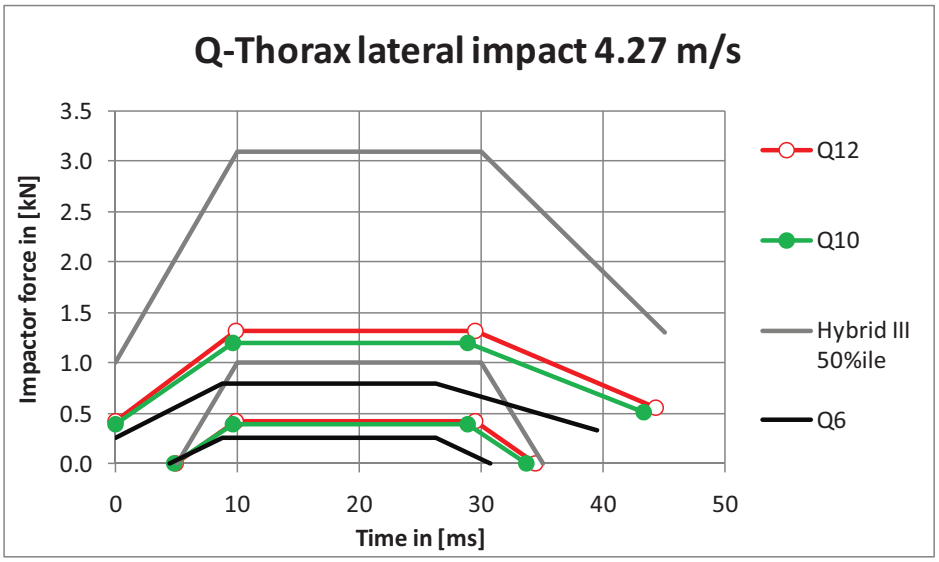

Figure 7: Thorax impactor force versus time biofidelity corridors for 4.27 m/s

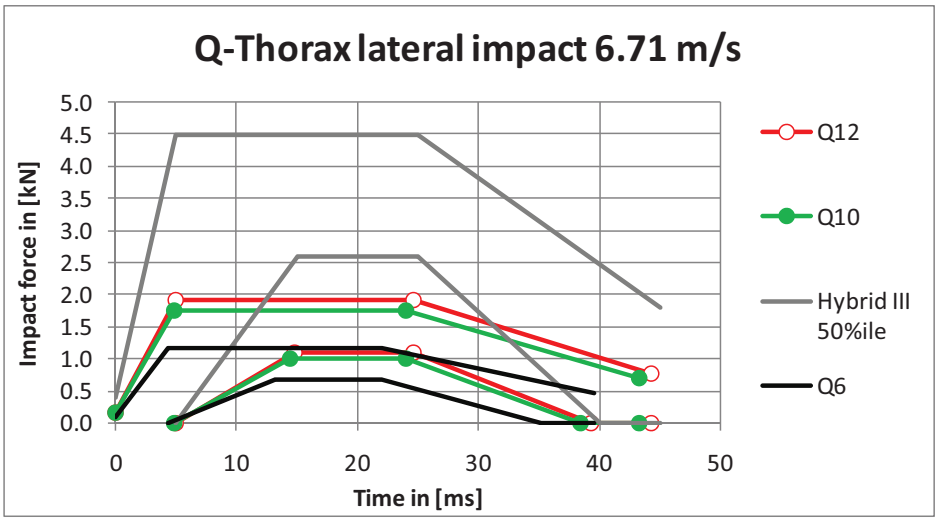

Figure 8: Thorax impactor force versus time biofidelity corridors for 6.71 m/s

Table 14: Q10 and Q12 Thorax lateral impact targets, ISO TR9790, ref. [xix] (Q6 and adult values are given for reference)

Description **Age in years**		**HIII 6YO** **6.0**	**HIII 10YO** **10**	**HIII 5th** **Small female**	**Adults** **-**
Scale Factors					
Mass		0.1239	**0.2944**	**0.5970**	1.00
Impactor mass in [kg]		2.9	**6.89**	**13.97**	23.4

Thorax impactor force and T1 acceleration versus time for 4.27 m/s impact

Pendulum force		ms	kN	**ms**	**kN**	**ms**	**kN**	ms	kN
Scale factors		**Not specified in ref. [xix]**						1.00	
Upper limit		0 6 19 28	0.5 1.1 1.1 0.6	**0** **7** **22** **32**	**0.8** **1.8** **1.8** **1**	**0** **8** **25** **37**	**1.2** **2.7** **2.7** **1.5**	0 10 30 45	1.7 3.7 3.7 2
Lower limit		0 6 19 25	0 0.5 0.5 0	**0** **7** **22** **29**	**0** **0.8** **0.8** **0**	**0** **8** **25** **33**	**0** **1.2** **1.2** **0**	0 10 30 40	0 1.7 1.7 0
T1 acceleration		ms	G	**ms**	**G**	**ms**	**G**	ms	G
Scale factors		**Not specified in ref. [xix]**						1.00	
Upper limit		0 9 31	2 16 0	**0** **11** **36**	**2** **18** **0**	**0** **12** **41**	**2** **18** **0**	0 15 50	2 15 0
Lower limit		4 9 23	0 9 0	**4** **11** **27**	**0** **9** **0**	**5** **12** **30**	**0** **10** **0**	6 15 37	0 8 0

Thorax impactor force versus time for high speed impact

Impact speed		6.0 m/s		**6.0 m/s**		**6.7 m/s**		6.7 m/s	
Pendulum force		ms	kN	**ms**	**kN**	**ms**	**kN**	ms	kN
Scale factors		**Not specified in ref. [xix]**						1.00	
Upper limit		0 3 16 28	0.3 1.4 1.4 0.7	**0** **4** **18** **32**	**0.5** **2.3** **2.3** **1.1**	0 4 20 37	0.8 3.4 3.4 1.6	0 5 25 45	1.2 5.2 5.2 2.5
Lower limit		0 9 16 28	0 0.8 0.8 0	**0** **11** **18** **32**	**0** **1.4** **1.4** **0**	0 12 20 37	0 2.1 2.1 0	0 15 25 45	0 3.2 3.2 0

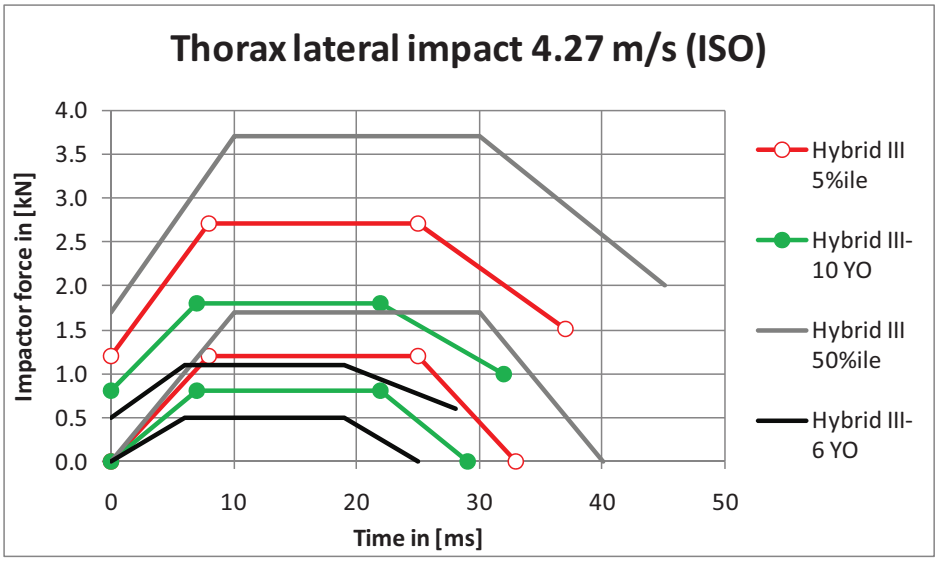

Figure 9: Thorax lateral impactor force versus chest deflection biofidelity corridors for 4.27 m/s impact

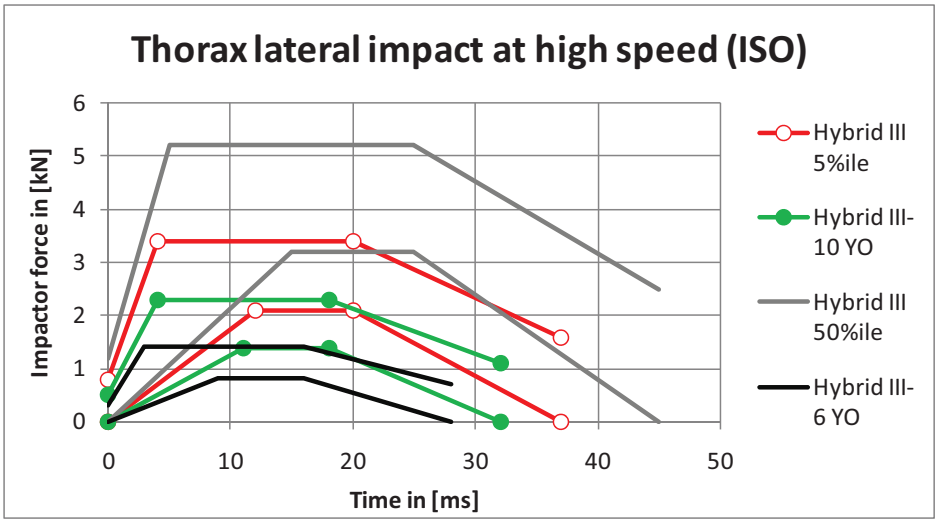

Figure 10: Thorax lateral impactor force versus chest deflection biofidelity corridors for 6.71 m/s impact

4.2.3.5 Side Impact Lumbar Spine biofidelity target

For Q6 lumbar spine a response target in forward bending is defined in ref. [xv].

Performance Target

The target specified in [xv] is scaled from Hybrid III and the referenced report provides detailed information about the original data, the test set-up, the instrumentation and the static lateral stiffness performance target. This target doesn't fit in the method used for Q3 as reported in [xvi]. The scaling method used is based on the geometrical data of the neck, assuming that the spinal cord development through the growth of a child is consistent over its complete length. In Table 15 the scaling factors, as well as the performance targets, for frontal lumbar static bending stiffness are specified, for reference the Q6 and adult values are specified as well.

Table 15: Q10 and Q12 Lumbar spine performance target (Q6 and adult values are given for reference)

Description **Age in years**		**Q6** **6.75**	**Q10** **10.5**	**Q12** **11.62**	**Adults** **-**
Scaling factor see Table 11		0.3710	**0.5082**	**0.5406**	1.00
Lateral bending stiffness in [Nm/rad]		104.2 (note)	**142.8**	**151.9**	281

Note: The value specified here deviates from the value in ref. [xv]: (81.5 Nm/rad). The value of 104.2 complies with scaling the methodology that is the basis of al the Q-dummy requirement (ref. [xvi]).

Means of Compliance

Because the same lumbar spine is used on Q1, Q1.5 and Q3 and the Q6 has a different one it is anticipated that the Q6 spine can also be used on Q10 or Q12. The lumbar spines of the current Q-dummies have the same stiffness for frontal and lateral bending. This is in line with what is done in the Hybrid III dummies. The relevance and the tolerance on the stiffness target are not yet established. In the design phase the targets will be further investigated to see whether the use of the Q6 spine on the Q10 or Q12 can be justified.

4.2.3.6 Side Impact Abdominal Biofidelity Requirements

For Q6 abdomen response targets for lateral impact are defined in ref. [xv]. The scaling methods used are extensively reported ref. [xvi] that specifies the Q3 response targets. These reports provide detailed information about the original data, the test set-up, the instrumentation and the performance targets. In reference [xix] also several side impact biofidelity requirements are specified. In the design phase the targets will be further investigated to see whether the use of the Q6 spine on the Q10 or Q12 can be justified.

Performance Target

NOT FURTHER SPECIFIED see [xv], [xvi] and [xix]

This performance target is anticipated to be not critical for the design. Extrapolation of the current design is not anticipated to give any problem.

4.2.3.7 Side Impact Pelvis Biofidelity Requirements

For Q6 pelvis response targets for lateral impact are defined in ref. [xv]. The report provides detailed information about the original data, the test set-up, the instrumentation and the performance targets. In reference [xix] also several side impact biofidelity requirements are specified. In the design phase the targets will be further investigated to see whether the use of the Q6 spine on the Q10 or Q12 can be justified.

Performance Target

NOT FURTHER SPECIFIED see [xv] and [xix]

This performance target is anticipated to be not critical for the design. Extrapolation of the current design is not anticipated to give any problem.

4.3 Functional Requirements

The Q10 or Q12 dummy will be designed as omni-directional dummy with the focus on frontal impact in line with the current Q-series. However in the design of this dummy, the possible development of a special side impact version in a future initiative will be kept in mind. Side impact design features or provisions for those features will be considered where possible and practical.

4.3.1 Test environment requirements

The dummy will be applied in tests to replace the 10 or 12 years old child size restrained with adult belt system and seated on a booster system (for example an UNECE Regulation 44 age group III Child Restraint System (CRS)).

4.3.1.1 Requirement

The Q10 and or Q12 dummy shall be suitable for application in test environments as described in the following protocols:

1. UNECE Regulation 44 age Group III and Directive 2003-20-EC or equivalent regulations to represent the largest occupant size. In the current UNECE R44 Group III upper limit with regards to occupant size is 36 kg. In the R44 sled test set-up there is no seat in front of the dummy. Currently a GRSP informal group on CRSs is developing a new test procedure for ISOFix Group I, in the future when the new procedures are extended to all types of CRSs the new procedures will supersede UNECE Regulation 44. It is not known how the occupant classification and the test setup(s) in future new regulation will be defined. It is likely that that the occupant size will be defined, in line with Directive 2003-20-EC, in terms of maximum stature or shoulder height.
2. EuroNCAP (European New Car Assessment Program)
   In this full-scale car crash protocols for frontal and side impact the child dummies are in a complete car interior including airbag interactions. Currently the old P1.5 and P3 dummy are prescribed for application on the back seats of the car. At this stage it is not known if and how, future EuoNCAP procedures will apply the Q- series.
3. Consumer test programmes such as NPACS (New Programme for the Assessment of Child-restraint Systems) established protocols in April 2008 on methods and assessment and the group agreed to the implementation on the research work completed together (ref. www.npacs.com). The actual implementation is to be decided by local organisations. Test programs based on the NPACS protocols are effective in the United Kingdom.
4. Research tests including real world accident reconstruction tests.

Note: In Europe there is no Out of Position (OOP) testing required in any regulatory or consumer test protocol. No special OOP-testing requirements will be set for the Q10/Q12. It is known that OOP tests are sometimes rather severe and the Q3 dummy suffered failures when exposed to them.

4.3.1.2 Means of Compliance

Based on the experience with Q6 and Q6s it is anticipated that the Q10 or Q12 dummy areas that are challenging will be:

1. Shoulder and neck area
   a. correct representation of the shoulder belt interaction is essential
   b. neck shroud will be required
2. Chest area
   a. top and bottom chest displacement to be measured
3. Pelvis area
   a. correct representation of the lap belt interaction is essential

b. important feature: pelvis bone shape and torso-leg configuration

Detailed requirements on this aspect will be formulated by EPOCh Task 2.4 during the submarining research activities.

4.3.2 Frontal Impact Severity Requirements

With regards to impact severity the design limits of the dummy cannot be specified in terms of sled or car deceleration pulse severity alone because in combination with a bad CRS it may result in load levels far beyond the human body tolerance. Therefore it is more appropriate to specify the design load requirements in terms of human body tolerance levels. The specification below is based on scaling of the Injury Assessment Reference Values (IARVs) developed for the Q-series and published in ref. [iii]. The values are valid for AIS3+ 50% risk. Within EPOCh Task 1.3 IARV's will be considered in detail, the values given below should be seen as a ball park level. Exceedance limits are established based on the UNECE R44 test experience with the Q-dummies described in ref. [iii]. The test data base available contains 152 Q-dummy tests on 30 CRS types, 74 CRS-dummy combinations with Q0 to Q6. It is assumed that tests with a Q10 and or Q12 dummy will result in the same level of IARV exceedances. The exceedance percentage, specified in Table 16, vary depending on the parameter considered. For reference the Q6 (AIS3+ 50% risk ref. [iii]) and Hybrid III-10YO and Hybrid III 5%ile and 50%ile are given based on UNECE Regulation 94 values ref. [xx]. The Hybrid III 50%ile values are the values on which the scaling is based.

4.3.2.1 Requirement

The Q10 or Q12 dummy shall be capable to be applied in tests that do not exceed 150 to 200% of the IARVs as specified in Table 16.

Assuming that the scaling is appropriate for prediction of the load levels the larger dummy it is anticipated that this requirement will make the Q10 or Q12 dummy robust enough for application in all current UNECE R44 homologated CRSs in frontal impact testing according to the NPACS protocol. In Europe no full scale car tests without appropriate CRSs or out of position tests are required.

4.3.2.2 Means of Compliance

It is anticipated that beyond the 150 to 200% IARV level the dummy may show permanent deformation and or failure. To prevent extensive overload on dummy parts, end stops may be built in where possible.

The use of advanced plastics and metal bones should be considered in arms and legs for durability.

An appropriate test matrix to demonstrate the robustness of the dummy will be developed and executed under EPOCh work package 3.

Table 16: Q10 and Q12 required load levels based on scaled IARV's together with ECE Regulation 94 Hybrid III IARV's

Parameter	Unit	Q6	Q10	Q12	HIII-10YO	HIII 5%ile	HIII 50%ile
		AIS3+ 50% injury risk ref. [iii]			UNECE R94 50%ile-values		
Head resultant acceleration	G	109	**108**	**109**	84	86	80
Exceedance limit 150%					[xx] Table D1 (scaled with Peak ACC ratio)		
Head HIC value	s	1389	**1413**	**1445**	1059	1113	1000
Exceedance limit 200%					[xx] Table D1 (scaled with HIC15 ratio)		
Upper neck tension Fz	N	2304	**2802**	**2937**	1820	2073	3300
Exceedance limit 200%					*(2290)*	*(2620)*	*(4170)*
					[xx] Table D2 (scaled down 3300/4170)		
Upper neck flexion moment My	Nm	143	**189**	**202**	78	95	190
Exceedance limit 150%					[xx] Table D2		
Chest deflection	mm	49	**46**	**47**	36	41	50
Exceedance limit 150%					[xx] Table D6		

4.3.3 Side Impact Severity Requirements

So far there are no side impact protocols specified in European regulations. In consumer test protocols for CRSs the current Q-series is required. These protocols focus on the evaluation of head containment and load management to the head. So far these tests do not show problems for the current Q-dummies to cope with the test severity. It is anticipated that the Q10 or Q12 designed in line with the current Q-dummies will be robust enough to assess UNECE R44 homologated CRSs in side impact with pulse and intrusion severities as specified in the NPACS and ISO protocols.

4.3.3.1 Requirement

The Q10 or Q12 shall be suitable for side impact test according to NPACS and ISO protocols, in line with the current Q-series. In Europe no full scale car tests without appropriate CRSs or out of position tests are required.

4.3.3.2 Means of Compliance

Lessons learned during the development of Q3s and Q6s will be taken onboard in design option trade off studies.

4.3.4 Durability Requirements

Users do not expect parts to fail during standard test procedures, test time and money is lost, possible delays obtaining new parts, bad feelings with customer loss of sales and loss in confidence. Durability should be the number one priority.

4.3.4.1 Requirement

Generally components should withstand up to 150% of there IARV and should generally survive a minimum of 150 tests at the 100% level without degradation of performance. See severity requirements in paragraph 4.3.2.1 above for specific components.

Parts should stay certified for up to 30 tests at the 100% level before re-calibration. There should be no permanent deformation, dislocation or failure of any parts within the above thresholds.

External damage from impacting rigid structures like tears and surface marking would be difficult to avoid but consideration should be provided to minimise this damage.

At the limits of ROM buffered stops should be utilised to prevent parts being highly stressed.

4.3.4.2 Means of Compliance

The durability will be taken care of during the development through good design, engineering judgement, selection of materials and CAE simulations. It will be evaluated through testing.

4.3.5 Repeatability and Reproducibility Requirements

For the dummy to be useable as a test tool specific targets must be maintained for acceptance

4.3.5.1 Requirement

On injury assessment parameters during calibration tests the coefficient of variation (CV) for repeatability should not exceed 7% for reproducibility the CV should not exceed 10%

The sensors are expected to operate within a CV of 1% during certification tests.

There should be consistent interaction with the restraint system or CRS e.g. no grooves to trap belt.

e.g. pelvis, shoulder belt routing.

4.3.5.2 Means of Compliance

Material selection, design, controlled manufacturing processes, component certification. A trade off study between sitting and standing pelvis will be performed.

4.4 Instrumentation Requirements

The selection of sensors may be clear cut with regard to well established and reliable products, however, new developments can be considered if suitable. In Table 17 a list of all the sensor channels that shall be incorporated in the Q10 or Q12 design is given.

Table 17: Q10 and Q12 instrumentation requirements

Sensor Type	Location	Direction	Remark	Channel count (x) side impact if different
Displacement Transducer	Upper rib cage	X or Y (and angle for side impact)	Two deflection transducers oriented in impact direction	1 (2)
	Lower rib cage		For side impact 2D-sensors are desired	1 (2)
	Shoulder	Y	*Side impact only* (application depend on Q3s and Q6s evaluation results)	0 (1)
Linear accelerometer	Head CG	X, Y, Z		3
	Thoracic spine T1	Y	*Side impact only*	0 (1)
	Thoracic spine T4	X, Y, Z		3
	Upper rib cage	X or Y	Accelerometers in impact direction	1 (1)
	Lower rib cage			1 (1)
	Pelvis	X,Y,Z		3
Angular rate sensor (ARS)	Head	ωX, ωY, ωZ		3
	Pelvis			3
Load cells	Upper Neck	6 axis		6
	Lower Neck			6
	Lower Lumber			6
	Femur		*Side impact only* Similar to Q6s design, evaluation results to be considered	0 (6)
	Shoulder	X, Y, Z	*Side impact only* (application depend on Q3s and Q6s evaluation results)	0 (3)
	Pubic	Y-force on hip cups	*Side impact only*	0 (1)
	Iliac crest (if necessary)	*X, Y, Z*	*To measure submarining*	*3*
Pressure sensor	*Abdomen*	*Internal foam pressure (INRETS) or Surface contact force (TUB) sensor system*	*Depending on availability of such a system, mature enough for direct application*	*Multi channel or 2 (not in total)*
Positioning sensor	Head	X and Y angle	These sensors shall be static only	2
	Thorax			2
	Pelvis			2

Total number of channels	**Frontal**	**46**
	Side	**(60)**

Sensors that are indicated with "Side impact only"

The sensors for shoulder displacement, T1 acceleration, shoulder loads, pubic load and to some extent also the femur loads are dedicated to side impact. These sensors are developed for Q3s and or Q6s in cooperation with NHTSA and Transport Canada. The full integration of these sensors is

beyond the scope of EPOCh. However, where possible and practical the provisions for those sensors will be implemented. The feasibility of implementation of special side impact features or provision for it shall be studied in the design concept phase a trade-off study will be made to justify design decisions.

Channel priority

The priority of these channels is not yet ranked.

Capacity indication

Indications for the required capacity magnitudes can be found in paragraph 4.3.2: The minimal level of capacity is 150 to 200% of the Injury Assessment Reference Value level.

Data Acquisition systems

Space allocation and provisions for on board a data acquisition system (in dummy DAS) will be considered in the design. (The actual implementation in the design depends on the DAS-system selected by the customer. The design with different DAS will meet the standard dummy mass and centre of gravity specifications. The prototype dummies delivered in EPOCh will not be equipped with an in dummy DAS.

Structural replacements

Structural replacements for sensors with equivalent mass and size shall be designed to restore the configuration of the dummy in case of operation without the sensor installed.

Means of Compliance

For the implementation of these sensor channels in the design, state of the art transducers can be applied.

4.5 Methods to Show compliance

The means of compliance is indicated in the performance targets and requirement definition paragraphs in section 4.1 to 4.4. In general design reviews in EPOCh work package 2 and tests performed in EPOCh work package 3 will provide justification data.

5 Discussion on Q10 or Q12 size selection

5.1 Introduction

To support the selection process/discussions a discussion of the presented Q10 or Q12 anthropometry targets is given under the following topics:

1. Comparison of CANDAT 10.5 year old anthropometry targets with main Hybrid III-10YO dummy dimensions
2. Comparison of CANDAT 12 year old anthropometry targets with main Hybrid III Small Female dummy dimensions
3. Anthropometry development of children from 10 to 12 year old
    c. How and when the pelvis bone develops towards maturity
    d. The influence of pelvis and leg mass on the submarining performance
4. Regulatory aspects and classification
    a. UNECE Regulation 44 boundary 36.0 kg
    b. Protection for children up to a Stature 1.50 meter
    c. American (NHTSA) view on largest child dummy
5. Practical constraints due to limited space in cars
6. Optimal representation of the largest children
7. Discussion in the GRSP Informal Group on CRS testing
8. Size selection recommendation, feedback from stakeholders and final decision

5.2 Comparison of CANDAT targets with existing dummies

Part of the consideration about dummy size was to investigate whether any existing dummies were appropriate for representing older children in child restraints. In Table 18 and Table 19 a comparison of the CANDAT target dimensions and masses with the actual dimensions and masses of the existing Hybrid III-10YO and 5%ile (small female) is given. The comparison brings significant differences to light; these are discussed in the following paragraphs.

Table 18: Comparison of CANDAT target dimensions with Hybrid III-10YO and Hybrid III 5%ile (small female) dimensions
(For shaded rows see notes at the bottom of the table)

CANDAT description	Priority	CANDAT target values				Actual dummy dimensions		
		CANDAT code	Q6 6.0 year old	Q10 10.5 year old	Q12 11.62 year old	Dimension ID	Hybrid III-10 year old	Hybrid III 5%ile
		See paragraph 4.1.4.2 Table 1				Ref. dummy manuals		
sitting height (to top of head)	1	p3	636	**748**	**773**	A	716	787
shoulder height sitting	1	p5				I+J	424	480
thigh height (sitting)	1	p34				F	113	127
lower arm and hand length	1-2	p56				G	235	252
shoulder-elbow distance	1	p51				I	277	287
buttock-knee length	1	p37				K	474	533
knee height	1	p40				M	381	406
buttock-popliteus length	1	p38				N	377	427
torso depth at nipples	2	P18				O	165	183
foot length	3	p48				P	196	226
stature	1	p2	1173	**1443**	**1500**	Q	1297	1499
head breadth	1	p67				S	142	142
head length	1	p66				T	183	183
hip breadth seated	1	p33				U	264	307
shoulder breadth (maximum)	1	p9				V	315	358
foot breadth	3	p49				W	76	86
head circumference	1	p68				X	539	539
torso circumference at axilla	2	p15				Y	704	866
torso circumference at waist	2	p23				Z	709	775
torso height at axilla (ref.)	3	p12				AA	343	305
torso height at waist (ref.)	-	p20				BB		165

Notes: p5 measured as external dimension incl. part of shoulder slope whereas I+J is to top of shoulder joint bracket
p56 measured to the finger tip whereas G is to the wrist pivot
p40 measured as external dimension whereas M is to the knee pivot
p12 and p20 measured in standing posture whereas AA and BB are in seated posture

Table 19: Comparison of CANDAT target masses with Hybrid III-10YO and Hybrid III 5%ile (small female) dimensions

CANDAT description	CANDAT target values				Actual dummy dimensions		
	CANDAT code	Q6 6.75 year old (see note)	Q10 10.5 year old	Q12 11.62 year old		Hybrid III-10 year old	Hybrid III 5%ile
	See paragraph 4.1.4.2 Table 1				Ref. dummy manuals		
Head Assembly	m1					3.73	3.73
Neck Assembly	m2					0.80	0.91
Upper Torso Assembly with Jacket	m3					8.15	12.02
Lower Torso Assembly	m4					8.72	13.25
Torso total	*m5*					*16.87*	*25.27*
Upper Arm, Left or Right	m6					0.81	1.18
Lower Arm, Left or Right	m7					0.61	0.90
Hand, Left or Right	m8					0.17	0.28
Upper Leg, Left or Right	m9					2.68	3.13
Lower Leg, Left or Right	m10					2.23	3.27
Foot, Left or Right	m11					0.41	0.79
Total Dummy Masses	*m12*	*23.00*	***35.50***	***40.00***		*35.21*	*49.00*

Note: The Q6 dummy is increased in mass corresponding with 6.75 year old while the dimensions correspond with 6 year old

5.2.1 CANDAT 10.5 yo targets versus Hybrid III-10YO dimensions

The 10.5 year old targets can be compared with the actual dimensions and masses of the Hybrid III 10 year old dummy. Below the major deviations of actual dimensions of the Hybrid III 10YO with respect to the CANDAT targets are listed (a negative value means that the Hybrid III 10YO dummy is smaller than the Q10.5):

Dimension	Description	Deviation
A	Seating height	-4.2 %
I+J	Shoulder height sitting	-10.4 %
I	Shoulder - elbow distance	-5.5 %
N	Buttock - popliteus length	-9.7 %
Q	Stature	-10.1 %
Z	Torso circumference at waist	+19.4 %

The average deviation taken over 13 important dimensions is 7.6 %. If the Torso circumference at waist (dimension ID Z) the average deviation over 12 dimensions becomes 4.3 %

Below the major deviations of actual masses of the Hybrid III 10YO with respect to the CANDAT targets are listed (a negative value means that the Hybrid III 10YO dummy is smaller than the Q10.5):

Description	Deviation
Head mass	+8.1 %

Torso mass	+13.6 % (Upper torso +58 %, Lower torso -10 %)
Arm mass	-20.1 %
Leg mass	-14.7 %
Total dummy mass	-0.8 %

The Coefficient of Variation taken over the 4 deviations mentioned is 16.6 %.

Conclusion

The Hybrid III-10 year old is slightly shorter than the target specified for 50 percentile of 10.5 year old children. The dummy circumferential dimensions are in compliance or larger which means that the Hybrid III-10 dummy is more relatively fat. This is confirmed by the mass properties that show that the torso contains considerable more mass and overall the dummy although smaller in stature (-4.2 %) and shoulder height (-10.4 %) is comparable in mass (-0.8 %). The mass distribution over upper and lower torso has a high deviation. This may well be a matter of definition of the location of the split line. Therefore it is ignored in the overall comparison. It is recommended to design the new dummy that should represent older children with a distribution over upper and lower torso in line with Q3 and Q6 properties.

The Q10 dummy that was designed along the same lines as the other Q dummy family members would be able to make use of all the research results obtained in the previous 13 years with the Q dummies. The Hybrid III 10YO may be maintained as a dummy robust enough to be applied in out of position (OOP) testing. Experience with Q3 and Q6 has shown the OOP testing with Q dummies can result in failures and it is anticipated that this could be applicable for the Q10 or Q12 dummy as well.

5.2.2 CANDAT 11.62 yo targets versus Hybrid III Small Female dimensions

The 11.62 year old targets can be compared with the actual dimensions of the Hybrid III small female dummy. Below the major deviations of the Hybrid III small female with respect to the CANDAT targets for 11.62 year old are listed (a negative value means that the Hybrid III 5th percentile female dummy is smaller than the Q11.62):

Dimension	**Description**	**Deviation**
I+J	Shoulder height sitting	-4.2 %
F	Thigh height (sitting)	6.2%
I	Shoulder-elbow distance	-5.7%
K	Buttock - knee length	+4.7%
U	Hip breadth seated	+8.9%
Y	Torso circumference at axilla	+20.9%
Z	Torso circumference at waist	+26.3%

The average deviation taken over 13 important dimensions is 9.7 %. If the Torso circumferences (dimension ID's Y and Z) the average deviation over 12 dimensions becomes 4.6 %.The dimensions of the SIDIIs dummy show a similar deviation from the targets for 12 year old.

Below the major deviations of actual masses of the Hybrid III small female dummy with respect to the CANDAT targets are listed (a negative value means that the Hybrid III 5th percentile female dummy is smaller than the Q11.62):

Description	Deviation
Head mass	+6.3 %
Torso mass	+51.4 % (Upper torso +108 %, Lower torso +21 %)
Arm mass	+4.0 %
Leg mass	-0.2 %
Total dummy mass	+22.5 %

The Coefficient of Variation taken over the 4 deviations mentioned is 24.2 %. The mass distribution of the SIDIIs dummy (44.1 kg) and the WorldSID 5th dummy (45.9 kg) are different and more difficult to compare. Taking into account that these dummies have no lower arms, the total body mass of these dummies confirms the trend that the small females are significantly different from the CANDAT 12 year old anthropometry.

Conclusion

The Hybrid III 5%ile (small female) is with regards to stature, seating height and shoulder height comparable in size with 50 percentile 12 year old children. However in some details the deviations are significant. The dimensions and masses of the torso deviate the most: circumferential dimensions round about +25 % and the hip breadth over +9%. This is confirmed by the mass distribution. The total mass of the Hybrid III Small Female is 23 % higher and the torso mass even 51 %. The mass distribution over upper and lower torso seems to deviate very much. This may well be a matter of definition of the location of the split line. Therefore it is ignored in the overall comparison. It is recommended to design the new dummy that should represent older children with a distribution over upper and lower torso in line with Q3 and Q6 properties. The higher mass of a small female that is mainly due to higher torso mass indicates that the torso of the 12 year old child is far from maturity. Based on this indication it can be assumed that the shape of pelvis bone structure of 12 year old children will considerably differ from that of small females. All in all it is concluded that a 12 year old child and small females are not comparable with regards to anthropometry and as such may be significantly different in the way they interact with a restraint system.

5.3 Anthropometry development for children from 10 and 12 year old

It is not known yet if there are, besides the difference in dimensions and mass properties, significant differences in maturity between 10 and 12 year old children. In-depth data on this subject may give some insight in the development of children with regards to vulnerability on the other hand accident statistics may be helpful to select the most injured size. This is particularly important with regards to submarining performance. The question is: which child is more prone to submarining, the 10 year old ones with less mature pelvis bones or the 12 year old ones with more pelvis and leg mass?

Remark: If a 11.6 year old child submarines less easily than a 10.5 year old child (because of changes in pelvis geometry), a Q11.6 with scaled 10.5 year old pelvis geometry would be a conservative test tool (it would be a slightly more strict test than required for a 11.6 year old child).

5.4 Regulatory aspects and classification

5.4.1 European regulations

Current UNECE Regulation 44 on CRS testing

In the current Child Restraint System (CRS) testing regulations (UNECE Regulation 44) the dummy that represents the oldest children is the P10 dummy. This dummy has approximately the anthropometry of a 10 year old child, specified among others with mass 32.0 kg, stature 1376 mm. If the CANDAT data for 6 and 10.5 year old is interpolated for 10 year old the mass and stature indications for 10 year old become 33.9 kg and 1413 mm. This means that CANDAT specifies for 10 year old a dummy heavier and larger than the P10 dummy. Based on the UNECE R44 classification the upper limit for CRS use is 36 kg. Therefore the Q10 dummy anthropometry is based on the properties of 10.5 year old children (see paragraph 4.1.2). The 36 kg body mass corresponds approximately with anthropometry of 50 percentile 10.5 year old children (CANDAT 10.5 yo: Stature 1443 mm, Shoulder height 473 mm, Mass 35.5 kg).

Note: If necessary the CANDAT-data can be interpolated between 10.5 and 11.0 years old to tune the total body mass to exactly 36 kg.

It should be noted that the Q-series dummies are no longer expected to replace the P-series in UNECE Regulation 44; instead, a new regulation is being developed specifically for ISOFix

Directive 2003-20-EC Seat belt wearing law

Historically, children have ceased to use child restraints much beyond the age of 5 years. However, recently the Directive for seatbelt wearing has changed so that children of a height up to 1500 mm and younger than 12 years must use a child restraint. This regulatory limit is adopted and has become mandatory in Sweden, Germany, Austria, Switzerland, Italy, Luxembourg, Ireland, Greece, Hungary, Poland and Portugal. The 1500 mm stature corresponds with anthropometry of 50 percentile 11.62 year old children (CANDAT 11.62 yo: Stature 1500 mm, Shoulder height 493 mm, Mass 40.0 kg). This has led to consumer confusion, as there are no child restraints on the market approved to restrain children who are heavier than 36kg. The directive allows countries to deviate from the 1500 mm stature rule down to a minimum stature of 1350 mm. This stature corresponded with a 50%lie CANDAT stature at an age of 8.95 year old.

Q10 as compromise between a stature of 1500 and 1350 mm

If the variation in local legislation remains in Europe so that statures from 1500 mm down to 1350 mm are allowed as maximum limit to use CRS, the Q10 (10.5 yo) may be a reasonable compromise. On the other hand, very few countries have adopted the lower height limit and manufacturers will develop one product that they will sell across all European countries. In the table below an overview of the main dimensions is given.

	CANDAT age	Stature	Shoulder height	Total body mass
Stature 1.35 m allowed minimum:				
Q9 dummy:	8.86 yo	1350 mm	444 mm	29.6 kg
Q10 dummy:	10.50 yo	1443 mm	473 mm	35.5 kg
Stature 1.50 m regulatory maximum:				
Q12 dummy:	11.62 yo	1500 mm	493 mm	40.0 kg

5.4.2 American view on largest child dummy

In Appendix B the American point of view as expressed by NHTSA (Matthew Craig) in answers on a short questionnaire is given.

5.4.3 Provisional conclusion on regulatory harmonisation

Based on the considerations on regulatory aspects as given above it can be concluded that with regards to dummy size, harmonisation between Europe and America remains open when 10.5 year old anthropometry is selected for the new dummy. In case the new dummy will be base on 11.6 year old anthropometry, harmonisation will be more difficult if not impossible. If enforcement of the Directive 2003-20-EC is only possible through the development of a 1500 mm stature dummy harmonisation between Europe and the rest of the world must be considered as a secondary issue.

5.5 Practical constraints due to limited space in cars

The current fleet of cars offer some times limited seating height at the rear seat. Several car design considerations (such as aerodynamics) can be the reason for this limited seating height. The 10.5 year old has a sitting height of 748 mm. Together with a booster cushion thickness of 80 to 100 mm the height on the bench will reach 828 to 848 mm high. This can be compared with the sitting height of a 50%ile Hybrid III dummy being 884 mm. For 11.6 year old geometry the dummy plus booster (773 mm + 80 to 100 mm = 853 to 873 mm) is almost as large as the 50%ile sitting height. The 10.5 year old geometry gives a better chance that the dummy together with an appropriate CRS can be used in small cars whereas a larger dummy will be limited in its application. However, there will be a problem in the real world where children will not be able to use the rear seats with a child restraint if the vehicles do not change. Both the 10.5 and 11.6 years old geometry are conflicting with the current UNECE R44 requirement for maximum upward head trajectory limit of 840 mm above the seat-seat back intersection point (CR point). This R44 requirement has been updated recently previously it was 800 mm. If it was necessary to relax this requirement for test with the P10 (sitting height 725 mm), a dummy with a larger geometry would

need even higher trajectory limits. It is not know how the current 840 mm trajectory limit relates to the available space in modern cars; however it can be assumed that higher boundaries (up to 900 or 950 mm) will not reflect the space available in a vehicle. A solution to this issue would be to use a smaller dummy (10.5) and reduce the vertical excursion allowance in R44, to reflect this. In addition, a classification could be introduced for vehicles that will identify to parents when a vehicle can and cannot accommodate a child under 1500 mm on a booster system.

5.6 Optimal representation of the group of largest children

It is not known how important it is to test with the largest size or with a dummy that is close to the largest possible child in the CRS. May be accident statistics can give a justification of which child size at the high end of CRS application is the most vulnerable. If a dummy of a certain size represent a group of children scattered around that its geometry properties, than an 11.62 yo 50%ile dummy (stature 1500mm, Shoulder height 493 mm, mass 40 kg) represents also children larger than 1500 mm that should not use the CRS any more. A slightly smaller dummy than the maximum size may represent the group of large children much better than a dummy fully tuned to the maximum size.

In Figure 11 it is illustrated how Q10 (10.5 yo) and Q12 can represent the large children that make use of a CRS under Directive 2003-20-EC (with a stature up to 1500 mm). The shaded are indicates the group of CRS user that the Q10 and the Q12 will represent.

In Figure 12 the body mass versus stature for CANDAT as well that for the current Q-dummies (Q0, Q1, Q1.5, Q3 and Q6) and Hybrid III dummies (HIII-3yo, 6yo, 10yo, 5%ile and 50%ile) are given. Additionally the CANDAT envelops for 5 and 95 percentile are indicated with yellow windows for 1, 1.5, 3, 6, 10.5 and 11.6 year old. This picture provides and overview of position of the dummy sizes in the grow curve.

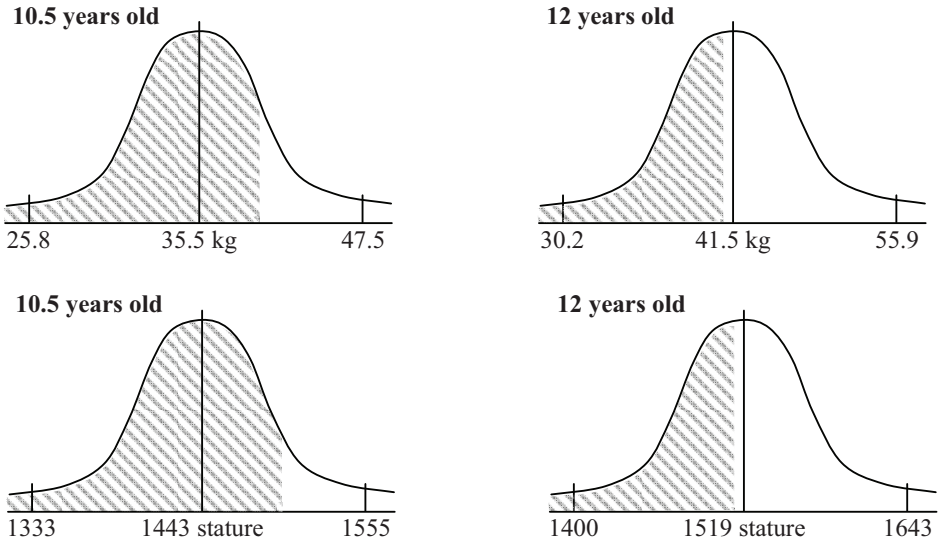

Figure 11: Q10 and Q12 child group representation (not to scale)

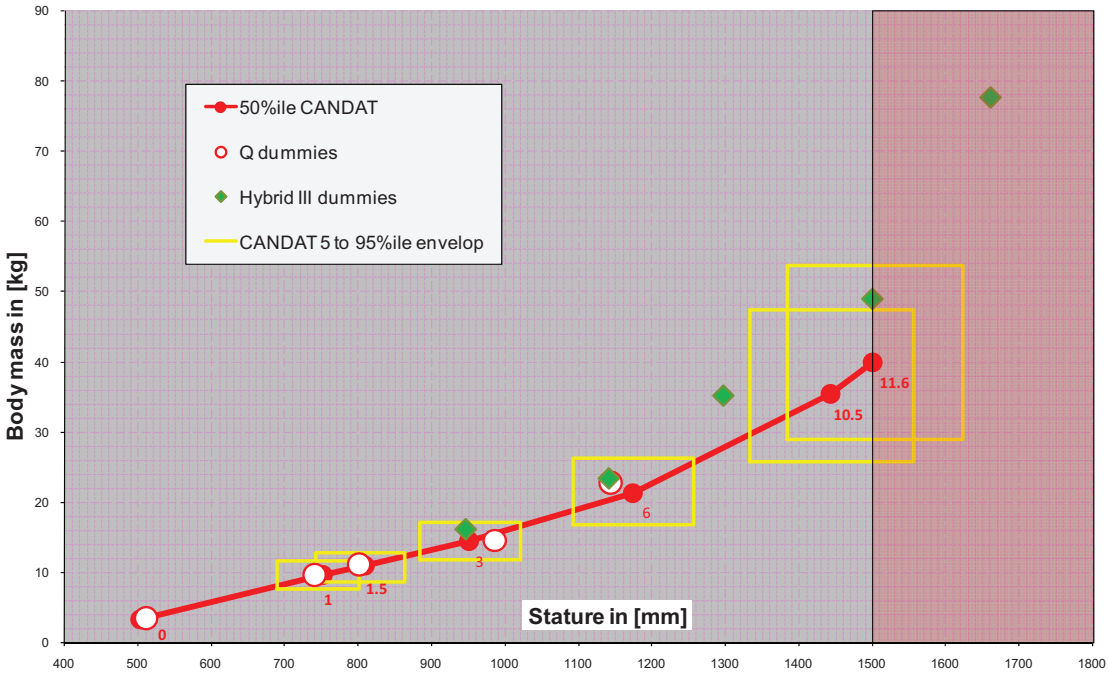

Figure 12: Body mass versus stature for CANDAT and the current dummies. Additionally the CANDAT envelops for 5 and 95 percentile at 1, 1.5, 3, 6, 10.5 and 11.6 year old are indicated

5.7 Discussion in GRSP Informal Group on CRS testing

In Appendix C the discussion on the dummy size selection in the meeting of the GRSP informal Group in CRS testing is summarised.

5.8 Size selection recommendation, feedback and final decision

5.8.1 Main options

The two main options that are possible are:

- Definition of a Q10 dummy representing children of 10.5 year old with the anthropometry targets as presented in paragraph 4.1.4.2.

  (CANDAT 10.5 year old: Stature 1443 mm, Sitting height 747 mm, Shoulder height 473 mm, Mass 35.5 kg)
  Note: If necessary the CANDAT-data can be interpolated between 10.5 and 11.0 years old to tune the total body mass to exactly 36 kg.

  The dummy size represents an average of the largest children that use CRSs

- Definition of a Q12 dummy representing children of 11.62 year old with the anthropometry targets as presented in paragraph 4.1.4.2.

  (CANDAT 11.62 year old: Stature 1500 mm, Sitting height 773 mm, Shoulder height 493 mm, Mass 40.0 kg)

  This dummy size represents the ultimate height of children that use CRSs

5.8.2 Derivative options

If both boundaries, 36 kg body mass (UNECE Regulation 44) and 1500 mm stature (Directive 2003-20-EC), remain as they currently are for the assessment of child safety for older children two design options are possible:

- Definition of a Q11 dummy representing large children of 10 year old and lean children of 12 year old.

  (CANDAT: 11.1 year old: Stature 1471 mm, Sitting height 760 mm, Shoulder height 483 mm, Mass 37.7 kg)

  In this option the complete dummy will be designed against 50 percentile target for 11.1 year old children. (If this option is selected new anthropometry and biofidelity targets should be defined)

- Definition of all moulded parts (head, thorax, abdomen, pelvis, arms and legs) against 11.1 year old targets and make the shoulder height and torso mass adaptable to comply those for 10.5 and 11.62 year old targets.

  From this approach two dummy configurations will appear that show small differences: The variations possible through adaptors will be:

  - Shoulder height 19.8 mm (CANDAT 10.5 yo: 473.4 mm, 11.62 yo: 493.2 mm),
  - Seating height 25.2 mm (CANDAT 10.5 yo: 747.6 mm, 11.62 yo: 772.8 mm) and
  - Torso mass 1.84 kg (CANDAT 10.5 yo: 14.85 kg and 11.62 yo: 16.69 kg).
  - Head and neck mass 0.17 kg (CANDAT 10.5 yo: 4.19 kg and 11.62 yo: 4.36 kg).
  - Overall the dummies will not comply with the CANDAT targets of 10.5 or 11.62 year old children.
    - Stature variation limited to 25.2 mm (compromised: 57.5 required)
      Maximum stature 1483.9 mm (16.1 mm short target: 1500 mm)
      Minimum stature 1458.7 mm (13.7 mm longer target: 1443 mm)
    - Total mass variation limited to 2.01 kg (compromised: 4.5 kg required)
      Maximum mass 38.7 kg (1.3 kg lighter target: 40.0 kg)
      Minimum mass 36.8 kg (1.3 kg heavier target: 35.5kg)

  The disadvantage of this option is that the differences of these two variants of the dummy are not easily recognisable. This makes the configuration control complex and may be a cause of errors in the application of the dummy.

5.9 EPOCh team discussion and recommendation and final conclusion

To come to a deliberated recommendation the current UNECE Regulation 44 P10 dummy as well as the Q10 and Q12 are compared with regards to several key aspects in Table 20. In Table 21 the PRO's and CON's of the Q10 and Q12 as far as generated in the EPOCh project team are listed.

After intensive discussion the EPOCh team decide to recommend the selection of Q12 (stature 1500 mm) for the dummy to be developed. The main argument for this recommendation is that Directive 2003-20-EC requires children up to a stature of 1500 mm to use a CRS. The Q12 dummy with 50%ile anthropometry of children with a stature of 1500 mm will represent the user of the ultimate height, with a 50%ile mass for the crash safety tests which would allow the Regulation for child seat type approval to be updated to be in line with the seat belt wearing Directive.

The recommendation to proceed with the design of a Q12 dummy was presented in the stakeholder forum meeting organised by the EPOCh team, presented to the informal GRSP group working on the new regulation and in subsequent contact that the EPOCh team members had with other stakeholders.

Table 20: P10, Q10 and Q12 comparison

Aspect	P10	Q10	Q12
Specification			
Age [years]	ca. 10	10.5	11.62
Stature [mm]	1376	1443	1500
Sitting height [mm]	725	748	773
Shoulder height [mm]	483	473	493
Total mass [kg]	32	35.5 kg	40.0
Mass		Close to current upper boundary specified for Group III CRSs	
Homologation	Recent UNECE R44 head trajectory criterion release from 800 to 840 mm above seat/back intersection point	In general the current UNECE R44 criteria can be assessed. (Standards for CRS testing are being revised to adapt them to recent EC-directives.)	Represents the upper limit of children that should make use of a CRS. Can be included in the further discussions of new CRS standard.
Children on coaches			Children transport is considered up to 16 years old. Therefore a 12 yo dummy will allow a better design of CRS for coaches and buses.
Directive 2003-20-EC, the current seatbelt wearing law, required CRS use up to 1500 mm stature. Countries are allowed to go down to 1350 mm.		The majority of countries in Europe adopted the 1500 mm rule others deviate from it down to 1350 mm. The Q10 has average geometry between both practices. The Q10 representing an average 10.5 yo child can be considered to represent a wide group of large children, the 95%ile 10.5 yo child has a stature of 1555 mm.	The Q12 dummy would allow CRS to be tested with the ultimate user size.
Submarining research		Submarining research will be performed regarding to appropriate anthropometrical dummy requirements.	
Statistical most injured size	Not known maturity of 10-12 yo children. Vulnerability development of children. The dummy size can be advised through the statistical most injured size, however 12 yo children are not in CRSs at the moment.		

Table 21: Q10 and Q12 PRO's and CON's

	Q10	**Q12 (tuned to stature 1500 mm)**
Age	**10.5 yo**	**11.6 yo**
Stature	**1443 mm**	**1500 mm**
Sitting h	**748 mm**	**773 mm**
Shoulder h	**473 mm**	**493 mm**
Mass	**35.5 kg**	**40.0 kg**
PRO's	• Represents an average of the large children to cover the full current range of allowed stature limits under Directive 2003-20-EC: 1350 to 1500 mm. • Leaves possible introduction of Q-dummies in UNECE R44 as currently defined open. • Potential harmonisation with dummy size in America	• Represents the ultimate body height of children that use CRSs under Directive 2003-20-EC. • Allows assessment of head injury of the tallest children (most at risk due to head excursion. • Allows ultimate CRS assessment in consumer test for the full range of CRS using children as legally required • Enforces CRS and car manufacturers to design to Directive limits.
CON's	• Would not allow CRS manufacturers to test for children at the maximum child height required by the EC Directive. • Would not allow assessment of protection afforded to older children in consumer tests	• Too large for application under current UNECE Regulation 44 (which uses the P-series dummies).

5.9.1 Feedback from stakeholders

A summary of the main opinions expressed in the stakeholder feedback are as follows:

In the stakeholders forum meeting on June 10, 2009 in Paris the following three stakeholder representatives participated:

1. Francoise Cassan
   representing the CASPER project (project coordinator)
2. Pierre Castaing
   representing GRSP Informal Group on CRS testing (chairman) and EuroNCAP (board member)
3. Luis Martinez
   representing EEVC WG12 (member) and WG18 (chairman)

All three participants expressed their preference for the development of the Q10 dummy because it is common practice that an average size of a certain user group is used in crash testing. The Q10 can represent a large group of users smaller and larger than. The Q12 on the other hand can only represent user up to 1500 mm stature. Beyond the limit children will not use a CRS anymore. In the meeting the pictures shown in Figure 11 were presented to illustrate the child group representation.

After the stakeholder forum meeting the EPOCh team has approached a wider group of stakeholder representatives including policy makers to collect additional feedback. Finally the EPOCh recommendations were presented in the meeting of the GRSP Informal Group on CRS testing on July 02, 2009 in Brussels [xxi]. The 29 experts and policymakers that attended this meeting as well as the 88 people on the GRSP Informal Group mailing list were requested to respond through E-mail on their preference and the arguments behind it.

The people that responded were:

- Pierre Castaing (UTAC, GRSP and EuroNCAP, France),
- Jim Hand (Department of Transport, UK),

- Luis Martinez (University of Madrid, EEVC WG12 and WG 18, Spain),
- Philippe Lesire (LAB, Renault, France),
- Francoise Cassan (LAB, France),
- Farid Bendjellal (Britax, France),
- Hans Ammerlaan (Department of Transport, The Netherlands) and
- Julie Brown (Prince of Wales Medical Research Institute, Australia)

All respondents expressed their preference for Q10 dummy. The following arguments are mentioned to support the selection of Q10:

1. Directive 2003/20/EC can be implemented by an age limit of 10 years and based on CANDAT data the statures can vary from 1310 to 1520 mm (in line with the 2003/20/EC limits between 1350 and 1500 mm) and the masses between 24.54 and 44.71 kg.
2. The 10 yo pelvis is more adapted to highlight problems of submarining than the 12 yo one.
3. For head trajectory limitation a reduced criterion value for Q10 can be defined to account for the larger dimensions of the ultimate stature of 1500 mm specified in Directive 2003-20-EC.
4. In crash testing the worst condition is never tested. Test procedure always specify "mid seat position" and other average user conditions.
5. The gap between the dummy for the older children and the Q6 should not be too large.
6. Field studies show that the use of CRS is highly decreasing after 8 years of age. So the development of a Q12 dummy will only have a limited effect on the global protection of children even if it allows the development of new CRS adapted up to 12 years of age.
7. There is already a tool existing with very close dimensional characteristics, the Hybrid III 5^{th} Female, (even if the mass repartition is slightly different) that could be used for an approach of the protection of 12 years old children.
8. The height that you could take for a 10 year old dummy is around 1450 mm which seems reasonable to ensure protection of a large part of children.
9. For children approaching the stature of 1350 mm it becomes difficult to persuade to still use their CRS this is difficult to neglect.
10. The rear seat safety performance optimized for small female can tested with a Q10 that represents the smallest sizes that would occupy it.

5.9.2 Final conclusion on size selection

Based on the feedback received from the stakeholders the EPOCh team has decided to proceed with the design of the Q10 dummy (Age 10.5 years old, Stature 1443 mm)

6 Conclusions

In this report dummy design requirements and targets for a prototype Q dummy representing adolescents were defined. A set of Anthropometry and Biomechanical targets as well as Functional and Instrumentation requirements was defined. Moreover methods to show compliance for the prototype dummy are indicated. To support a fare size selection process the requirements for both Q10 (10.5 yo anthropometry) and Q12 (11.6 yo anthropometry) are provided.

In addition to this relevant information on the dummy size selection is provided. This includes input from regulatory requirements from different EU countries as well as from other regions.

Initial recommendation for Q12

Based on this information the EPOCh consortium recommended the stakeholders to develop a Q12 dummy. This was based on the consideration that this dummy size, representing the ultimate child height and 50^{th} % mass that must currently use a CRS under Directive 2003-20-EC, provides the most up to date safety benefit.

Stakeholder feedback

During the stakeholders forum meeting on June 10, 2009 in Paris the preference for the Q10 was expressed. After the forum meeting the preference for Q10 was confirmed by all approached experts and policy makers. In paragraph 5.9.1 the stakeholder feedback including the underlying arguments are summarised. The main arguments are that a dummy with 10.5 year old anthropometry is the best average representative of group of older children the make use of CRSs, it will, together with the booster seat, fit into the rear of current vehicles and has been traditionally used in R44 and ties in with the 36 kg limit in the regulation.

Final decision to develop Q10

After consideration of all feedback and underlying arguments the EPOCh team has taken on board the feedback from the stakeholders and decided to proceed with the development of the Q10 dummy with 10.5 year old anthropometry

Acknowledgements

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Glossary of Terms and Abbreviations

Anthropometry	Description of the human body in terms of external and internal dimensions as well as body segment mass distribution
Biofidelity	The level of humanlike behaviour of a crash dummy under relevant impact conditions
CANDAT	Child ANthropometry DATa base developed by TNO in the early 90's of last century combining seven published anthropometry data sets as described in ref. [iv].
CHILD	European project "Child Injury Led Design" (2002-2006)
CREST	European project "Child Restraint Systems for Cars" (1996-2000)
CRS	Child Restraint System
EEVC	European Enhanced Vehicle-safety Committee (www.eevc.org)

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Appendix A Discussion on Biofidelity Issues

Q-series methodology versus ISO/TR9790 for lateral performance targets

Head lateral performance targets

The European- and ISO/TR9790 performance targets are not compatible. The European approach excludes the skull fracture cases in the data set because the dummies should operate in the severity level below skull fracture. The ISO/TR9790 performance targets are based on both facture and non-fracture head drop tests. This fundamental difference makes it rather difficult to harmonize both performance target definition methods. For the Q10 or Q12 head it is recommended to use the European methodology for side impact head performance evaluation, in line with evaluation performed for the rest of the Q-series see ref. [iii].

Neck lateral performance targets

From the comparison of the Q-series methodology and the ISO/TR9790, scaled values are given in Figure 13, it is clear that the requirements are not compatible. Only the upper limits of the corridors up to 35 degrees lateral flexion are more or less compatible. This reflects the difference in basis of both sets of requirements. European requirement are based on low severity volunteer test whereas the ISO/TR9790 data make use of the older cadaver test data in more severe test conditions generated by Mertz [xix]. It may be possible to extrapolate the child dummy side impact developments in America. The Q3s and Q6s have improved neck biofidelity that have been optimised and evaluated against ISO frontal flexion and extension as well as lateral flexion targets. However this approach would result in a Q10 or Q12 dummy that is not inline with the rest of the dummies in the Q-series. It is recommended to use the European methodology for side impact neck performance evaluation, in line with evaluation performed for the rest of the Q-series see ref. [iii].

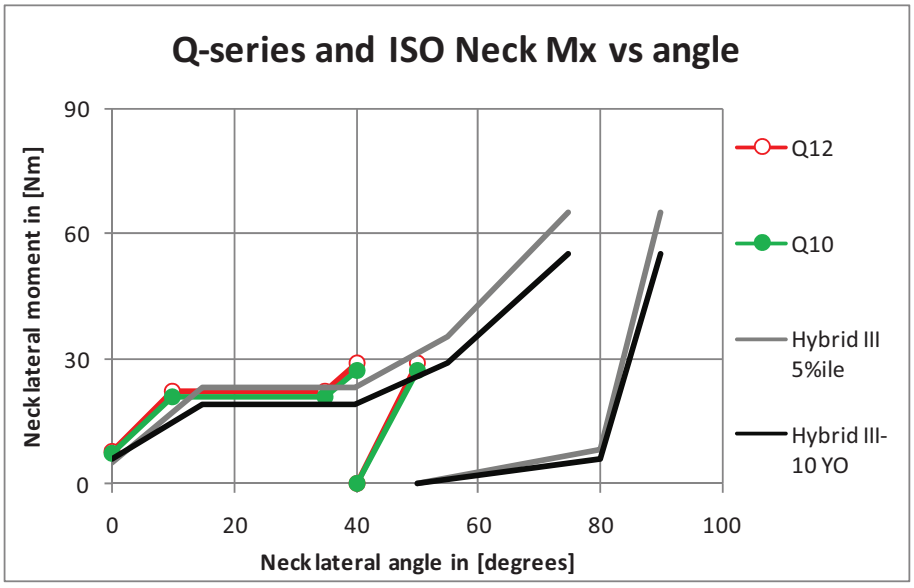

Figure 13: Neck performance targets comparison Q-series methodology versus ISO/TR9790

Thorax lateral performance targets

From the comparison of the Q-series methodology and the ISO/TR9790 scaled values are given in Figure 14 and Figure 15 it is clear that the requirements are not compatible. The Hybrid III -10YO corridors are higher with regards impactor force and shorter with regards timing than those for Q10 and Q12. The impactor mass for Hybrid III -10YO is 6.9 kg whereas that for the Q 10 is 8.8 kg. This can not justify the full difference and it is not known where these differences come from. It is clear that the two sets of side impact requirements are different although there is an area of overlap. Parallel evaluation with respect to both corridors is possible however it is recommended to use the European methodology for side impact thorax performance evaluation, in line with evaluation performed for the rest of the Q-series see ref. [iii].

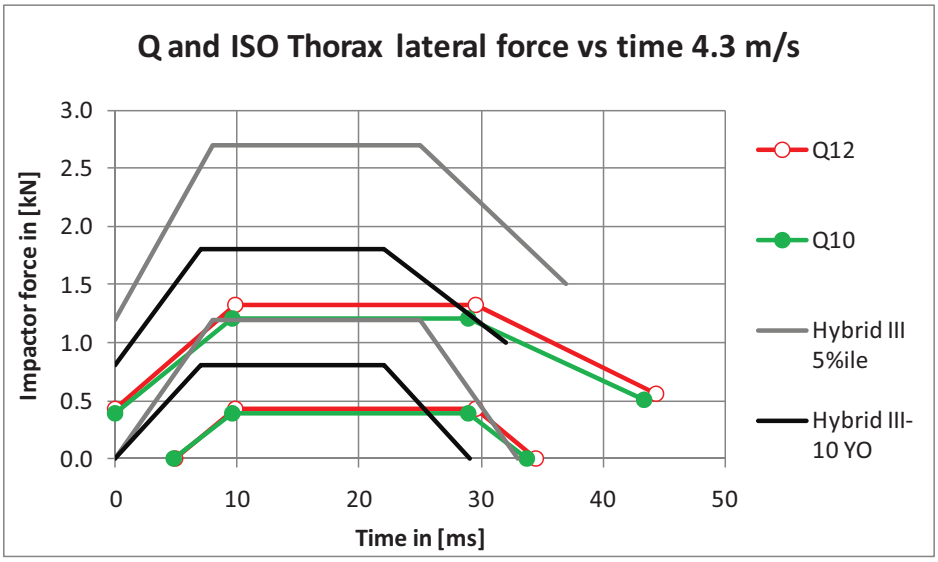

Figure 14: Thorax performance targets at 4.27 m/s impact comparison Q-series methodology versus ISO/TR9790

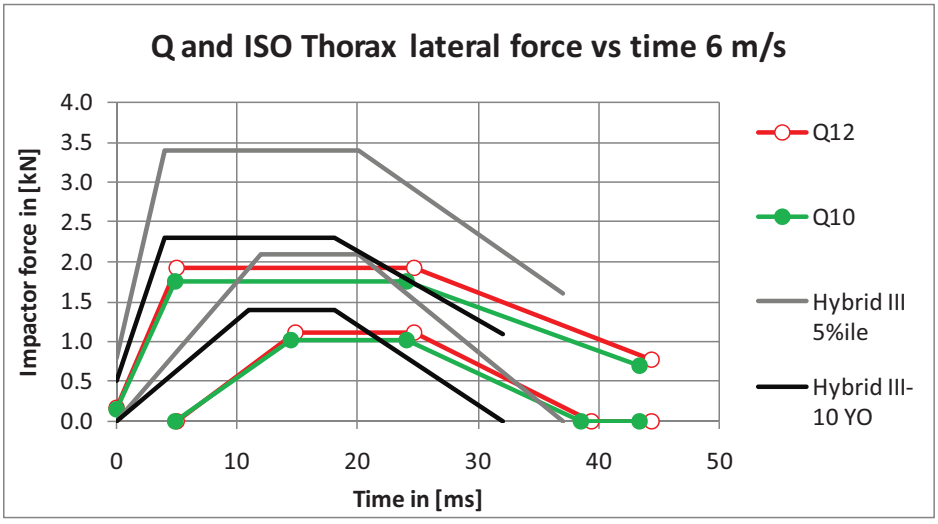

Figure 15: Thorax performance targets at high speed impact comparison Q-series methodology versus ISO/TR9790

Appendix B American view on largest child dummy

The paper that describes the developments of the Hybrid III 10 year old dummy [xiii] states in its abstract:

> *This paper describes the design and development of the Hybrid III 10-year-old crash test dummy. The size of the dummy was chosen to fill the gap between the Hybrid III 6-year-old and the Hybrid III small adult female dummy which is also about the size of a 13-year-old teenager.*

NHTSA (Matthew Craig) has been approached by E-mail with a few questions with regards to their view on the final largest child dummy size, NHTSA experiences with current Q dummies in frontal testing, problems etc, HIII 10YO size and maximum expected loading. Below the answers given by E-mail in July 2008 are quoted:

1. In Europe there are two streams the Europe the directive 2003-20-EC requires CRS use up to 1.50 meter. Countries are allowed to go down to 1.35 meter. The 1.50 meter boundary is applicable in Sweden, Germany, Austria and Swiss. The GRSP informal group on CRSs currently collects information on the reasons why countries select a certain boundary occupant size.
   What is the situation in America and how do you think it will develop in the future?
   What is your view on what dummy should be the high end Q-family member?
   NHTSA: *I don't think there is an official NHTSA position on this Most state laws saw 8 years or 80 pounds (36.3kg), and I think the height of 4'9"(1448 mm) is has been referenced. I'm not sure what is meant by "high end Q-family member" If the meaning is "what should be the biggest Q dummy I would say the Q-10.*

2. In America there are some experiences with Q-dummies in frontal impact especially in OOP- test.
   What are the lessons learned from the American Q-dummy frontal experiences?
   NHTSA: *We have not conducted OOP testing with the Q3s. Earlier testing with the frontal Q3 dummy conducted several years ago exposed many structural weaknesses of the dummy, in particular, the shoulder.*

3. The anthropometry of a 10.5 year old child (target to replace current UNECE R44 P10 dummy) is on average 7 to 8% larger than the actual Hybrid III 10YO dimensions. (Stature/mass for example Anthropometry: 1443 mm / 35.50 kg and Hybrid III 10YO: 1297 mm / 35.21 kg).
   How is the Hybrid III 10 YO size and mass positioned relative to the current data in American data?
   What is the actual 50%ile age of the Hybrid III 10YO dummy?
   What do you think about the required size and mass of a high-end CRS test dummy?
   NHTSA: *The term "10 year old dummy" is really a misnomer. Think of this dummy instead as a "large child" of a stature/mass to test booster seats for weights up to 80 lbs (36.3 kg). The H3 design represents an 8.5 YO in overall height and 10.5 YO in Weight, according to 50%ile male/female data in CDC growth charts from 2000. The original design targets for this dummy were determined by Mertz et all (Stapp 2001) using scaling methods The SAE H3 dummy family task force used these targets to develop the original prototype in 2000. Some compromises had to be made to the overall dimensions/mass of the physical dummy due to the need to match the individual segment dimensions/ masses with the basic construction techniques used in the Hybrid III family of dummies. As a result, the scaled segments and the final design did not perfectly match the anthropometry targets (it was shorter by roughly 3" (76.2 mm) from head to toe and about 2.7 kg heavier than the targets). However, even with these discrepancies, the dummy was determined by SAE and NHTSA to be sufficient for the purpose of testing booster seats in the intended weight range. One other thing to note is that there are tolerances of the individual segment dimensions/masses of the dummy, which do encompass a wider range of the 8 - 10YO child population (overall dummy 35.2 +/- 0.91 kg). There fore the dummy cannot be said to represent a specific age. Also note that there is no specified external dimension for the overall stature in the proposed NPRM – this is dictated by the individual segments.*

4. Dummies are meant to replace humans in tests. The dummy integrity should be guaranteed significant beyond the Injury Assessment Reference Values. Our proposal would be that the dummy should not show failure or permanent set up to loads equivalent to 150 to 200% of the IARV's.
   What do you think is reasonable with regards to the maximum loads that a dummy should be capable to take without failure or permanent set?
   NHTSA: *Again, there is not any official NHTSA requirement on the amount of load a given dummy must be able to withstand. To a certain degree it will depend on which body part you are considering For example with a skull and it HIC requirement, the skull will likely withstand 500-800% of the IARV before you see any damage. Chest compression is usually a different story. Many dummies cannot measure more than maybe 125% of the IARV because of physical space limitations – There simply isn't enough room in a dummy thorax to measure 2x the IARV. When VRTC evaluates a dummy, we typically conduct durability tests that we sometimes call "high energy" or increased severity tests. We conduct pendulum impacts in which we increase the KE of the impactor (either by dropping from greater height or adding mass) by 20 – 40%. We expect the dummy to survive this type of testing with no structural damage.*

Appendix C Discussion in GRSP Informal Group

The topic of dummy size selection has been discussed in the GRSP Informal Group on CRS testing. According to the minutes of their meeting on the 18th of June 2008 in Paris the discussion can be summarized by:

See Minutes of Meeting Paris, June 18, 2008:

http://www.unece.org/trans/doc/2008/wp29grsp/CRS-04-09r1e.pdf

> *Mr Waagmeester requested the group on anthropometry item and point of view of the group regarding pertinence to develop a Q10 dummy (stature/weight). Indeed, Sweden, due to evolution of child anthropometry, requests higher dummy, equivalent to Q12. Mr Waagmeester takes advantage of this meeting to consult members about future and dummy needed.*
>
> *Farid Bendjellal mentioned directive 2003/20/EC where prescriptions on child stature are given. Limit in the Directive is 1.50 metre but for some countries, 1.35 metre is tolerated. It was added that in Directive limits on weight are found, and in countries limit on age is tolerable too.*
>
> *Chairman concludes that the group must define applicable limits to avoid problems with so many restrictions. He requested automotive manufacturers regarding limit of age above which they guarantee that children without CRS are in safety in their vehicles.*
>
> *Mister Horn mentioned that sled tests are conducted with different dummy sizes, including the P10 with booster. Submarining is one of the key issues that are considered. Action Daimler*
>
> *Pierre Castaing summarizes dummy situation:*
>
> *To conclude dummy item members need to clearly define a work field, and limits that our group imposes. Exact limits in stature/weight and acceptable loadings in vehicle seat anchorages will be key parameters for the new regulation.*
>
> *In a first step the chairman will contact commission to know why and how limits, in Directive 2003/20/EC are defined. Action Chairman*
>
> *In a second time, chairman hopes to receive information from each country represented in the group regarding the usage or local regulation regarding child seats, as far as age limit, weight limit and/or stature limit are concerned. Action All*

See Minutes of meeting Vienna, September 02, 2008:

http://www.unece.org/trans/doc/2008/wp29grsp/CRS-05-06e.pdf

> *The Minutes were adopted with following changes: Doc. INF GR / CRS-4-9_Final*
>
> *Page 4 Daimler did not promise to perform tests with the P10 (with and without booster). Also the background for this request was unclear. Consumers clarified that the discussion at the time revolved around P10 and P12. Britax added the question was what is the largest dummy used. Daimler then replied that submarining is looked at with the different dummy sizes. Daimler confirmed but said it makes no sense without a CRS as indicated in the minutes. The minutes were amended to read: 'Mister Horn mentioned that sled tests are conducted with different dummy sizes, including the P10 with or without booster. Submarining is one of the key issues that are considered. He proposed to present some results from tests with P10, with and without CRS during next meeting.'*

There is no firm conclusion given in the minutes. Kees Waagmeester noted the following during the discussion in meeting in Paris (June 18, 2008) the personal notes read as follows:

> *High end dummy size 10 or 12 year old*
>
> *I brought up the question with regards to the size of the high end dummy. A lengthy discussion was the result. In Europe the directive 2003-20-EC requires CRS use up to 1.50 m. Countries are allowed to go down to 1.35 m.*
>
> | | |
> |---|---|
> | *Adriaan Siewertsen (Teamtex):* | *1.50 applicable Sweden, Germany, Austria and Swiss.* |
> | *Heiko Johannsen (TUBerlin):* | *It is important to know why countries limit the size to 10 YO.* |
> | *Philippe Lesire:* | *Public acceptance and potential mis-use are arguments.* |
> | *Robert Laupp (FAIR)* | *Proposed to make an overview of countries and the reasons they have for their position. The interaction between mass, stature/sitting height and age should be made clear.* |
>
> *Pierre Castaing (chairman) will initiate a review over Europe. He indicates the 1.35 m will be mandatory for use of CRS and 1.50 m optional.*