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ABSTRACT

The objective is to identify the various child injury mechanisms in frontal and lateral collisions and to determine the associated physical parameters, in order to provide injury risk curves or at least to recommend limits. Priorities are given in terms of injury mechanisms necessary to be reproduced in accident reconstructions and simulations, to the head, neck, thorax and abdominal injuries in different type of impacts.

The relevant injury with associated mechanical parameter is to be considered for definition of the models. This will lead to detailed model specifications which will integrate the prescript mechanical parameters into each segment models with high bio-fidelity. The current knowledge about the injury data of children in road traffic accidents was summarized in this report.

For the objective mentioned above, the general specifications were defined to develop child models with the relevant age groups. Within the CASPER project， it is expected to focalize on the models of the head-neck for youngest children (6 weeks, and 6 month, 1 year and 3 years) and on the abdomen and thorax for older children (3 and 6 years). A complete specification of child models with body segments was presented to develop a series of full body models in the Task 2.3.

Finally, the size of the mathematical models was defined for each body segments in terms of the anatomical structures for the head, neck, thorax/upper-extremities, and pelvis/lower-extremities. The detailed anatomical and mechanical properties for development of the specified mathematical models will be investigated and defined in the following Task 2.2-Geometrical and mechanical properties.

ABBREVATIONS

AIS	Abbreviated Injury Scale
CRS	Child Restraint System
DAI	Diffuse Axonal Injury
UNECE	United Nations Economic Commission for Europe
EEVC WG18	European Enhanced Vehicle-safety Committee Working Group 18
EU	European Union
EuroNCAP	European New Car Assessment Program
HIC	Head Injury Criterion
IARV	Injury Assessment Reference Value
ISO	International Organization for Standardization
LNL	Lower Neck Load Index
MOC	Total Moment about Occipital Condyle
MTO	Total Moment
NIC	Neck Injury Criterion
Nij	Normalized Neck Injury Criterion
Nkm	Neck Criterion rear impact
PMHS	Post Morten Human Subject
PRV	Protection Reference Value
SCIWORA	Spinal Cord Injuries Without Radiological Abnormality
TBI	Traumatic Brain Injury
WAD	Wrap-Around Distance, the distance from the ground to the point along the vehicle front structure.

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1. INTRODUCTION

The objective of this report is to identify the various child injury mechanisms and to determine the associated physical parameters in order to provide injury risk curves or at least to recommend limits.
Indications on injury mechanisms necessary to be reproduced are given for accident reconstructions with dummies and simulations with both dummy and human-like models for different body segments and in different type of impacts.

This document has been issued in order to guide the work in the different CASPER tasks. For practical reasons the guidelines for the different tasks are all regrouped into this document, which is referred as a deliverable in WP2.

Concerned tasks are:
T1.1 – *accidents (injury mechanisms) to be reconstructed physically using child dummies,*
T1.2 – *injury mechanisms to be reproduced by dummy models,*
T2.1 – *injury mechanisms to be reproduced by human models,*
T2.3 – *development of specific human segments and whole body models per age*
T2.4 – *accidents (injury mechanisms) to be reconstructed virtually using child mathematical models,*
T3.2 – *accidents to be collected,*
T4.2 – *solutions to be found in terms of child protection.*

The document is based on two main axes: - real world data analysis and results of the previous research work on child safety, including the CREST and CHILD projects, EEVC WG12 and EEVC WG18.

2. REAL WORLD DATA ANALYSIS

2.1 Child Accident Analysis by Impact Configurations (GIE RE PR)

For the real world data, looking at the literature, recent results can be obtained using mainly two sources: EEVC WG18 accidentology report (EEVC, 2006), and results of the CREST and CHILD projects (analysis presented during the dissemination workshop and conferences) (Kirk et al., 2006; Lesire et al., 2006).

In these documents, it is clearly established that:

- Injuries sustained by restrained children in cars are highly dependent on many parameters such as the type of collision, the crash severity, the type of restraint system used and the quality of its use, and of the level of development of the child's body (bones, soft tissues and organs - characteristics often categorized by children's ages).
- The level of scientific knowledge on injuries to children is not equal for all type of impacts.
- Most of the large databases (International and National) are not focused on the protection of children and do not offer sufficient detailed data that could help in this work.

2.1.1 Frontal Impact

In order to draw more detailed conclusions, WG18 has accessed and examined the following databases: CREST (as developed in the European collaborative research project), CCIS, GIDAS (German In-Depth Accident Study), GDV (German Insurance) and LAB. All of these databases have specific definitions and data collection methods, which makes it difficult to merge the data for a global analysis. Nevertheless, for frontal impact, generally sufficient information was available in each database to classify injury causation according to the different groups of child restraint systems used. For this CRS were put in categories according to the weight group existing in the ECE R44-03 (annex 1). In addition, as the CHILD accident database contains all accidents present in the CREST accident database to which data collected during the life of the CHILD project has been added, results of CHILD have been considered instead of the CREST ones for this document.

Carrycots (Group 0):
The number of crash cases available with this kind of restraint system is too low to conclude about the general injury mechanisms.

Rearward facing Infant carriers (Group 0/0+):
These systems seem to offer good protection to their users in frontal impact. Severe head injuries are the most frequently observed injuries with such CRS which suggests that introduction of effective padding may significantly reduce head injury risk. Three different injury mechanisms are hypothesised: impact through the shell with the dashboard (67% of rear infant carriers are on front passenger seats), direct impact of the head on supporting object and rebound. For these systems, limbs are also presenting a high number of injuries, with fractures occurring during the rebound phase.

Rearward facing systems with harness (Group 1):
More popular in Northern Europe, rear facing CRS (Group 1) have been seen to be more effective in frontal impact when compared to forward facing CRS. Severe head injuries are less frequent in frontal impact with such devices than with forward facing infant carriers. Limbs (especially arms) can also be injured.

Forward facing systems (Group 1):
For this type of system head injury is still a big issue. Impacts are one cause, but diffuse brain injuries are also observed due to angular acceleration that can occur either with or without impact. The neck is an important area to protect for children (younger than 4 years of age) in such devices even if these injuries are not very frequent, but they often lead to permanent disability. Chest and abdominal injuries are not very frequent with such systems but are present when the loading of the harness becomes very high: Extreme thoracic compression of the chest due to harness belt loading leads to severe chest injuries without any rib cage fracture. The penetration of the buckle into the abdominal area can also be a source of injury. This phenomenon has also been observed when the shoulders come out of the harness (with a little bit of slack) and the child has a large forward movement due to the fact that its upper part is not restrained anymore. It is very difficult to reproduce this movement using the existing child dummies mainly because their shoulders are not as soft as children’s shoulders, so the harness remains on the dummy’s shoulders.

Forward facing systems with shield systems (Groups 1 and 2):
The main sources of data examined are from the UK and France where these devices are not very popular. Therefore, no accident data are available at this time but some observations from experts were collected. Head contact with the top of the shield and risk of ejection (total or partial) are likely scenarios causing injuries.

Forward facing seats and adult seatbelts (Group 1/2/3):
In most of the analysis of databases these systems were considered as booster seats.
It is important to underline that there is a high risk of neck injuries for the youngest children using this kind of CRS. The regulation allows the use of such forward facing systems with the adult seatbelt for children that weight 9 kg and more.

Booster seats with adult seatbelts (Group 2/3):
The head is still the most important body area in terms of frequency of injury, but the relative importance of abdominal injuries increases with such restraint systems. The penetration of the seatbelt into the soft organs creates injuries at the level of liver, spleen, and kidneys. For these systems, the protection of the abdominal area is clearly a priority to ensure good protection of children using a CRS with the adult seatbelt. The chest does not seem to be a priority in terms of frequency of injuries. Nevertheless, as the chest cavity protects vital organs, it remains an important body segment. Focussing on severe injuries, ribs fractures are not very common because of the chest compliance for children, and internal injuries occur by compression of the chest by the seatbelt. No injury due to inertial loading has been noticed. The pelvis is not a priority body region in frontal impact. Limb fractures are numerous for children on booster seats, and booster cushions but do not seem to be a priority in terms of child protection for the moment.

Booster cushions with adult seatbelts (Group 2/3):
The situation for these systems is the same as for booster seats with an increase of the number of chest injuries, certainly due to the fact that children using these CRS are generally older than the ones using booster seats. The chest compliance is also different for children using these systems as group3.

Adult seatbelts:
It was observed in real life that the number of children only restrained by the adult seatbelt is not negligible, even if due to their age they should have been using an additional CRS. The regulations in the different European countries do not necessarily give the same limit for the use of a CRS, nevertheless, a tendency in this category of children has been drawn: body segments to be protected for children restrained by the adult seatbelt only are the same as for the ones using booster cushions but with worse injury outcome, especially in the abdominal region.

Advanced safety systems:
No in depth analysis has been conducted on this item in the CHILD accident database, mainly due to the level of information available in the database and of the few cases studied. It remains one of the working aims for the accident data collection.

Effect of misuse:
Results from the ad-hoc working group have been published on this item for frontal impact (Lesire et al., 2007). Please refer to them when needed.

2.1.2 Side Impact

For side impact, the sample from the different databases is smaller and it is not possible to go so far in the analysis. Nevertheless, some specific child safety databases are useful to assess the part of children injured in side impact.

Two approaches were considered in the analysis, the first one is the influence of the intrusion of the injury mechanisms and on the injury severity for restraint children, the second one tends to make a classification of the body segments of children for which a moderate or serious injury have been noticed per categories of CRS. There is here a difference with the frontal impact for which the analysis has been conducted per type of CRS: In side impact three categories were possible: shell systems (including both forward and rearward facing systems) in which the child is restrained by a harness, boosters (approved for different groups) and for which the child can be restrained by a harness (booster seats) or by the seatbelt (booster cushion with or without backrest) and finally children only using the adult seatbelt.

In the CSFC (Child Safety of French Country roads) database, which is representative of the overall situation for children in cars involved in a road accident (French situation in 1996), side impacts are the second most important type of impact in terms of number of children involved. In this study, side impacts represent 15.5% with 206 children involved. Out of these, 37% were uninjured, 43% sustained minor injuries and 20% were severely injured. The analysis has been divided into two categories of children, the ones seated on the struck side and the ones seated on the non-struck side.

82 children were in the first category, with 33 uninjured. A focus on the moderate injuries for children seated on the struck side, regardless of whether or not they are restrained, indicates that the body area that was injured most often was the head with 42% and remains the priority. The amount of upper limb injuries was 29% and the abdominal injuries 19%.

Concerning the distribution of the body areas for moderately injured children involved in side impacts seated on the non-struck side, it is remarkable that when compared with children seated on the struck side, frequencies are equivalent, with injuries to the head remaining at around 40% and the injuries to the chest and lower limbs significantly increased. Severe injuries to the neck and pelvis have also been noted.

As the sample representing children severely injured in side impact is low, it was not possible to take this analysis further, especially with regard to the effectiveness of different restraint systems. Injuries to the head remained very high and seemed to be around 75% of the total body area injured for children involved in side impacts, who were restrained in forward facing child seats on the struck side. This reduced to around 50% under the same conditions but for a child using a booster cushion in addition to the seatbelt, and around 40% for children using only the 3 point belt. The difference seen here is not only due to the restraint system but also to the difference in height of the children and corresponding impact areas with the interior of the vehicle.

The analysis of the content of the CHILD accident database has been completed in order to analyse the influence of different parameters on the injury severity and the distribution of injuries on the different body segments. The CHILD accident database contains 284 restrained children who were involved in severe side impacts (not representative of real world situation due to case selection criteria). Of these, 48% were not injured, and 148 had a detailed medical report.

The analysis has clearly indicated that intrusion was an important parameter on the injury severity level, and that a small variation in the direction of the impact does not seem to make great difference on the protection of children. However, a more focussed analysis taking into account the influence of the intrusion at the position where the child is seated for the different types of restraint systems has been performed.

In side impact also, children using a CRS are more likely to be uninjured or only slightly injured than those using only the adult seatbelt. A clear influence of the appropriateness and of the quality of use of the restraint systems on the level of injuries was found, both on the struck and non struck side. For some other parameters such as the direction of forces and type of car, the results of analysis did not show any clear difference.

Out of 156 children being on the struck side in the accident, 134 received direct intrusion and 22 did not (impact on engine block or front door). There is a huge difference in the distribution of injury severity between them. As being confronted by intrusion itself seems to be important, for the coming analysis, children have been separated into 2 categories, those who sustained direct intrusion, and the other ones.

For children with intrusion, the sample size did not allow for so many categories of CRS as for frontal impact but three categories have been created: shell systems (forward and rearward facing - mainly covering ECE R44 group 0, 0+ and 1), booster seats and booster cushions (covering ECE R44 group 2 and 3, and sometimes group 1) that are used in combination with the adult seatbelt, and finally the adult seatbelt itself was considered as a category of restraint system.

CHILDREN WITH DIRECT INTRUSION

Shell systems (Group 0/0+/1):
In this category, 50 children were injured, and 57 serious injuries (AIS2+) were counted. Their repetition across the different body segments showed that 75% of them occurred to the head and face, 7% to the cervical spine, 4% to the chest, 5% to the abdomen, 7% to limbs and 2% to the pelvis (figure 2-1). Cervical spine injuries were often associated with brain haematoma and often led to a permanent disability or to the death of the child.

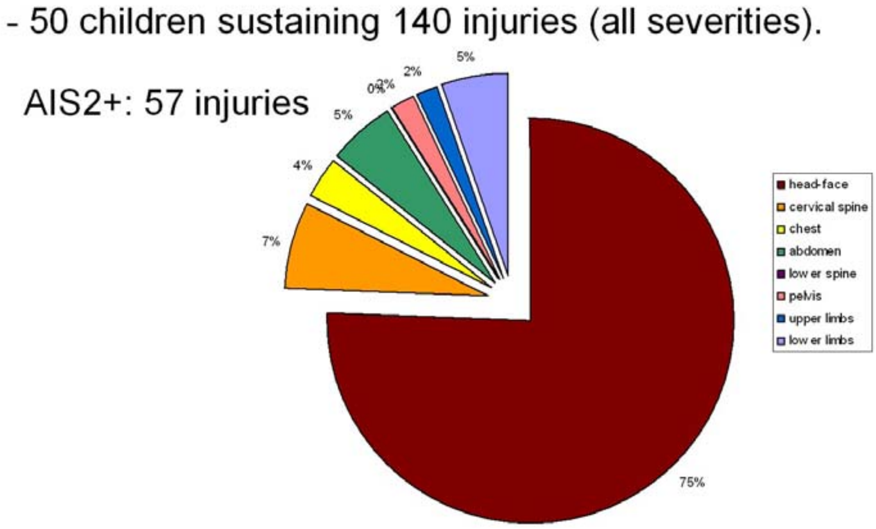


Figure 2-1: Repartition of injuries for shell systems

Booster seats & cushions used in combination with the adult seatbelt (Group 2/3):
35 children are in this category and they sustained 70 AIS2+ injuries. Here again the head remains the most injured body segment with just over half; the chest becomes more important than in the first category with 17% of the total and the abdomen reaches 9% of the total number of severe injuries. Limbs represent 20% (figure 2-2).

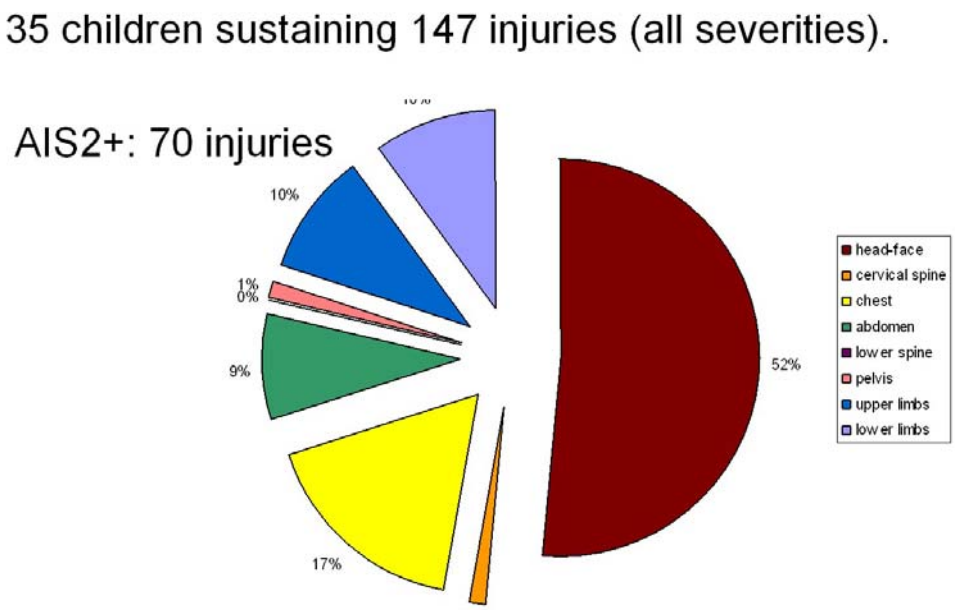


Figure 2-2: Repartition of injuries for booster seats and cushions

Adult seatbelt:
49 children represent the sample of this category; they sustained 111 AIS2+ injuries, with a score of 40% for the head, 14% for the chest, 10% for the abdomen and more than 25% for limbs (figure 2-3).

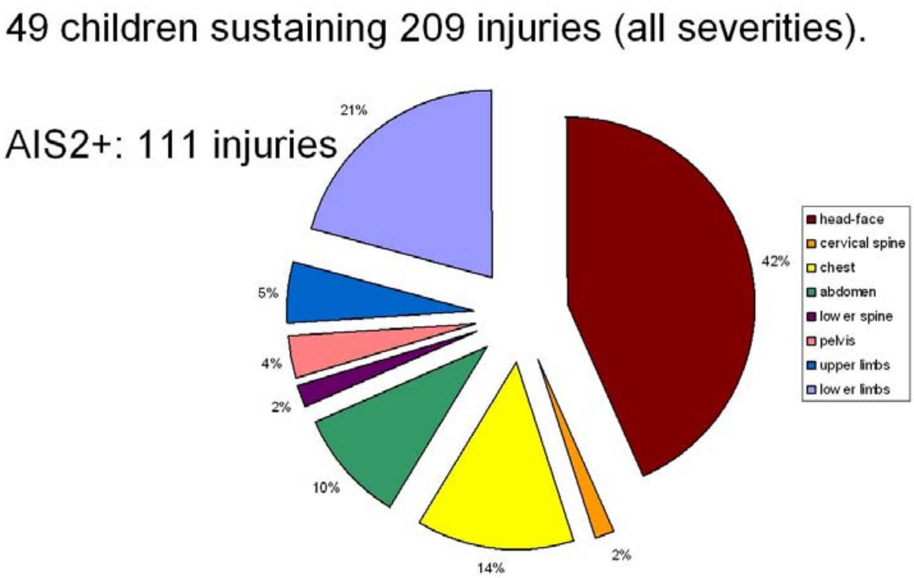


Figure 2-3: Repartition of injuries with seat belt only

INJURY CAUSATION:
This analysis was performed with no differentiation of the types of restraint systems, due to difficulties with sample size.
HEAD: the injury cause is an impact of the head on a rigid part of the car or through the padding of the CRS.
CERVICAL SPINE: injury mechanism and injury causation are not clearly defined but these children often also suffered head injuries, that could let suppose that head impact occurred.
CHEST: It was here possible to distinguish injury causation per type of CRS:

- In shell systems, the injury mechanism is the compression of the chest inside the shell; no rib cage fracture noticed,
- For boosters, the chest is compressed by the door panel,
- For children using the seatbelt, the main injury mechanism is the fracture of one or more ribs followed by internal organ injuries.

It is also important to note that in side impact the interaction with other occupants in the same row is possible.
ABDOMEN: injuries are mainly due to the door panel intrusion and sometimes to the booster base that intruded in the abdominal region (in case of prominent armrests).
PELVIS: some fractures have been observed for children seated on boosters or using only the adult seatbelt.
UPPER LIMBS: shoulder and arm impacts occur with the intruding door panel.
LOWER LIMBS: tibia fractures have been observed for all types of restraints. Femur fractures were common and only seen for children on boosters or using the adult seatbelt only.

INFLUENCE OF INTRUSION VALUE
The distribution of injury severity per range of maximum intrusion on the considered vehicle was done, and not surprisingly, the number of severe and critical injuries globally increases with the intrusion value.

It is important that dummies and models used or developed in the project can give different answers according to this parameter.

SIDE AIRBAGS
There are only a few cases, so not possible to make a statistical analysis, but it would be interesting for the working group in charge of solutions to have a close look at these accidents case by case.

CHILDREN WITHOUT DIRECT INTRUSION
In the CHILD accident database, the number of children involved in a side impact and located in the area where no intrusion occurs (non struck side or struck side with no direct intrusion on the child) is 131 with 91 using an additional CRS and 40 only using the adult seatbelt. 32 of them were not injured. 270 injuries were reported for the 99 injured children but 54 of them suffered only minor injuries (contusions, bruising,...). The total number of AIS2+ injuries is 100 dispatched across 45 children (figure 2-4).

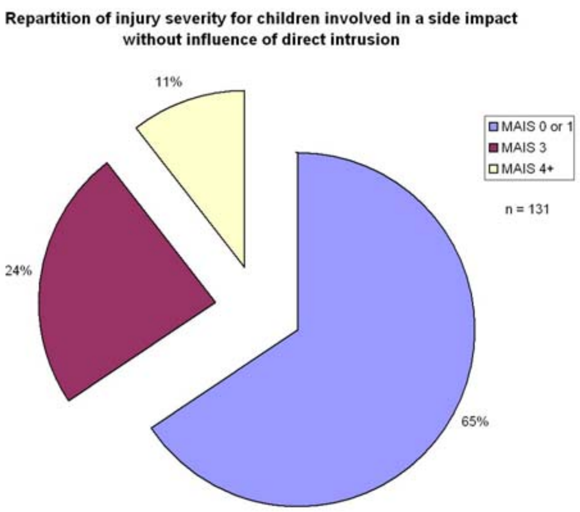


Figure 2-4: Repartition of AIS 2+ injuries, without direct intrusion

No big difference was found between injury mechanisms for children using a CRS and the ones using the adult seatbelt. The distribution of the 100 injuries of AIS2+ level sustained by restrained children in a side impact without intrusion on the occupied seating place is as follows:
HEAD: 57% of the total concerns the head or the face. Severe brain injuries are all associated with evidence of impact (contusion or fracture) on a rigid part of the car or of the CRS.
CERVICAL SPINE: only two cases reported, but without evidence of impact. In both cases children were fatally injured.
CHEST: No fracture of the chest has been notified but lung contusions occurred during some impacts with door panel (on opposite side) or because of the interaction with another occupant.
PELVIS: some fractures due to occupant interaction
ABDOMEN: internal organs contusions and wounds due to the seatbelt penetration remain rare but have been observed in some occasions.
LOWER LIMBS: only fractures of femur (and pelvis) have been reported
UPPER LIMBS: fractures were reported to the different bones.

2.1.3 Rear Impact

The only database that we can use for the distribution of children's injuries through the different body segments for the rear impact configuration is CSFC (LAB).
On a sample of 83 children involved, about 60% sustained no injury, 30% were slightly injured and 10% received severe injuries. The distribution of the 47 body areas injured (all injury severities) for this configuration is shown below. The head represents 30% of the total, and remains the most often body area injured. The number of lower limb injuries tends to be equal to the number of head injuries (figure 2-5).
The cervical spine injuries represent 13% of the total
The sample is not important enough to focus only on severe injuries occurring to children involved in rear impacts.

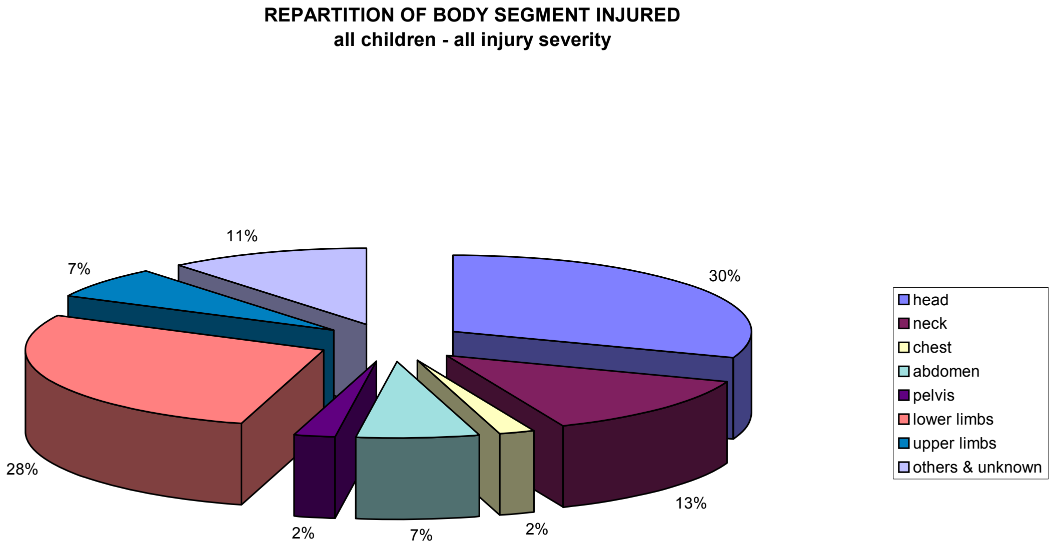


Figure 2-5: Rear impacts – injury distribution across body segments

2.1.4 Roll-Over

For **rollovers** again, only CSFC database shows the distribution of injuries on the different body segments. The number of vehicles involved only in rollover in the CSFC96 database is 131, with 184 children involved in this crash configuration. Of this number, 40% were not injured, 35% were slightly injured and 26% sustained severe injuries.

For serious injuries (AIS2+ level), they were recorded on 66 body segments and the distribution is shown on the Figure 2-6.

Head injuries still remain the highest in number. For the upper limbs, the number is 23%. Neck injuries and abdominal injuries also have to be considered in terms of number and severity (figure 2-6)

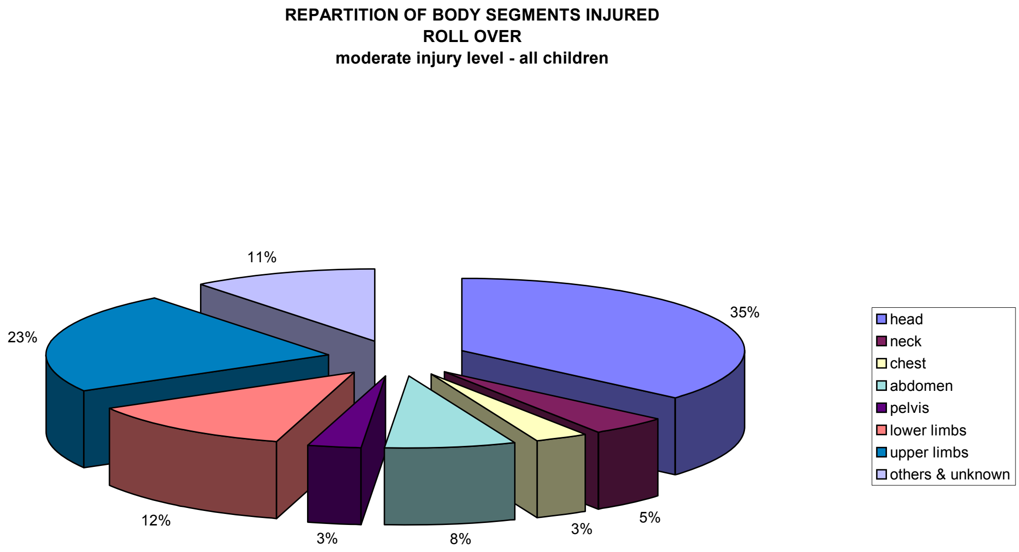


Figure 2-6: Roll overs – injury distribution across body segments

2.2 Child Accident Analysis for Head and Neck Injuries (UdS)

2.2.1 Head Injuries

Injuries resulting from traffic collisions are a major cause of childhood death, hospitalization, and disability throughout the world. Head trauma is the most frequent cause for death and hospital admission in childhood. In industrialized countries five times more children die from head trauma than from leukemia, the next leading cause of death in children over the age of one year (Cramer, 1995; Kasperk and Paar, 1991; Keller and Vane, 1995; Maier-Hauff et al., 1993).

Martin et al. (2003) published statistical results on 19538 injured children collected from 1989 to 2000. The Trauma Audit Research Network (T.A.R.N.) database showed that head segment is the second most injured anatomical part just after limb segment (Figure 2-7).

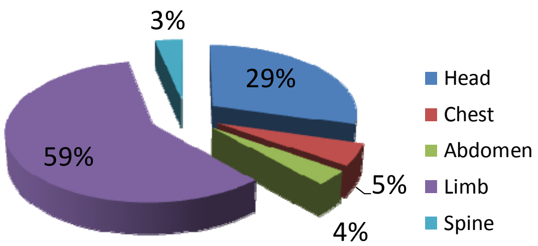


Figure 2-7. Anatomical part involved in the 19538 cases (Martin et al. 2003, T.A.R.N database).

In urban areas and particularly in economically disadvantaged communities, children are at increased risk especially for pedestrian injuries. Urban factors associated with elevated rates of child pedestrian injuries include high traffic volume, frequency of walking, and paucity of off-street, outdoor play areas. A total of 9521 severe injuries occurred to northern Manhattan children over the 13-year period (1983– 1995) were analysed by Maureen et al in 1999, and of these injuries, 1512 (15.8%) were traffic related.
Traffic was the second leading cause of severe injury in this population (after falls which accounted for 24.2%, and before assault, which accounted for 10.5% of the severe injuries). Among school-aged 5 to 16-year-old children, 22.1% of all severe injuries were traffic related. Nearly two thirds of the children who were severely injured and 75% of those who were killed in traffic were pedestrians. The next leading categories were bicyclists (16%), car passengers (9%), and motorcycle drivers (4%). A total of 245 of severe injuries from all causes were fatal, and of these 32 (13.1%) were traffic related.

In Germany, each year approx. 83,000 children younger than 15 years are hospitalized after head trauma. About 80% of these children present with mild (contusion), 20% with moderate or major brain trauma (Brambrink, 2002). The causes of Traumatic Brain Injury (TBI) are different among age groups (Kraus et al., 1990). Infants mostly suffer from falls or are assaulted. Toddlers more frequently are injured as passengers in motor vehicle accidents, while falls still account for the majority of injuries. As children grow older, TBI is more often caused by traffic accidents and by accidents during sports (Figure 2-8, Table 2-1, Kraus et al., 1990).

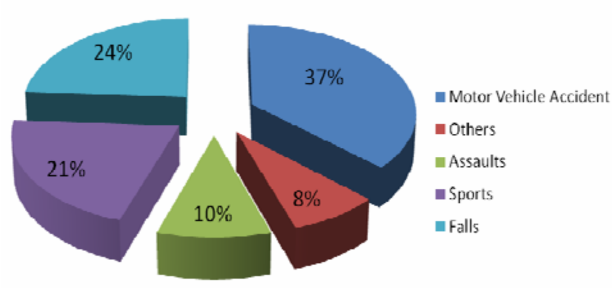


Figure 2-8. Causes of traumatic brain injury in children (Kraus et al. 1991)

Table 2-1. Causes of traumatic brain injury in children (Kraus et al. 1991)

Age groups (years)	Motor vehicle accident (%)	Falls (%)	Assaults (%)	Sports (%)	Other (%)
<1	7	69	17	2	6
1–4	22	51	5	16	6
5–9	31	31	1	32	5
10–14	24	18	5	43	10
15–19	55	9	17	10	10
Total	37	24	10	21	8

Infants mostly suffer from falls or are assaulted. Toddlers more frequently are injured as passengers in motor vehicle accidents, while falls still account for the majority of injuries. As children grow older, traumatic brain injury is more often caused by traffic accidents and by accidents during sports.

In 2006, Ducrocq et al., published a study on 585 child trauma. In this population 67% of the victims were males and 33% were females. Multiple traumas were noted in 52.5% of the cases, isolated head trauma in 38.5%, and extra or subdural hematoma in 9%. Predominant mechanisms of accident were falls from heights and Motor Vehicle Accidents (MVAs). Mechanisms differ from age, falls being the leading cause of trauma in children <2 years (56.6%) and MVAs in children >2 years old (71%). Among MVAs, pedestrians/MVAs were more frequent in children between 6 and 12 years of age, whereas cycle accidents are more often frequent in children >12 years. In children <2 years, child abuse was suspected in 15.5% of the cases for this study.

During the CHILD project, 284 restrained children who were involved in severe side impact were analysed.
Statistical analyses were carried out per different groups of child restraint systems used.

In the category of shell systems, 50 children were injured, and 57 severe injuries (AIS2+) were counted. Their repartition across the different body segments showed that 75% of them occurred to the head and face (Figure 2-9a).
35 children are in the category of booster seats used and they suffer seventy AIS2+ injuries. Here again the head remains the most injured body segment with a little bit more than the half. (Figure 2-9b)
Finally 49 children are representing the sample of adult seatbelt used category. They sustained 111 AIS2+ injuries, with a score of 40% for the head (Figure 2-9c).

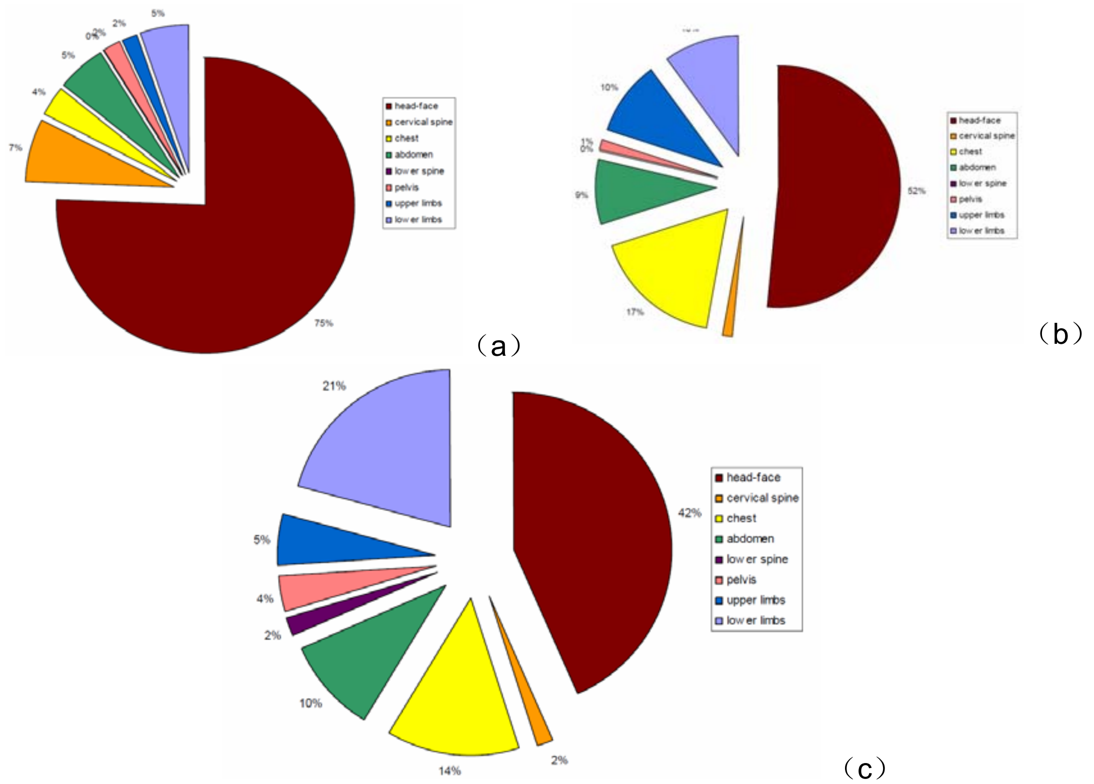


Figure 2-9. Repartition of injuries for (a) shell systems, (b) booster seats and cushions and (c) adult seatbelt. (CHILD project)

2.2.2 Neck Injuries

The spinal cord injury is relatively low (2% to 3%) among pediatric trauma victims. This is in contrast to adults where cervical spine injuries constitute 30% to 40% of all vertebral injuries (Dickman et al. 1989).

In the CHILD project a review of 669 accidents coming from different country (France, Spain, Italy, United Kingdom, Sweden and Germany) was conduced. Statistic was undertaken under different impact configuration and CRS type. As it illustrated in Figure 2-9 the neck are rarely involved 5%. It appears clearly that the head is the most frequently injured anatomical part (among 30%). Neck injuries appear typically by using the Seat Belts system (3%).

The Trauma Audit Research Network (T.A.R.N.) database contains data on 19 538 injured children collected from 1989 to 2000 (Martin et al. 2003). Only 527 (2.7%) suffered spinal column fracture / dislocation without cord injury and 109 had cord injury (Figure 2-10, Figure 2-11). Thirty children sustained Spinal Cord Injury Without Radiological Abnormality (SCIWORA). Martin et al. (2003) specify also that the spinal cord injury and SCIWORA occurred more commonly in children aged < 8 years. The

Table 2-2 summarizes the data collected by this author.

Table 2-2. Patient and injury characteristics in the overall data set and spinal injury (Martin et al. 2003, T.A.R.N. database)

	All pediatrics injuries (n=19 538)	**All spinal injuries** (n=627)	**Fracture/Dislocation without cord injury** (n=527)	**Cord injury** (n=109)	**SCIWORA** (n=30)
Median age (Y)	9	12	13	9	5.5
Sex					
Male (%)	13170 (67.4)	387 (58.5)	305 (57.9)	64 (58.7)	17 (56.7)
Female (%)	6398 (32.6)	275 (41.5)	222 (42.1)	45 (41.3)	13 (43.3)
Mechanism of injury					
Road Traffic Crash n (%)	8276 (42.4)	330 (49.8)	241 (45.7)	72 (66.1)	22 (73.3)
Fall > 2m n (%)	2454 (12.6)	167 (25.2)	155 (29.4)	15 (13.8)	2 (6.7)
Fall < 2m n (%)	4380 (22.4)	82 (12.4)	66 (12.3)	12 (11)	3 (10)
Sport n (%)	1595 (8.2)	49 (7.4)	43 (8.2)	5 (4.6)	1 (3.3)
Other n (%)	2805 (14.4)	34 (5.1)	22 (4.2)	5 (4.6)	2 (6.7)

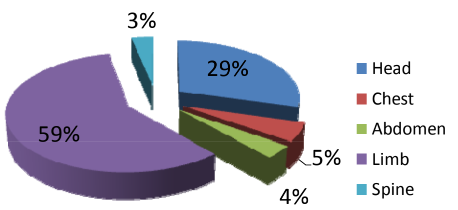


Figure 2-10. Anatomical part involved in the 19 538 cases (Martin et al. 2003, T.A.R.N database).

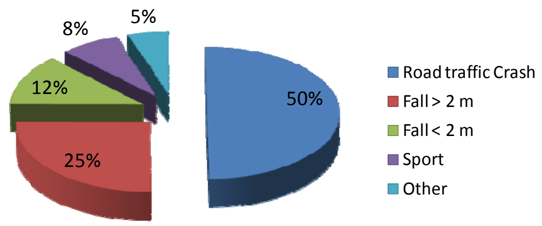


Figure 2-11. Mechanism of injury responsible of the spine injury (Martin et al. 2003, T.A.R.N database).

The study published by Kokoska et al. 2001 defines the characteristics of pediatric cervical spine injuries. The database “National Pediatric Trauma Registry” (N.P.T.R) account 24 740 cases with 408 children having cervical spine injuries (1.6%). The mean age was 10.5 (1 to 20) years. Leading mechanism were motor road traffic crash (44%), sports (16%), pedestrian injuries (14%) and bicycle (25.6%). We can note that the percentage of road traffic crashes is similar as in the previous database (T.A.R.N.) establish by Martin et al. 2003.

Overall, most of the neck injuries (69%) occurred between C1 and C4. Young children more often sustained high cervical spine versus low cervical spine (C5-C7) when compared to older child. The mean age of children with high cervical spine injuries (9 years old) also was significantly lower than those with low neck injuries (13 years). The relationship between child age and level of cervical spine is depicted in Figure 2-12.

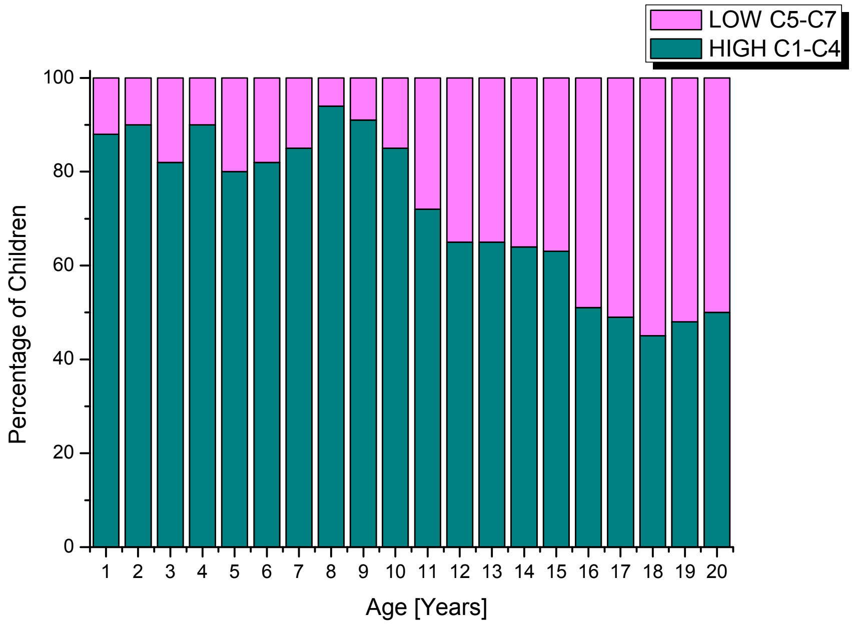


Figure 2-12. Relationship between patient age and level of cervical spine (High, C1 to C4; low, C5-C7). Kokoska et al. 2001 (N.P.T.R. database).

In the database analyzed by Kokoska et al. 2001 the most common types of cervical spine injuries were fractures (55.9%), followed by dislocations (25.2%) and SCIWORA (18.9%) as illustrated in Figure 2-13. Approximately the same percentage was found with the T.A.R.N. database i.e. (70% fracture/dislocation and 9 % of SCIWORA injuries).

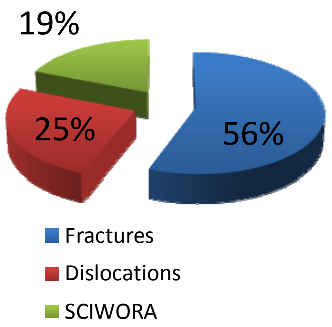


Figure 2-13. Percentage of type injuries for the cervical Spine. Kokoska et al. 2001 (N.P.T.R. database).

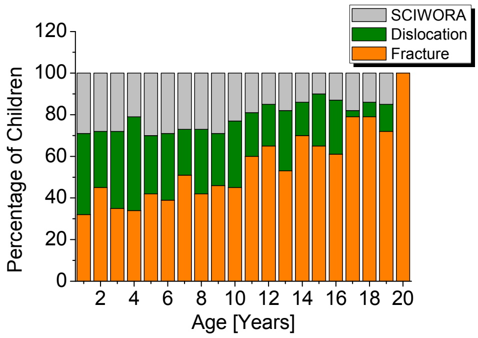


Figure 2-14. Relationship between patient age and type of cervical spine injury. Kokoska et al. 2001 (N.P.T.R. database).

In addition it appears, in Figure 2-14 it's appears that the dislocation and the SCIWORA injuries decrease as a function of age and that more fracture are observed. These observations can be explained by the biomechanical and anatomic differences that exist in the developing pediatric cervical spine. Young children have proportionally larger heads with underdeveloped neck musculature and are thus more susceptible to flexion and extension injuries. In addition the articulating facet joints in young children are more horizontally oriented, leading to greater spine mobility and less stability. Finally, in a young child, the interspinous ligaments, cartilaginous end plates and joint capsules have greater laxity and elasticity.

2.3 Child Head Impacts in Side Collisions (Chalmers)

From 1995 to 2005 (except 1997), the National Automotive Sampling System–Crashworthiness Data System (NASS-CDS) recorded 2,732,141 child occupants aged up to 12 years old who were involved in motor vehicle crashes in U.S.. 53% of them were identified in frontal crashes, followed by 27% in side impacts. The remaining 11% and 9% were in rollover and rear end crashes (McCray et al., 2007). Although the numbe of the child occupants in side impacts was much less than the number in front crashes, the injury risk for the children in side impacts was high. Orzechowski et al. (2003) concluded that children in side impacts were more than 3 times as likely to have an ISS>15 than children in frontal crashes. Furthermore, side impacts resulted in a 2.5 times greater risk of sustaining an AIS 2+ head injury, a 3.7 time greater risk of AIS 2+ cervical spine injury, and a 4.0 times greater risk of chest injury. Arbogast et al. (2004) found that the injury risk for children in side impacts (4.5 injured children per 1000 crashes) was significantly higher than for children in frontal crashes (2.7 injuries per 1000 crashes). This section investigated the impact conditions and the characteristics of the head injuries for child occupants in side impacts.

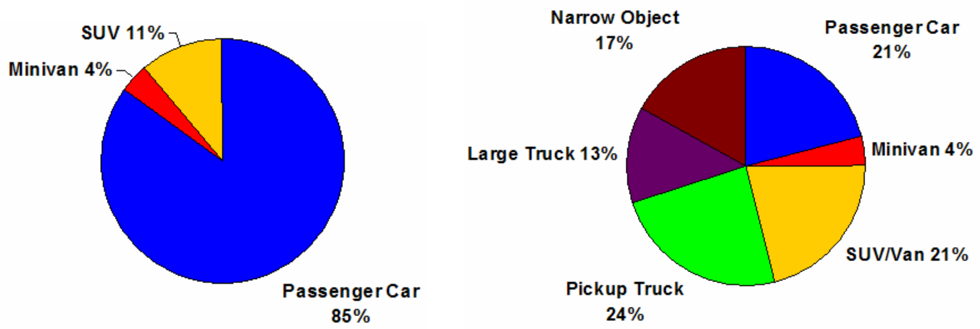
2.3.1 Child Occupants

Impact Conditions

Vehicle type

It was identified that passenger cars were overrepresented in both struck vehicles and bullet vehicles in side impacts involving child occupants. Arbogast et al. (2005) examined 30 side impacts in which involving 32 child occupants aged from 1 to 4 years old and restrained in a forward facing child restraint system (CRS). Of these 32 children, 25% (8 children) were injured AIS 2+. In these 30 cases, more than 65% of the struck vehicles were passenger cars, followed by 25% of passenger vans; if considering the cases involving the children injured AIS 2+, 85% of the struck vehicles were passenger cars and the remaining 15% were passenger vans. For all the 30 cases, 40% of the bullet vehicles were passenger cars, followed by more than 20% of pick-up trucks; for the cases involving AIS 2+ injured children, 60% of the bullet vehicles were passenger cars.

Maltese et al. (2007) investigated the near side impacts involving 24 seat-belted child occupants aged from 4 to 15 and AIS 2+ injured. The vehicle types of the struck and bullet vehicles are shown in Figure 2-15. Passenger cars were overrepresented in the struck vehicles; considering the bullet vehicles, pick-up trucks were the most common vehicles.



(a) Struck vehicles (b) Bullet vehicles

Figure 2-15 Vehicle types in child near side impacts (adopted from Maltese et al., 2007)

Impact direction

Langwieder et al. (1996b) investigated 64 side impacts involving 69 restrained child occupants injured AIS 2+. The impact directions in these crashes are shown in Figure 2-16. The major (83%) of the accidents showed a perpendicular loading between 60-90 degrees.

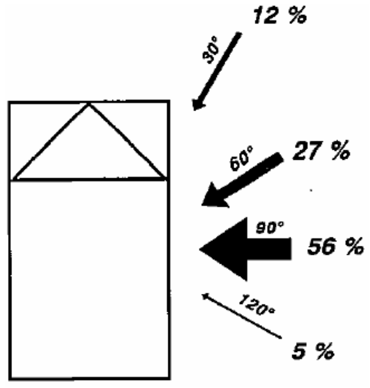


Figure 2-16 Impact directions of 64 side impacts (adopted from Langwieder et al., 1996b)

NASS-CDS defined side impacts as those for which the general area of damage was on the left or right side of the vehicle. Based on this definition, the impact directions in the NASS-CDS cases involving 1618 children aged from 0 to 12 years old are indicated in Figure 2-17. The data were grouped by degrees from the longitudal axis of the vehicle. It can be seen that most of the impacts happened on the direction of 2 and 10 o'clock (McCray et al., 2007).

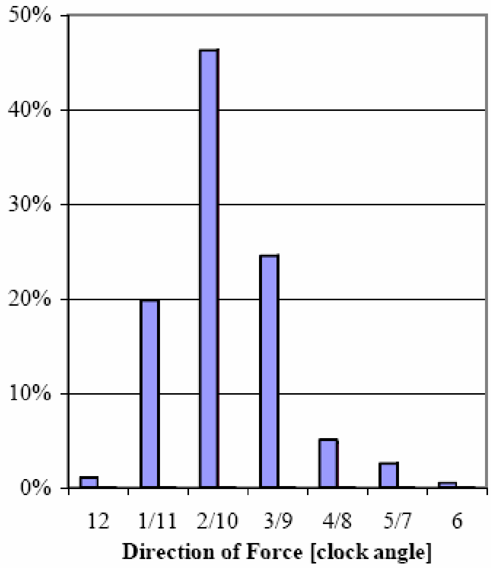


Figure 2-17 Impact directions of NASS-CDS side impacts (adopted from McCray et al., 2007)

The paper of Maltese et al. (2007) defined a side impact as one in which the struck vehicle sustained damage to its side plane with a pricipal direction of force (PDOF) that was 45 to 135° or 225 to 315° relative to the vehicle longitudal axis. The distribution of impact directions in this study is shown in Figure 2-18. It can be seen that 88% of the cases had a PDOF between 60 to 90° and 270 to 300°.

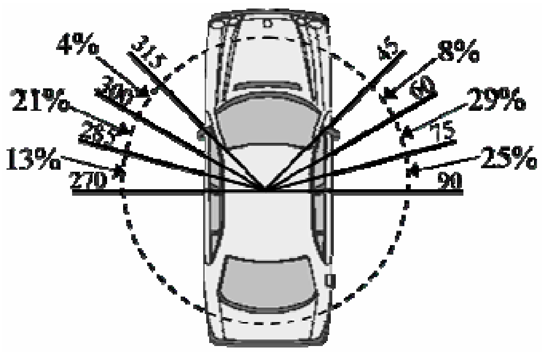


Figure 2-18 Impact directions in 24 near side impacts (adopted from Maltese et al., 2007)

Scullion et al. (2008) examined the near side impacts in NASS-CDS from 1991 to 2006, in which 595 child occupants aged from 7 to 13 were involved. The impact angles in the cases were grouped from 0 to 180° referring to the longitudal axis of the vehicle, as shown in Figure 2-19. The direction on 60° to the car longitude axis was overrepresented.

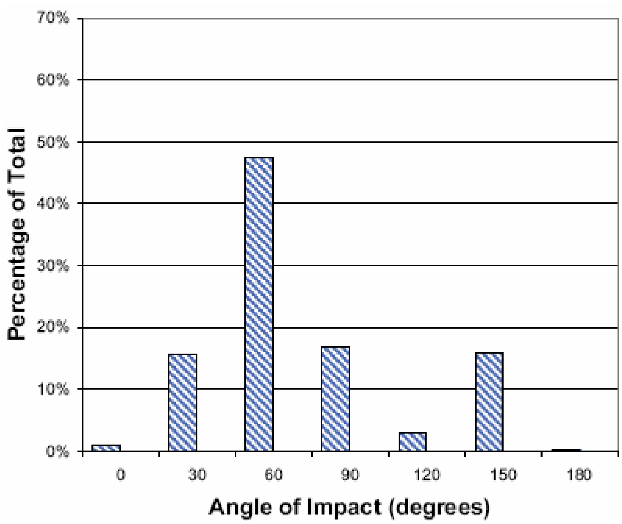


Figure 2-19 Impact directions of NASS-CDS near side impacts (adopted from Scullion et al., 2008)

Impact speed

Langwieder et al. (1996a) conducted an in-depth analysis on 69 restrained child occupants aged from 0 to 12 who suffered AIS 2+ injuries in side impacts. In this study, the impact speeds of the bullet vehicles are listed in Table 2-3. 70% of the selected cases showed an impact speed up to 50 km/h.

Table 2-3 Impact speeds of bullet vehicles (adopted from Langwieder et al., 1996a)

Speed (km/h)	0-30	-50	-80	>80
Percentage	38%	32%	24%	6%

The delta-v's of the cases investigated by Scullion et al. (2008) are indicated in Figure 2-20. It can be seen that 50% of the cases occurred at delta-v equal to or higher than 16 km/h.

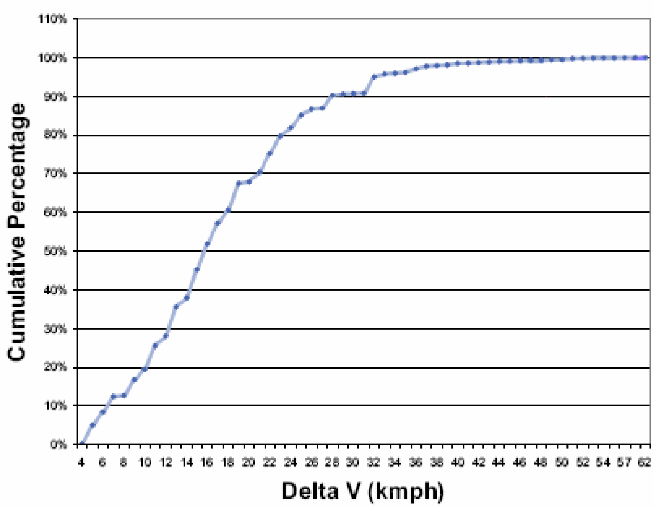


Figure 2-20 Delta-v's in NASS-CDS near side impacts (adopted from Scullion et al., 2008)

The results from Langwieder et al. (1996a) and Scullion et al. (2008) are different. There are several explanations for this difference. One explanation is that Langwieder was looking at AIS2+ injuries while for NASS other sampling schemes are relevant (tow-away criterion). Another explanation is that comparison of databases is only possible if the definitions used to collect/analyze data are similar. This is may be not the case here as it is possible to find in the NASS database side impacts with a direction of forces very close to the ones observed in frontal impact (30° and less). At last, the results were obtained in completely different regions of the world.

Seating position

It was identified that the near side impacts resulted in higher risk of injury to child occupants. Langwieder et al. (1996a) found that, 67% of the 69 children were sitting on the struck side, 9% on the center seat, and 24% on the non-struck side. Arbogast et al. (2004) identified that the injury risk for children on the struck side of the crash was significantly highest (8.9 injuries per 1000 crashes) comparing with the much lower risk of the children on the non-struck side of the crash (2.1 injuries per 1000 crashes). Howard et al. (2004) also concluded that injury severity scores were statistically higher for children seated on the near side than for those seated on the center seat and far side. Maltese et al. (2005) found that the risk of injury was lower to children seated on the non-struck side (1.4%) as compare to those on the struck side (2.6%). The injury risk to children seated in the center rear position (3.0%) was close to those on the struck side.

Head Injuries

Injury distribution

Langwieder et al. (1996b) analyzed the injury distribution and severity of the 69 child occupants, as indicated in Table 2-4. For the injuries at all the AIS levels, the head and the upper and lower extremities were the most frequently injured body parts. For the AIS 3+ injuries, the head was overrepresented by 49%. The following thorax accounted for the 18% of the AIS 3+ injuries.

Table 2-4 Injury severity versus body region (adopted from Langwieder et al., 1996b)

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	Total
Head	8	13	9	6	19	3	58
Thorax	1	0	7	7	0	0	15
Abdomen	3	5	4	2	0	0	14
Pelvis	3	2	1	0	0	0	6
Spine	2	1	2	1	1	6	13
Upper Extremity	7	11	1	0	0	0	19

Lower Extremity	6	5	7	0	0	0	18
Total	30	37	31	16	20	9	143

Arbogast et al. (2005) analyzed the injury distribution of the 8 child occupants who was injured AIS 2+. It was identified that 33% of the injuries inflicted on the child head, 25% on the face, 25% on the lower extremity, and 17% on the neck and spine. The child head-face was the most frequently injured body part.

Maltese et al. (2007) analyzed the AIS 2+ injury distribution from the 24 children (see Figure 2-21). The head (34%), abdomen (27%), pelvis (21%) and thorax (17%) were identified as the most frequently injured body parts.

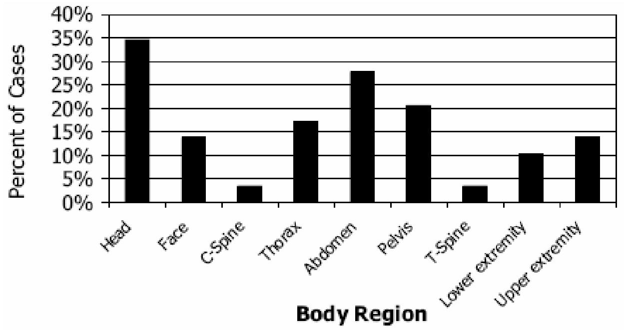


Figure 2-21 Distribution of AIS 2+ injuries of 24 children (adopted from Maltese et al., 2007)

McCray et al. (2007) investigated the injury distribution (see figure 2-22) and severity (see Table 2-5) of 28 child occupants aged from 1 to 3 who involved in NASS-CDS side impacts from 1995 to 2004 (except 1997) with delta-v equal to or higher than 30 km/h. For the injuries at all the AIS levels, the head and torso were the most injured body part. For the AIS 3+ injuries, the head accounted for 53% and the torso represented 47%.

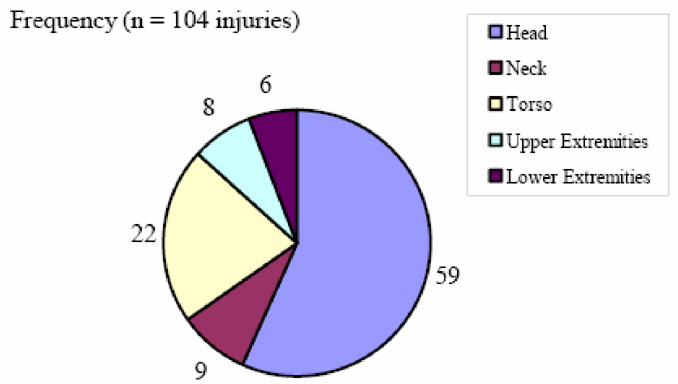


Figure 2-22 Injury distribution of 28 child occupants (adopted from McCray et al., 2007)

Table 2-5 Injury severities versus body regions (adopted from McCray et al., 2007)

Body Part	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Total
Head	49	1	3	2	4	59
Neck	9	0	0	0	0	9
Torso	6	8	2	4	2	22
Upper Extremity	7	1	0	0	0	8
Lower Extremity	5	1	0	0	0	6
Total	76	11	5	6	6	104

Scullion et al. (2008) analyzed the injury distribution of the 595 child occupant, as indicated in Figure 2-23. The head-face was the most frequently injured body part.

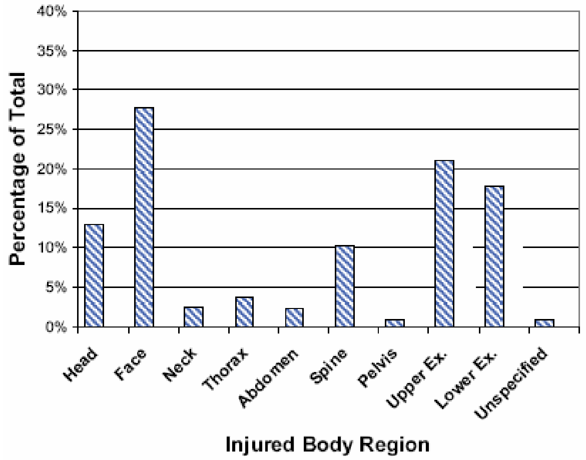
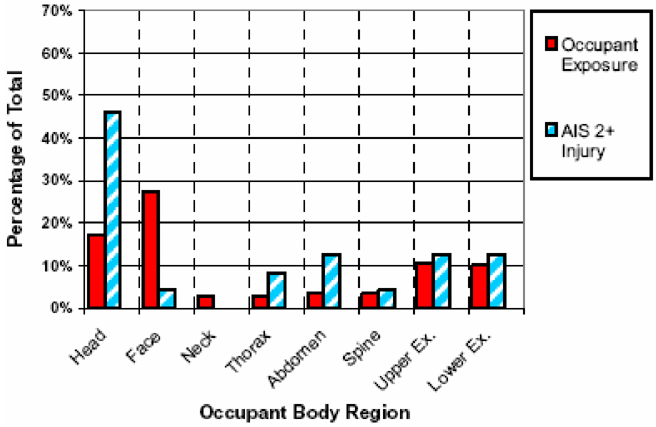
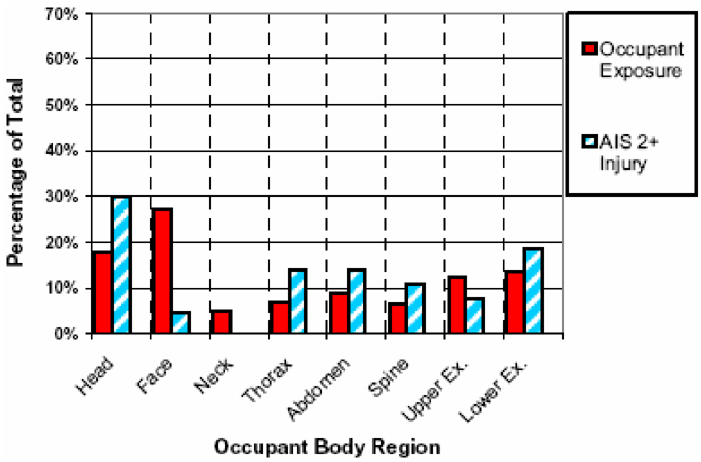


Figure 2-23 Injury distribution of 595 child occupants (adopted from Scullion et al., 2008)

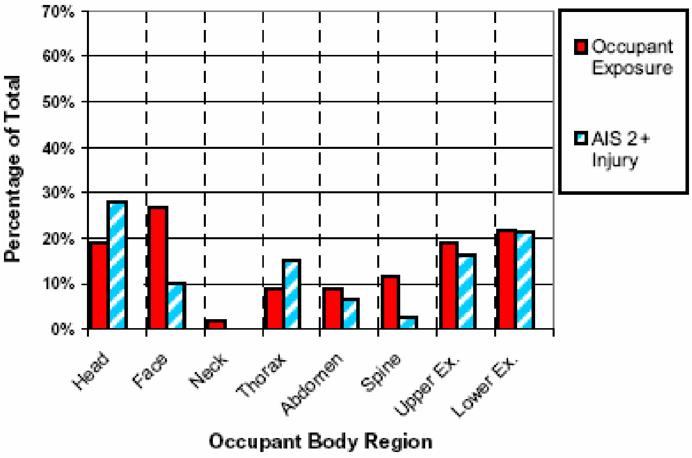
Scullion et al. (2009) analyzed the injury characteristics of 699 child occupants aged from 1 to 12 who were involved in the near side impacts recorded in NASS-CDS from 1993 to 2007. This analysis was conducted based on the three restraint types of toddler, booster, and belted for the child occupants. The distributions of the occupant exposures and injuries are shown in Figure 2-24. It can be seen that, for every group of the children, the head-face was the most frequently injured body part. The head was the major body part which was injured AIS 2+.



(a) Toddler-type of constraint



(b) Booster-type of constraint



(c) Belted-type of constraint

Figure 2-24 Distributions of occupant exposures and injuries by body parts (adopted from Scullion et al., 2009)

Head impact location

Maltese et al. (2007) presented the impact points for the AIS 2+ injuries in the head/face (see Figure 2-25). The majority of head and face contact points were found horizontally within rear half of the window, and vertically from the window sill to the centre of the window.

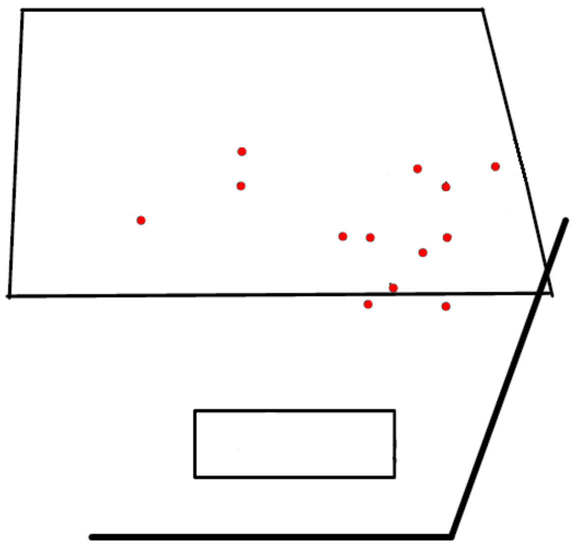


Figure 2-25 Impact points for AIS 2+ head/face injuries (adopted from Maltese et al., 2007)

McCray et al. (2007) investigated the causation for the head injuries of the 28 child occupants, as indicated in Figure 2-26. The major causations of the head injuries were the interior surface (door panel), flying glass, and child seat.

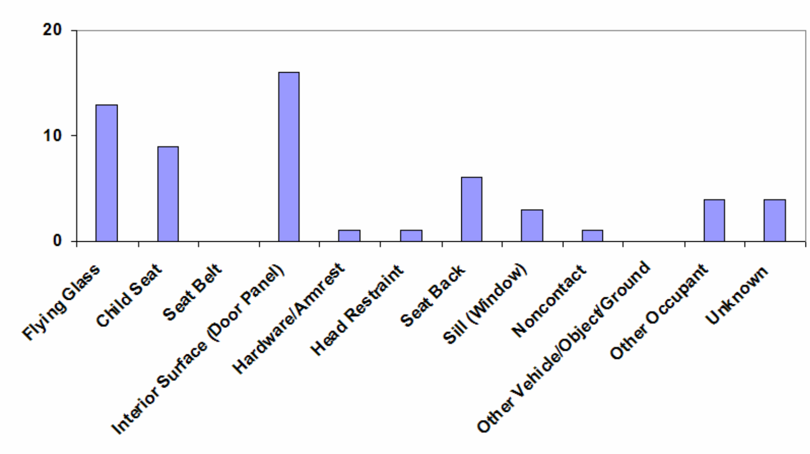
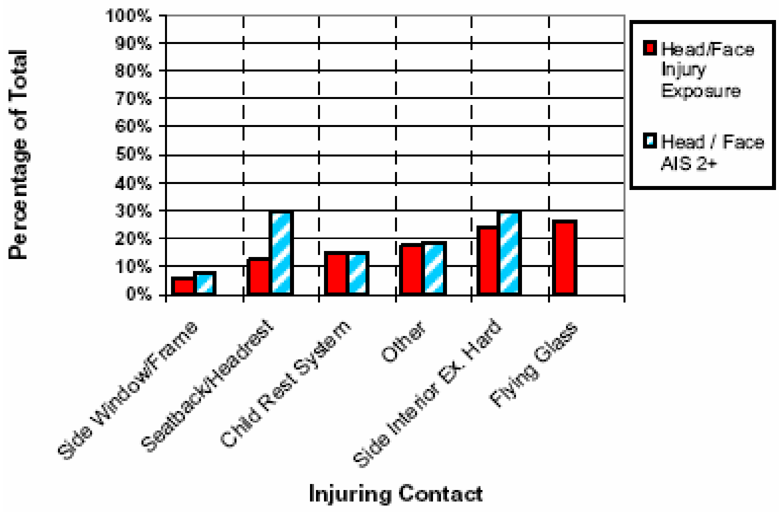
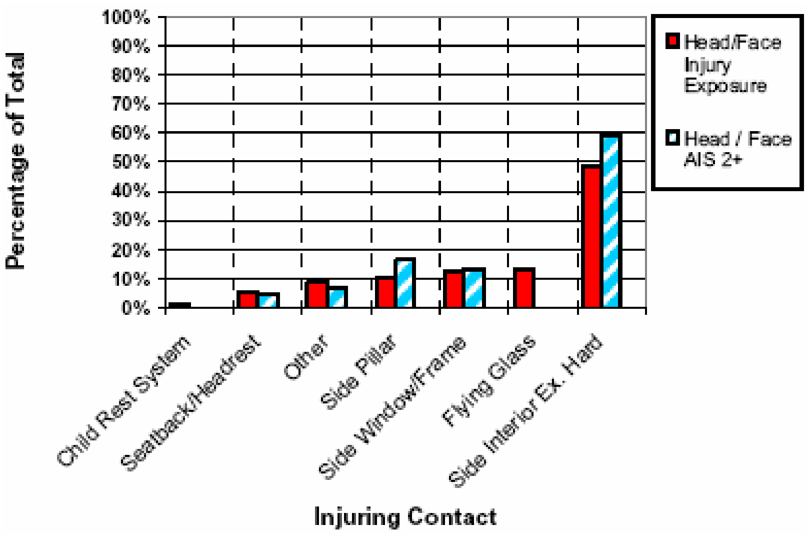


Figure 2-26 Injury causations for head injuries (adopted from McCray et al., 2007)

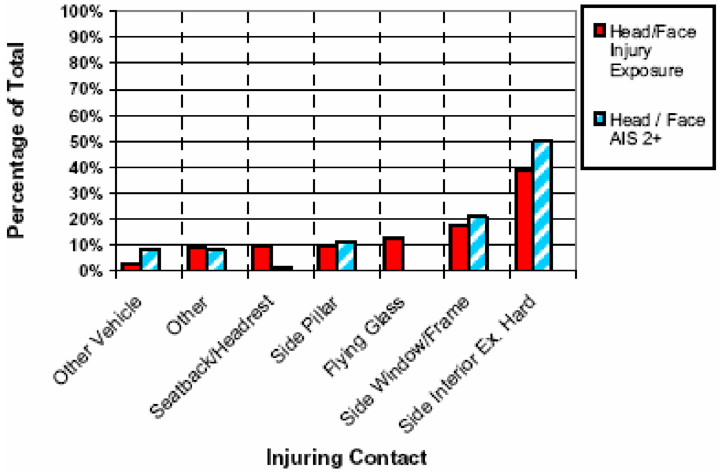
Scullion et al. (2009) investigated the injury causations for the head-face injuries of the 699 child occupants (see Figure 2-27). The interior side was the major contact source for the AIS 2+ head-face injuries.



(a) Toddler-type of constraint



(b) Booster-type of constraint



(c) Belted-type of constraint

Figure 2-27 Distributions of head/face injuries and AIS 2+ head/face injuries by contacts (adopted from Scullion et al., 2009)

2.3.2 Child Pedestrians

This section is the summary of the research conducted by Yao et al. (2007). This part investigated the head injuries and the corresponding injury biomechanics in child pedestrian accidents and to determine the correlation of the head injuries with injury related physical parameters. In this study, 23 cases were selected from the German In-Depth Accident Study (GIDAS) to carry out an in-depth accident analysis. The MADYMO program (TNO, 2004) was used to reconstruct the accidents with child pedestrian models developed at Chalmers University of Technology. The results from reconstructions were analyzed to determine the correlation between calculated physical parameters and the injuries sustained by the accident victims. In the present study, the focus was on injuries induced by car impacts. Injuries caused due to secondary ground impacts were not considered in this investigation.

<u>Head Injuries</u>

Injury distribution

Of the 23 children involved in the accidents, 11 were males and 12 were females. At the moment of impact, children could be running, walking fast, walking or standing. It was found that 47% of the children were running while no child was standing still when the car hit him/her. The accident data also showed that 98% of the children were impacted from the lateral direction.

The distribution of AIS2+ injuries is shown in Table 2-6. It was observed that the head and lower extremities were the most frequently injured body parts in the accidents. Of total 23 AIS2+ injuries, 9 were head injuries and 5 were lower extremity injuries, which accounted for 39% and 22% respectively.

Table 2-6. Injury distribution by body regions

Body Region	AIS1	AIS2+
Head	28.0%	39.1%
Neck	2.0%	4.3%
Thorax	12.0%	13.0%
Upper Extremities	26.0%	8.7%
Abdomen	4.0%	8.7%
Pelvis	6.0%	4.3%
Lower Extremities	22.0%	21.7%
Total Injuries	50	23

Table 2-6 shows that only 23 injuries were AIS2+, while 50 injuries were AIS1. This result is comparable with the findings from Otte's study (1999) which investigated the injury severities of two pedestrian groups: pedestrians up to 12 years old and pedestrians older than 12. The results showed that for child pedestrians, MAIS2+ injuries accounted for 27%, which was much lower than the 43.5% for adult pedestrians. It seems that children suffered less serious injuries than adults. This observation may be due to that children are usually involved in pedestrian accidents at lower impact velocities with a lower exposure to dangerous traffic environments.

The relationship between car impact speed and head injury risk (AIS2+) was established using a logistic regression model. The probability of AIS2+ head injury can be determined by the equation:

$$p(AIS \geq 2) = \frac{1}{1+e^{12.9891-0.3917x}} \qquad (2\text{-}1)$$

where x is the car impact speed. Eq. (2-1) calculated that at an impact speed of 30 km/h, a child pedestrian has 23% risk of sustaining an AIS2+ head injury.

Calculated head injury parameters

The relationship between calculated HIC15 and car impact speed is shown in Figure 2-28. Nonlinear correlations were achieved by second-order polynomial curves for both HIC values calculated from high stiffness hood and low stiffness hood. Figure 2-28 shows that at an impact speed above 40 km/h, the HIC value has a high probability to be larger than 1000.

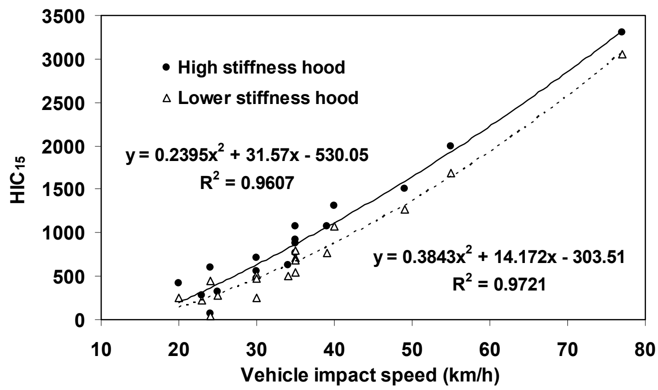


Figure 2-28 Correlation of the car impact speed and HIC

<u>Head Impact Conditions</u>

Head impact location

The contact position of a pedestrian's head on a car could be defined using WAD along the car-front surface. Results from accident reconstructions show that the WAD had an average value of 1124 mm and a standard deviation of 116 mm for the child pedestrians. These figures mean that the head of child pedestrian has a high probability of hitting the hood top. Figure 2-29 presents the head impact locations on the hood. The WAD is greatly dependent on the pedestrian height. To eliminate the influence of the pedestrian's size, the ratio of the WAD to the height of pedestrian was calculated. The statistical analysis shows that the average ratio of WAD to pedestrian height is 0.91 with a standard deviation of 0.06.

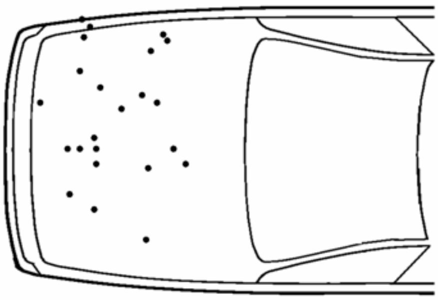


Figure 2-29 Head impact location

Head impact timing and velocity

Six reconstructed accident cases were selected and divided into two groups. Three children had the same height of 110 cm and another three children had the same height of 140 cm. These two height categories represent two different child groups: small-sized children (mean 5 years old) and medium- sized children (mean 10 years old).

The head impact velocity is defined as the relative head velocity against the car. Figure 2-30 plots the time history of the head velocities of these two child groups. For the children who were 110 cm high, the head impact timing varies from 52 ms to 72 ms due to different impact speeds; for the children of 140 cm high, the head impact timing varies from 72 ms to 165 ms. The results show that the head impact timing varied in a wide range due to car impact speed and pedestrian height. The higher impact speeds and smaller pedestrian height could result in shorter head impact timing.

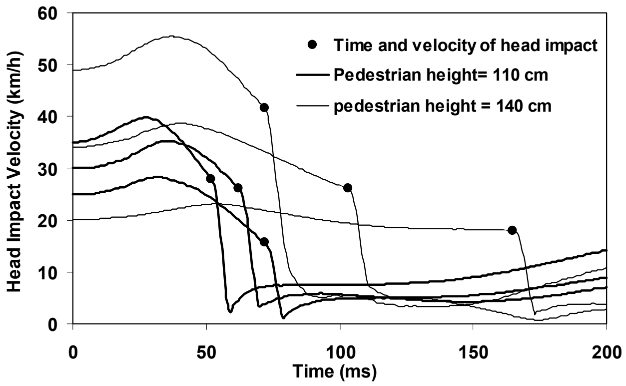


Figure 2-30 Time history plots of the head resultant velocity with respect to car front

The head impact speed appears to be proportional to car impact speed as shown in Figure 2-31. It also indicates that the head impact speed is usually smaller than the car impact speed since most dots are under the line y=x (Figure 2-31).

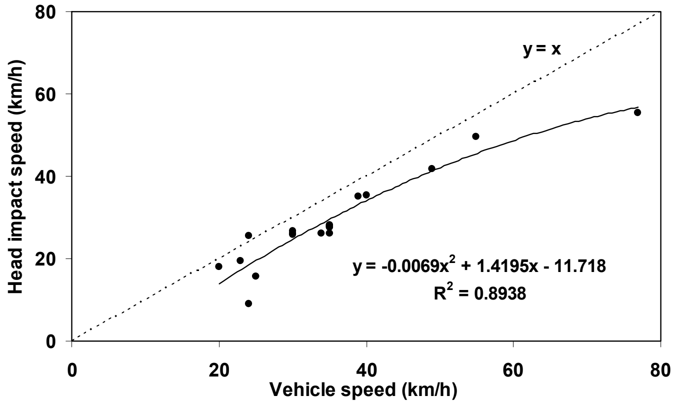


Figure 2-31 Relationship between head impact speed and car speed

Head impact angle

A head impact angle is defined as the angle of the head resultant velocity vector with respect to the horizontal line when the head touches the car hood (Yang, 2005). This angle could be influenced by several factors such as the height of pedestrian, the height of hood edge, hood angle and car impact speed. The individual contribution of each factor to the head impact angle should be investigated with parameter studies. A statistical analysis of the results from the reconstruction shows that the average impact angle is 66° with a standard deviation of 12°. Figure 2-32 shows the relationship between head impact angle and car speed. The results show that the head impact angle decreases with higher car impact speed. An explanation is that as the car impact speed increases, the neck bends more, which leads to a smaller head impact angle.

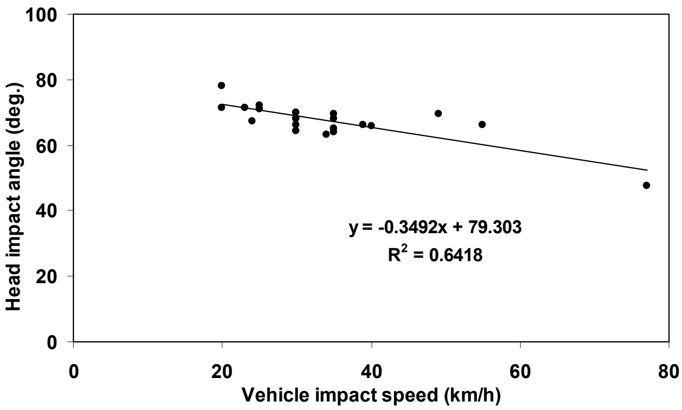


Figure 2-32 Relationship between the car impact speed and head impact angle

Logistic regression curve of HIC vs. AIS2+ head injury risk

For each reconstructed accident case, two HIC values were obtained based on two hood stiffness levels. The relationships between the HIC15 value and head injury severity were then examined using the logistic regression model.

Figure 2-33 shows that HIC15 value, using either high stiffness or low stiffness hood property, is correlated with the AIS2+ head injury severity. As the magnitude of these value increases, the head injury risk also increases. Figure 2-33 shows that at an HIC value of 700, the corresponding AIS2+ head injury risk varies between 40% and 68% with an average value of 59%.

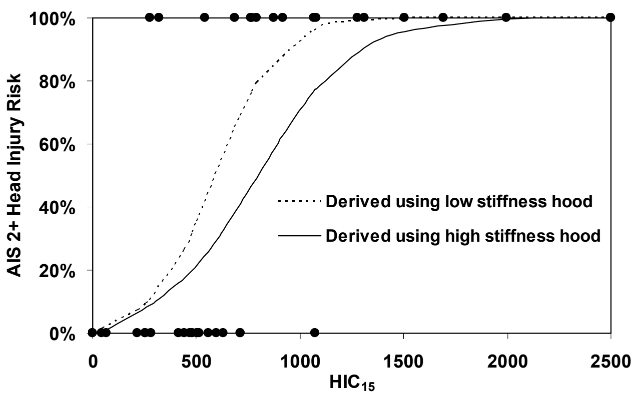


Figure 2-33. Logistic regression curve of HIC vs. AIS2+ head injury risk

2.3.3 Comparison of Head Impact Conditions and Injuries between Child Occupants and Pedestrians

Injury Distribution

For the child occupants in side impacts, the head was the most frequently and seriously injured body part. Langwieder et al. (1996b) found that, for the AIS 3+ injuries of the child occupants in side impacts, the head was overrepresented by 49%. The following thorax accounted for 18% of the AIS 3+ injuries (see Table 2-4). Arbogast et al. (2005) analyzed the injury distribution of 8 child occupants who was injured AIS 2+. It was identified that 33% of the injuries inflicted on the child head, 25% on the face, 25% on the lower extremity, and 17% on the neck and spine. Maltese et al. (2007) identified that the head (34%), abdomen (27%), pelvis (21%) and thorax (17%) were the most frequently injured body parts of child occupants in side impacts (see Figure 2-21). McCray et al. (2007) found that the head accounted for 53% of the AIS 3+ injuries of child occupants in side impacts and the torso represented 47% (see Table 2-5). Scullion et al. (2009) found that the head was the major body part of child occupants which was AIS 2+ injured insid impacts.

For the child pedestrians, the head and lower extremities were the most frequently and seriously injured body parts. Of total 23 AIS2+ injuries in Table 2-6, 9 were head injuries and 5 were lower extremity injuries, which accounted for 39% and 22% respectively.

From the analysis, it can be determined that, for both the child occupants and pedestrians, the head was the most frequently and seriously injured body part.

Head Impact Location

In the study of Maltese et al. (2007), the majority of head and face contact points were found horizontally within rear half of the window, and vertically from the window sill to the center of the window (see Figure 2-25). McCray et al. (2007) found that the major contact sources of head injuries were the interior surface (door panel), damaged glass, and child seat (see Figure 2-26).

For child pedestrians, the results from accident reconstructions show that the WAD had an average value of 1124 mm and a standard deviation of 116 mm for the child pedestrians. These mean that the head of child pedestrian has a high probability of hitting the hood top. Figure 2-29 presents the head impact locations on the hood.

Although different impact locations were identified for the heads of the child occupants and pedestrians, the characteristics of the impact were similar. They were both blunt impact on flat surfaces and the stiffness should not differ too much.

Head Impact Speed

For the child pedestrians, the head impact speeds appeared to be proportional to but lower than the car impact speeds. The car impact speeds of the most cases investigated in the paper of Yao et al. (2007) were between 20 to 60 km/h. The impact speeds of the child pedestrians' head were therefore in the range of 15 to 45 km/h.

For the child occupants, the head impact speeds were not investigated in the collected papers in this study. However, Langwieder et al. (1996a) presented the distribution of the impact speeds of the bullet vehicles (see Table 2-3). 70% of the selected cases showed a impact speed up to 50 km/h. Scullion et al. (2008) presented that 80% of the cases occurred at the delta-v from 8 to 28 km/h (see Figure 2-20).

The head impact speed of the child occupants is to be investigated in further study.

<u>Conclusions</u>

From the analysis above, it can be concluded that:

- For both the child occupant and pedestrian, the head was the most frequently and seriously injured body part.
- Although different head impact locations were identified for the child occupants and pedestrians, the characteristics of the impact were similar. They were both blunt impact on flat surfaces and the stiffness should not differ too much.
- The head injuries suffered by the child occupants should be comparable with the injuries of the child pedestrians.
- The head impact speed of the child occupants is to be investigated in further study.

3. INJURY BIOMECHANICS

3.1 Injury Mechanism Developed from the Accident Reconstructions Using Q Dummy (GIE RE PR)

The data used to develop the injury criteria are the results of reconstructions made in CREST and CHILD and validated against actual accidents. The validation process to assess the injury mechanisms is an in-depth comparison of the reconstruction and the real world accident, including vehicle internal and external deformations, child restraint systems deformations and evidence of occupant kinematics. Around 50 cases with Q dummies were used for analysis.

3.1.1 Head

In frontal impact:

The data are drawn from 40 cases of accident reconstructions with dummies. The physical parameter measured on the dummies was the head linear acceleration. The real world accident head injuries were directly paired with crash test records, head linear acceleration and 15 ms HIC values (figures 3-1 and 3-2). No angular velocity or angular acceleration was measured. Data were scaled in order to correspond to the Q3 dummy equivalent value.

In order to investigate the influence of head contact on injury, a distinction was made between cases with or without head contact, either against the vehicle interior or on a body part. **When only cases with head injuries are taken into account**, in 12 cases the head injury mechanism was an impact and in only 3 cases there was no contact. In 2 cases without contact, a haemorrhage was observed at the base of the brain; the injury mechanism may well have been a consequence of the severe cervical injury that occurred in the 2 cases.

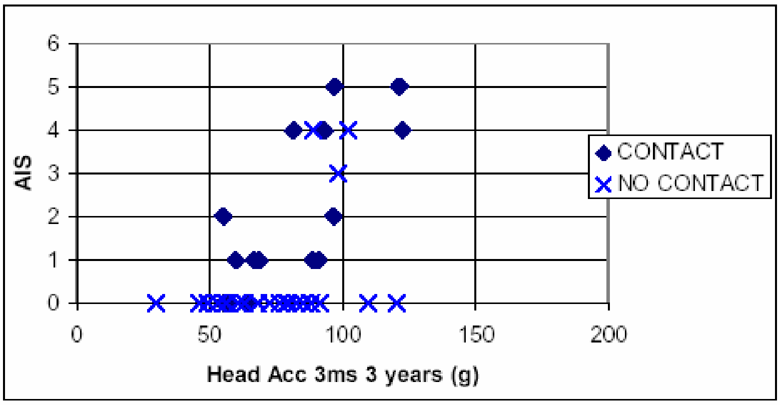


Figure 3-1: Head acceleration with and without head contact for 3 years old

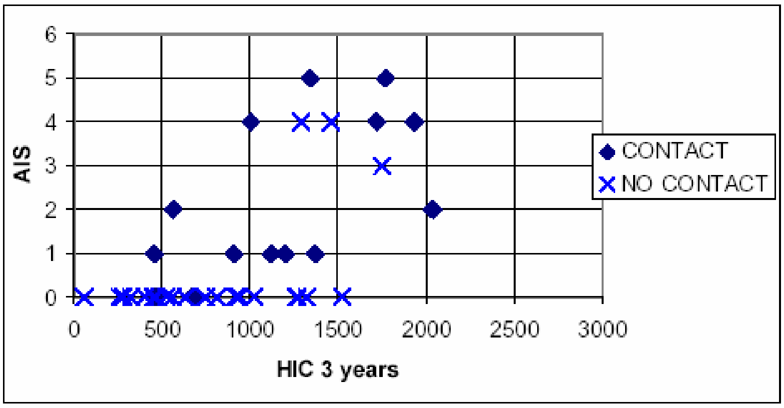


Figure 3-2: Head Injury Criteria with and without head contact for 3 years old

The following Table 3-1 gives the cases distribution, by head contact and no head contact

Table 3-1

Number of cases	Head contact	No head contact
With head injuries	12	3
Without head injuries	3	20
Total of cases	15	23

For the head two important points must be emphasized:

- most of the head injuries were caused by a contact,
- when there is no contact, most often there is no injury.

The data were used to construct injury risk curves. In the CHILD database, there were very few cases with AIS≥ 4 head injuries and very few cases with skull fracture. Therefore AIS≥ 4 and skull fracture injury risk curves were not drawn. AIS≥ 3 head injury is a severe injury and seems to be the best injury threshold. Therefore Q3 dummy AIS≥ 3 risk curves were drawn based on 3ms acceleration and 15ms HIC. The curves were constructed with the certainty method and logistic regression (figure 3-3).

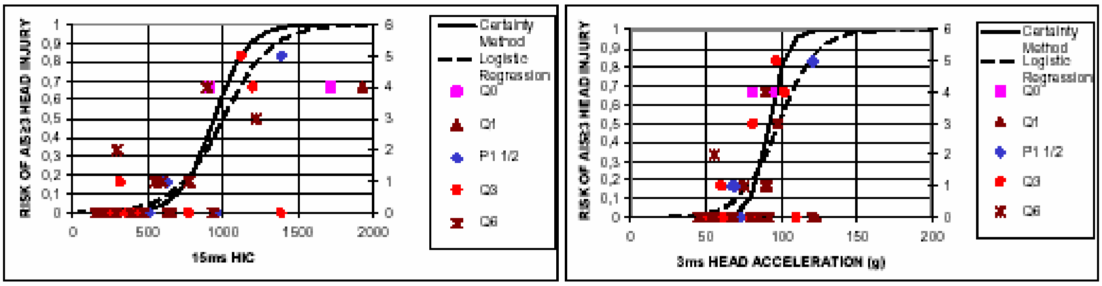


Figure 3-3:Q3 head injury risk curves and data dots resulting from the CHILD project

These injury risk curves have to be compared to those obtained by scaling Injury Assessment Reference values (Mertz et al., 2003; Palisson et al., 2007), which are represented below (Figure 3-4):

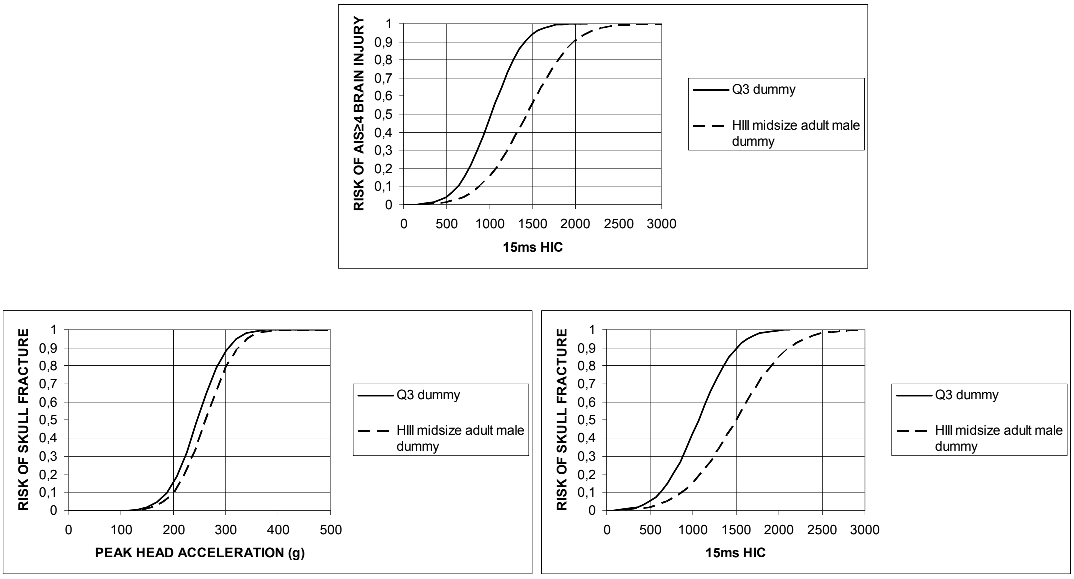


Figure 3-4: Injury risk curves resulting from scaling reference data are different from those taken from the CHILD project.

Data coming from the CHILD project were directly determined for the Q dummies. As injury risk curves and criteria were obtained by both methodologies (scaling reference values coming from the literature and processing the CHILD project results), the most accurate and proposed injury criteria for the head in frontal impact are chosen to be those coming from the CHILD project, as there are sufficient data to establish these criteria.

The AIS≥ 4 injury risk curve based on 15ms HIC and the skull injury risk curve based on peak acceleration obtained by scaling adult data can not be compared to the AIS≥ 3 injury risk curves based on 15ms HIC and on 3ms acceleration resulting from the CHILD project. As far as reference data are concerned, no injury risk curve based on head 3ms acceleration and no AIS≥ 3 injury risk curve based on 15ms HIC are available in the literature. In the CHILD project data, there are very few cases with AIS≥ 4 injury or with skull fracture. Therefore injury risk curves could not be constructed. Since AIS≥ 3 injury corresponds to a severe injury, it might be the best injury threshold. Therefore the proposed head injury criteria result from the CHILD project and correspond to the 15ms HIC values and the 3ms accelerations. The 15ms HIC levels corresponding to 20% and 50% of risk of an AIS≥ 3 head injury are presented in the table below, as well as the 3ms acceleration levels corresponding to 20% and 50% of risk of an AIS≥ 3 head injury.

Table 3-2

15ms HIC	20%	50%
Calculated with the Certainty method	790	940
Calculated with the Logistic regression	780	1000

Table 3-3

Head 3ms acceleration	20%	50%
Calculated with the Certainty method	84g	92g
Calculated with the Logistic regression	81g	99g

In side impact:

In all side impact cases reconstructed, the head injury mechanism was a contact injury. An acceleration threshold was observed between injured and non-injured, from 50g. The thresholds are indicated in the table (Table 3-4) below:

Table 3-4

Acceleration 3ms	0 – 50g	50 – 89g	≥ 99g
AIS	0	1 - 5	≥ 5

No injury risk curves could be constructed because the sample size was not large enough, but the observation of an acceleration threshold between injured and non- injured is encouraging for the continuation of selection of such cases to be reconstructed in the frame of CASPER.

The Q3 dummy injury criteria were scaled to Q0, Q1, Q1.5 and Q6 with the appropriate scaling factors described in the EEVC Q dummies report (EEVC, 2008). For each of the dummies and for each of the injury criteria parameters, the scaled adult value from UNECE R94 as well as the values for AIS 3+ 20% and 50% injury risk, for both Certainty Method (CM) and Logistic Regression (LR) is given. Figure 3-5 shows the various sets of IARV', plotted against the dummy age.

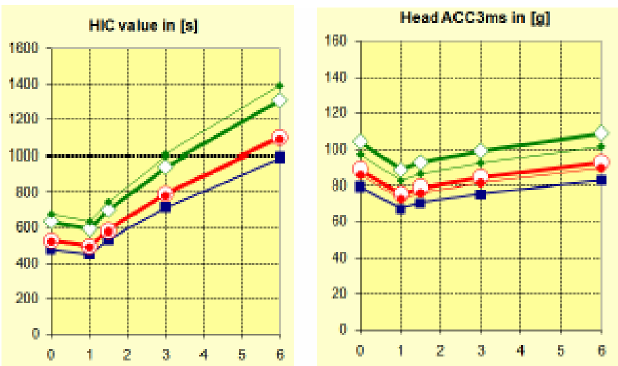


Figure 3-5: HIC and 3 ms head acceleration against dummy age

3.1.2 Neck

The data are drawn from around 40 dummy tests in frontal crashes. The method is a detailed analysis of the real world accident neck injuries and mechanisms in order to associate good physical parameters to each kind of injury.

In frontal impact, as regards the neck, several physical parameters are measured on the dummies; these are the shearing force (Fx), the traction force (Fz) and the flexion moment (My). It is necessary to have a very in-depth analysis of the real world accident neck injuries and mechanisms in order to associate the pertinent physical parameter to each kind of injury. The data are shown in the graphs below for the different parameters (figures 3-6 and 3-7).

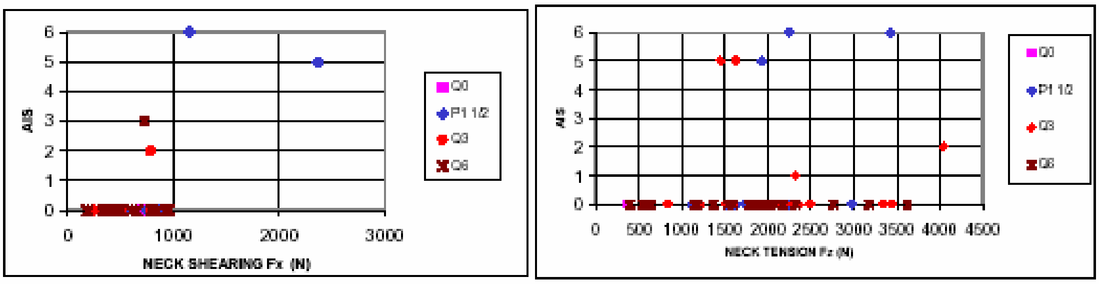


Figure 3-6: Q3 neck forces resulting from the CHILD project

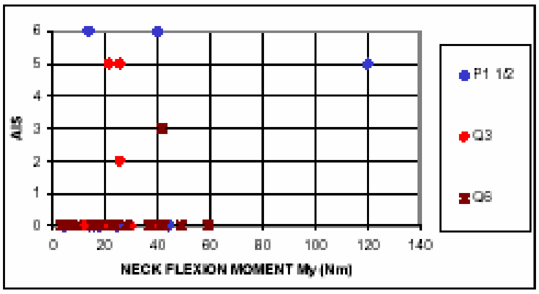


Figure 3-7: Q3 neck moment resulting from the CHILD project

The dens fractures were explained by a flexion of the dens; in a case with a rupture of the spinal cord, the flexion was so large that there was a contact of the chin with the chest. The main parameter associated with the injury mechanism is the moment of flexion My and the secondary parameter is the shearing force Fx. Fz is not involved.

The fractures of the odontoid and cervical vertebrae were also explained by a large flexion and an excessive tension (Fz).

Obviously there are very few cases with injury for each parameter in the CHILD data base, and not enough to neither enable the construction of injury risk curves, nor do the limited number of cases allow for validating injury mechanisms. Only some injury tendencies were observed and they are summarized in the table (Table 3-5) below:

Table 3-5

Injury severity	Fx	Fz	My
No neck injury AIS 5+	< 730 N > 1000 N	< 1450 N	< 13 Nm

No neck injury is observed below 730 N of shearing force, below 1450 N of traction force and below 13 Nm of flexion moment. Only AIS 5+ injuries are observed beyond 1000 N of shearing force.

It is essential that efforts are made to increase the sample size for frontal reconstructions with neck injuries in order to improve the observed thresholds and be able to construct injury risk curves.

Injury risk curves were established from scaling adult data as regards the neck compression and the neck flexion moment and scaling data of the 3 year old Hybrid III dummy for the neck tension force and neck extension moment. They are given below (figures 3-8 and 3-9):

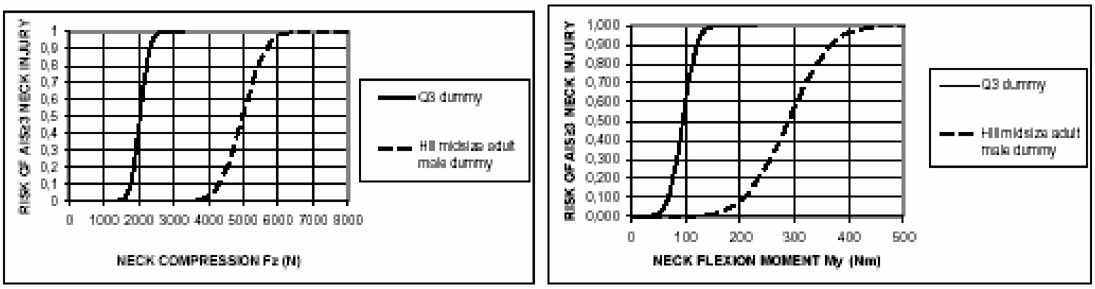


Figure 3-8: Q3 neck injury risk curves resulting from scaling adult data

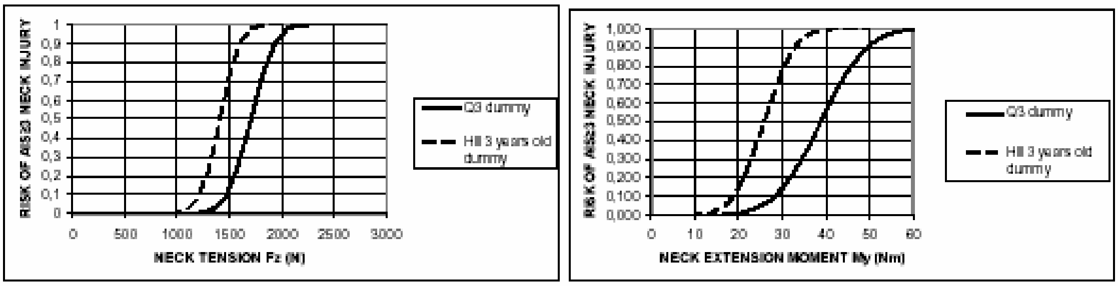


Figure 3-9: Q3 neck injury risk curves resulting from scaling the 3 year old child dummy

Because of the lack of data with neck injury, injury risk curves were not drawn in the framework of the CHILD project. However, injury risk curves based on tension force and flexion moment obtained from scaling reference data can be compared to the CHILD project data (figure 3-10). The injury risk curve based on tension force resulting from scaling is coherent with the CHILD data. No neck injury is observed below 1450N of tension force in the CHILD database and the scaled AIS≥ 3 injury risk curve indicates a 3% risk for a 1220N tension. As far as the flexion moment is concerned, the scaled injury values are much higher than the CHILD project data. Therefore, the proposed neck injury criterion is the tension force Fz issued from scaling. The tension force levels corresponding to 20% and 50% of risk of an AIS≥ 3 neck injury are presented in the table (Table 3-6) below:

Table 3-6

Neck tension	20%	50%
Obtained from scaling	1555N	1705N

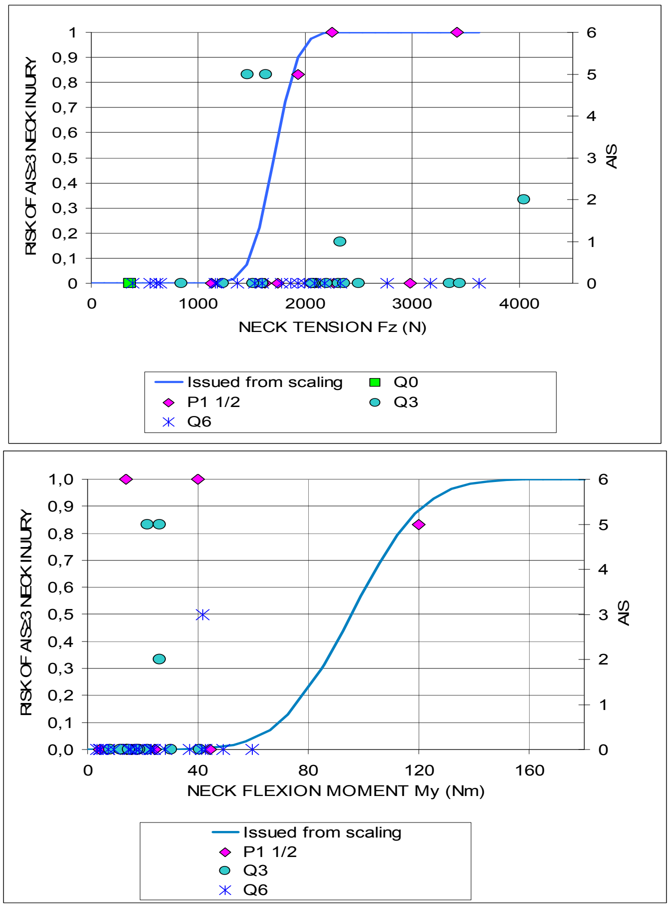


Figure 3-10: Q3 CHILD project neck data and Q3 neck injury risk curves resulting from scaling

The various sets of IARVs are plotted below for the different ages of dummies.

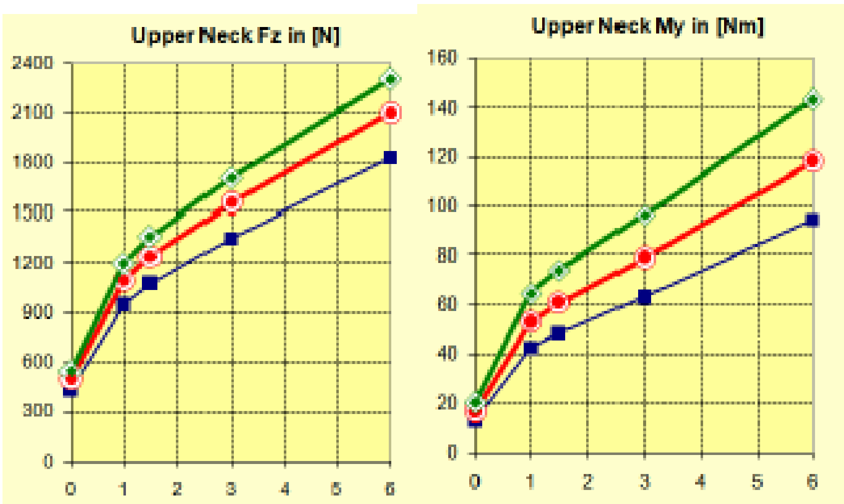


Figure 3-11: Neck IARVs against dummy age

There are no data with neck injuries in **side impact.**

3.1.3 Thorax

In frontal impact, injury risk curves can be based either on chest accelerations or chest deflection values provided respectively by accelerometer recordings, string potentiometers or infrared cells measurements.

During the CREST project it was shown that acceleration is not relevant for this body segment because the sample of cases included rear facing, forward facing CRS, harnesses, shields, two and three point belts, resulting in different kinds and levels of thoraxinteractions. Dummy chest deflections, due to belt loading, measured during the reconstructions proved to be relevant. Values from the CREST and CHILD projects have been compiled in order to plot injury risk curves for the thorax, and, as the thorax is obviously a visco-elastical body part, the viscous criterion V*C was also calculated to draw up a corresponding logistic regression.

A total of 24 cases were available for analysis. The thoracic deflection was measured on Q3 and Q6 dummies. Figure 3-12 gives the distribution of cases taken into account for the analysis versus AIS.

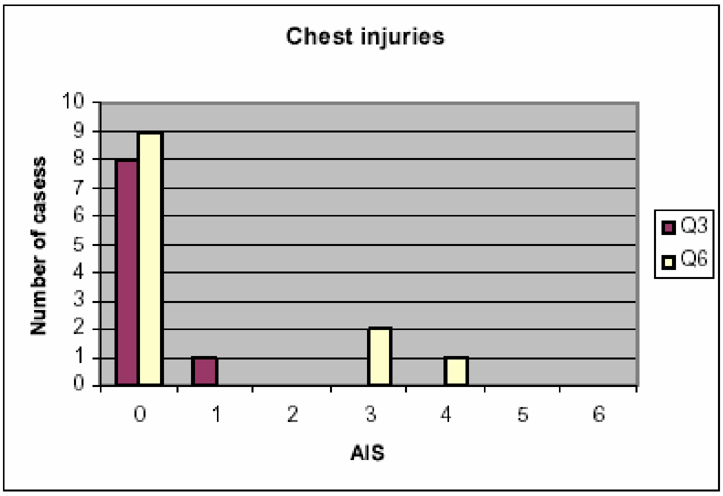


Figure 3-12: Distribution of cases available as a function of AIS

Real world accident injuries were directly paired up with the deflection dynamic measurements acquired with the Q3 and Q6 dummies. Data were scaled in order to correspond to the Q3 dummy equivalent value.

Correlations were made between AIS and chest maximum dynamic deflection.
In the CHILD database, there is no case with AIS≥ 4 thorax injury. Therefore AIS≥ 4 injury risk curve was not drawn. AIS≥ 3 chest injury is a severe injury and seems to be the best injury threshold. Q3 dummy AIS≥ 3 risk curves were drawn for the chest deflection (in the CHILD database, the deflection is due to belt loading).

The curves were constructed with the certainty method and logistic regression (figure 3-13).

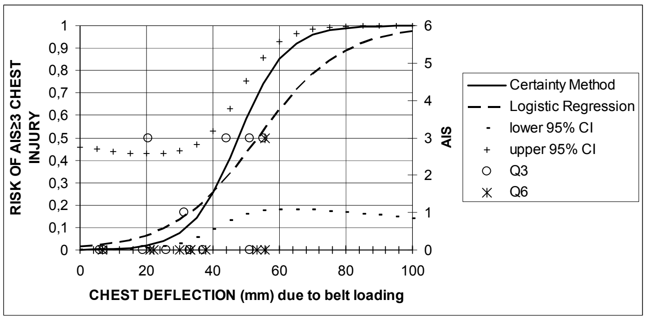


Figure 3-13: Q3 thorax injury risk curves and data dots resulting from the CHILD project

Injury risk curves resulting from scaling are shown below (figure 3-14):

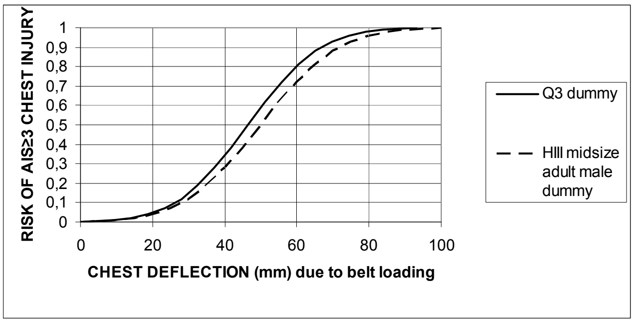


Figure 3-14: Q3 thorax injury risk curves resulting from scaling

The only criterion obtained from both methodologies, the CHILD project database and scaling reference values, is the peak sternal deflection due to belt loading. A very good match is observed between the curve resulting from the scaling and the curve issued from the CHILD database calculated with the Certainty Method). Therefore the proposed chest injury criterion is the chest deflection due to belt loading issued from the CHILD project calculated with Certainty Method and consolidated by scaling reference data (figure 3-15).

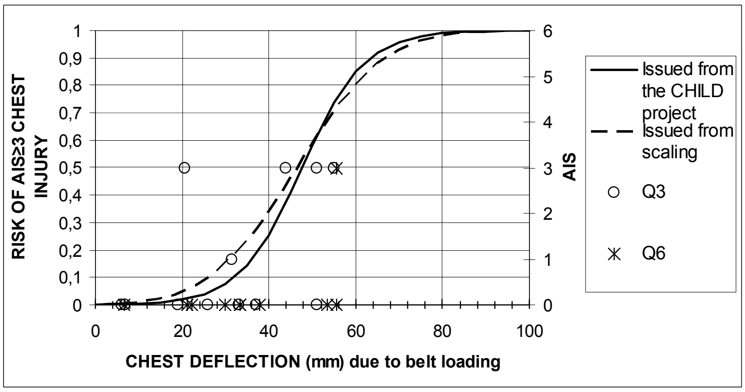


Figure 3-15: Q3 chest injury risk curves resulting from scaling and from the CHILD project

The chest deflection levels corresponding to 20% and 50% of risk of an AIS≥ 3 injury are presented in the following table (Table 3-7).

Table 3-7

Chest deflection due to belt loading	20%	50%
Resulting from the CHILD database	38mm	48mm
Resulting from scaling	33mm	46mm

The various sets if IARV's for the chest are plotted against the different ages of dummies on figure 3-16.

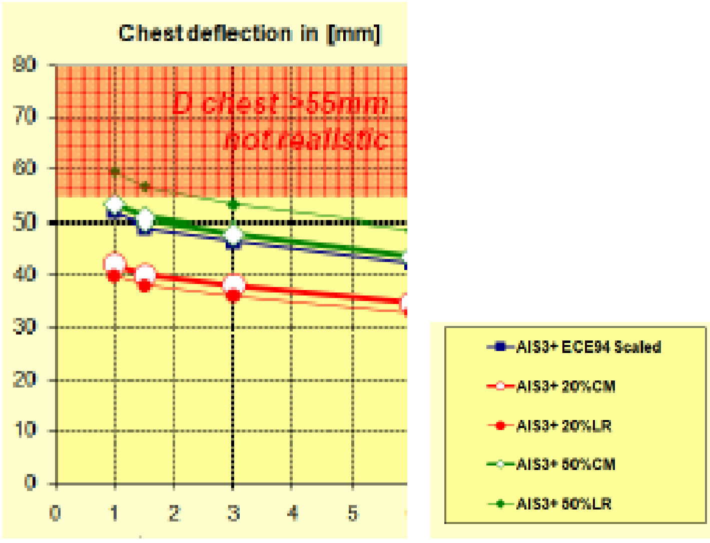


Figure 3-16: chest IARVs against dummy age

3.1.4 Abdomen

The data taken into consideration are those from the reconstructions performed during the CHILD project, owing to the significant differences between dummy versions. Only Q-series dummies were used in these reconstructions.
The Q3 and Q6 dummies were fitted with abdominal sensors. As a whole, the number of validated cases was limited and the following figure (3-17) shows the distribution of theses cases versus AIS.

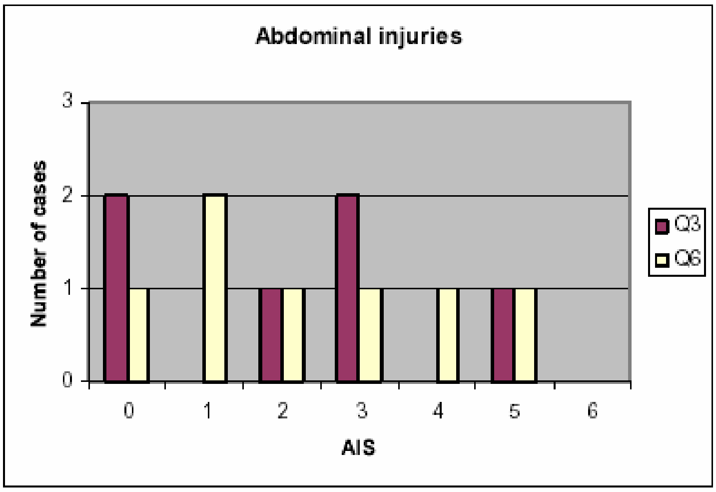


Figure 3-17: Distribution of the cases available versus AIS

The following figure (figure 3-18) shows the abdomen AIS distribution versus abdomen pressure for the Q6 dummy and the AIS 3+ injury risk curve.

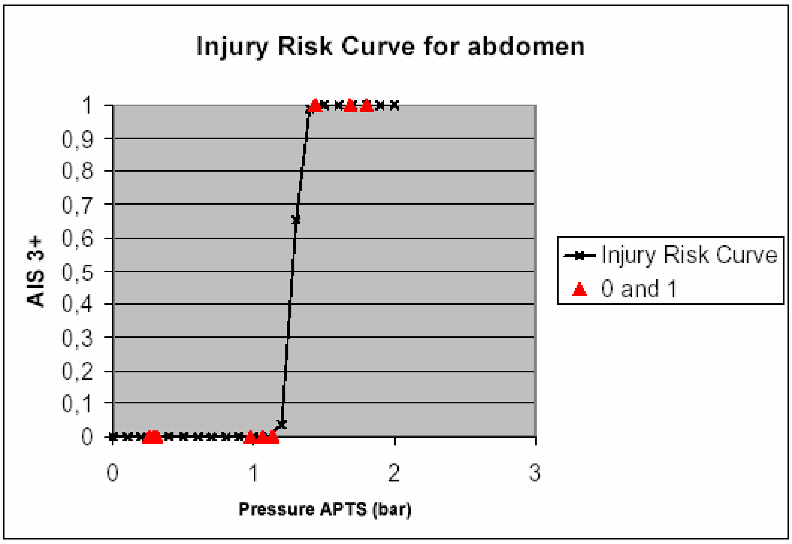


Figure 3-18: Abdomen AIS 3+ injury risk curve (higher values of right and left measurement sensors considered (1.28 bars for 50% risk of AIS 3+)

Two different sensor concepts APTS (Abdominal Pressure Twin sensors) and MFS (Matrix Force Sensor) have been developed and used during the CHILD project for both Q3 and Q6 dummies. As the abdominal blocks of Q3 and Q6 have a comparable size, no scaling techniques are necessary for the analysis of injury risk and corresponding load limits.

For the **APTS** sensor two different injury criteria were analyzed:

- the internal pressure
- P*V (product of the pressure by the pressure rate)

Figure 3-19 below shows the distribution of cases available according to the AIS values.

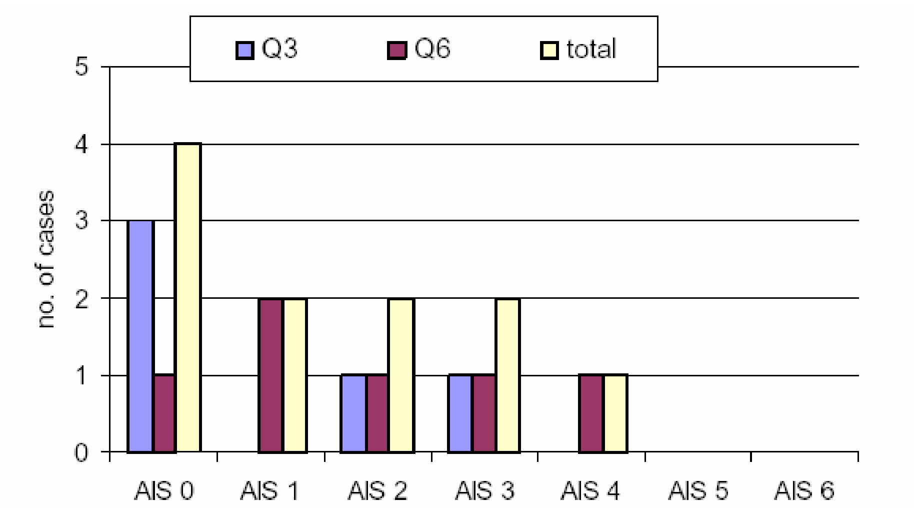


Figure 3-19: Number of APTS available cases

Most of the available cases are without abdominal injuries. No cases with AIS 5 or 6 were available.
The analysis of the intra-abdominal pressure indicates a clear step in AIS 3+ risk between 1.4 and 1.7 bars, as shown in figure 3-20:

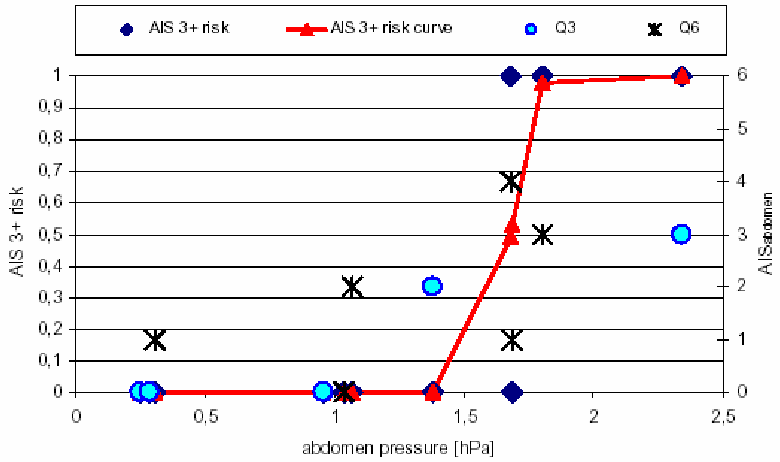


Figure 3-20: Intra abdominal pressure

If we look at the P*V criterion, the situation is not as clear as for the intra-abdominal pressure (figure 3-21).

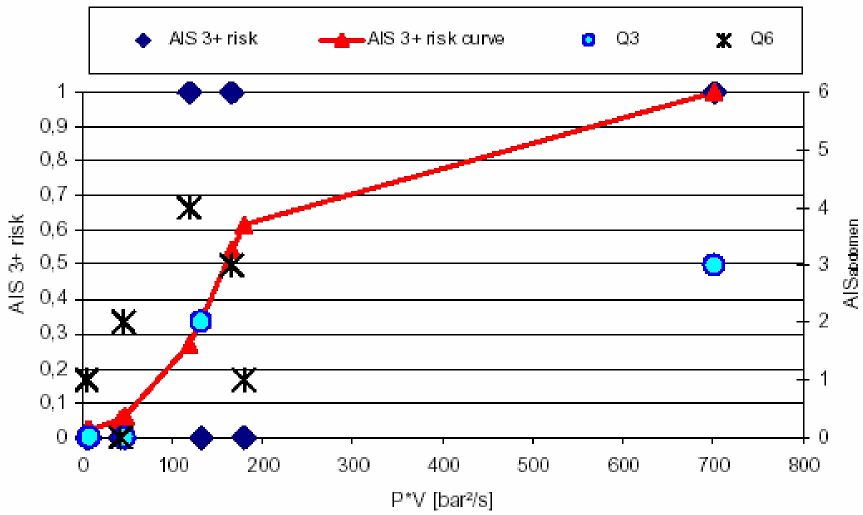


Figure 3-21: P*V criterion

The intra-abdominal pressure seems to be already rate dependent. For that reason the P*V criterion seems to include the rate twice.
As a conclusion for the APTS sensors, the intra-abdominal pressure seems to represent the best injury criterion. Minor injuries are observed at intra-abdominal pressure levels up to 1.4 hPa, while a pressure above 1.7 hPa results in AIS 3+ injuries.

Table 3-8

Internal pressure	0 – 1.4 hPa	≥ 1.7 hPa
AIS	0 - 2	AIS 3+

For the **MFS** sensor three different injury criteria were analyzed:

- the surface pressure
- the maximum (local surface) pressure
- the surface force

The number of cases available is limited. Most of the available cases are without abdominal injuries. For the Q6, there was one case with AIS 4 and one with AIS 5. No cases with AIS 1 or AIS 6 were available.

The analysis of the abdominal surface pressure shows a clear step in AIS 3+ risk curve, between 0.14 and 0.2 N/mm^2, as can be seen on the following figure 3-22:

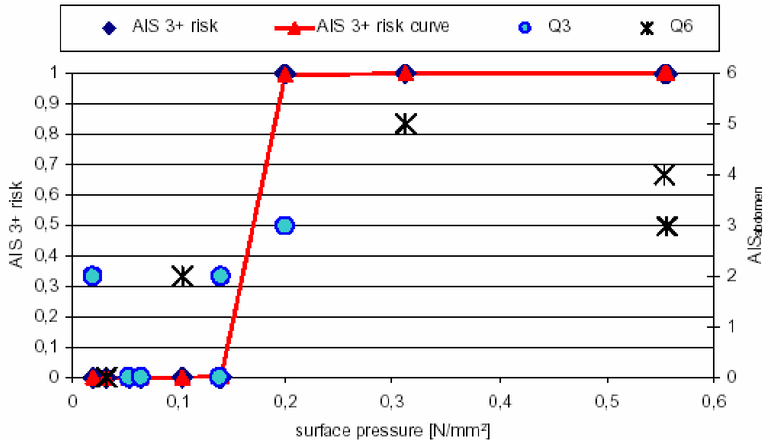


Figure 3-22: abdominal surface pressure

As regards the maximum located surface pressure, the shift between 0 and 100% AIS 3+ injury risk curve is not as clear as for the average surface pressure (figure 3-23).

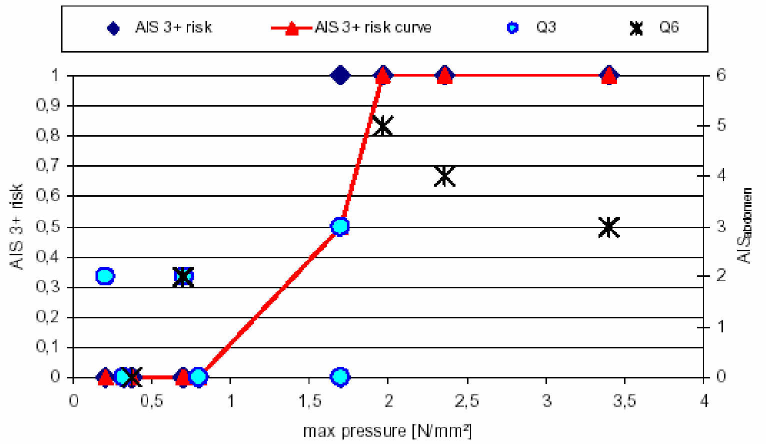


Figure 3-23: abdominal maximum pressure

The surface force, being the product of the surface pressure of each sensor by the area size of the surrounding area of the sensor should allow the assessment of the applied force to the entire abdominal block. The injury risk curve shows a shape comparable to that of the surface force. The step between no risk and high risk is between 3800 N and 4200 N as shown below (Figure 3-24):

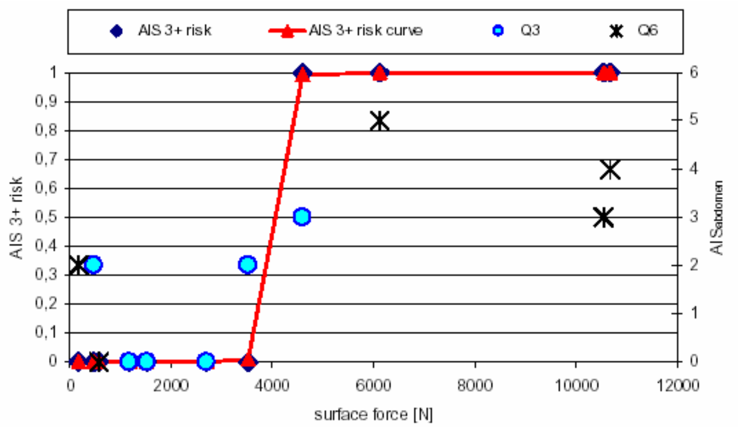


Figure 3-24: abdominal surface force

As a synthesis, the average surface pressure and the surface force offer the best correlation with the AIS 3+ injury risk. As the surface pressure is felt to be independent from individual size, the surface pressure is prioritized as describing the mechanism and the occurrence of abdominal injuries.
The following table indicates that minor injuries are observed at abdominal surface pressures up to 0.17 N/mm^{2}, while a pressure above 0.2 N/mm^{2} results in AIS 3+ injuries.

Table 3-9

Surface pressure	0 – 0.17 N/mm^{2}	> 0.2 N/mm^{2}
AIS	0 - 2	AIS 3+

The number of cases is currently too low to allow establishing significant injury risk functions, so that new reconstructions with these two abdominal sensors are necessary.
Preliminary load limits for AIS 3+ injuries can be settled as 1.7 hPa for the APTS sensor and 0.2 N/mm^{2} for the MFS sensor.
Other parameters had been investigated as no abdominal sensors were available in the past. It was the case of the chest compression and the MY for the lumbar spine, but they did not correlate with the injuries. The use of these two abdominal sensors (APTS and MFS) shows a considerable potential for the prediction of abdominal injury risk; the levels have to be confirmed by more tests.

3.1.5 Remarks

Some facts have to be emphasized as regards the behaviour of the Q dummies in frontal impact. The well known injury mechanism associated to submarining is not correctly reproduced by the Q dummies even if the lap strap is initially located on the pubis. This is explained on the one hand by the too stiff lumbar sacral joint due to the high stiffness of the rubber lumbar cylinder and on the other hand to the high response to vertical compression of the abdominal block. Furthermore, the gap between thighs and pelvis, at the level of the groin, catches the lap strap, preventing it from sliding towards the iliac wings.

3.1.6 Conclusions

The objectives of establishing PRV's for the Q dummies family are more or less difficult and ambitious depending on the body segments.
For the head, most of the injuries in frontal impact were caused by a direct contact. It is also the case in lateral impact.
For the chest, the study is rather simple because principally the rib cage determines the response, the injury mechanisms and the resistance threshold of whole body part; moreover, dedicated sensors to measure the chest deflection are simple and reliable.
With regard to the abdomen, such an objective is quite ambitious and difficult, because the abdomen contains, additionally to organs like the liver, the intestines, the spleen and kidneys, fragile membranes such as the peritonea and mesentery as well as large vessels. The injury mechanisms have to be further investigated.

The combination of both methodologies (scaling reference values coming from the literature and processing the CHILD project results) allows assessing new head, neck and chest injury criteria specific to the **Q3** dummy. The aim of this study was to provide new injury criteria to the European Enhanced Vehicle-safety Committee (EEVC) that wishes to promote the use, in regulation, of more biofidelic child dummies and biomechanical based tolerance limits.

The proposed head injury criteria were estimated by the CHILD project reconstructions and calculated with the Certainty Method.

- 15ms HIC
  - 15ms HIC = 790 corresponding to a 20 percent risk of an AIS≥ 3 head injury
  - 15ms HIC = 940 corresponding to a 50 percent risk of an AIS≥ 3 head injury
- Head 3ms acceleration
  - γ_{3ms} = 84g corresponding to a 20 percent risk of an AIS≥ 3 head injury
  - γ_{3ms} = 92g corresponding to a 50 percent risk of an AIS≥ 3 head injury

The proposed neck injury criteria were defined by scaling reference values in coherence with the CHILD project database:

- Neck tension:
  - Fz = 1555 N corresponding to a 20 percent risk of an AIS≥ 3 neck injury
  - Fz = 1705 N corresponding to a 50 percent risk of an AIS≥ 3 neck injury

The proposed chest injury criterion resulted from the CHILD project and was consolidated by scaling reference values:

- Thorax deflection due to belt loading:
  - δ_{Th} = 38mm corresponding to a 20 percent risk of an AIS≥ 3 chest injury
  - δ_{Th} = 48mm corresponding to a 50 percent risk of an AIS≥ 3 chest injury

- Intra abdominal pressure
  - APTS internal pressure above 1.7 hPa corresponding to AIS 3+ injuries,
  - MFS surface pressure above 0.2 N/mm^2 corresponding to AIS 3+ injuries.

For the other Q dummies the values of IARVs are given in the following tables (Table 3-10), which are extracted from the EEVC WG12 report on Q dummies. They are scaled from the values of the Q3 dummy.

Table 3-10

ECE R94 (scaled) injury criteria IARVs per dummy

		Unit	Q0	Q1	Q1.5	Q3	Q6
Head Impact Criterion	HIC_{36}	s	477	447	526	710	986
Head Acceleration 3ms	A_{3ms}	g	79	67	70	75	82
Upper Neck Tension Force	F_z	N	433	951	1080	1350	1824
Upper Neck Flexion Moment	M_y	Nm	13	42	48	63	94
Thorax Chest Deflection	D_{chest}	mm	NA	52	49	46.5	42

AIS3+ 20%CM injury criteria IARVs per dummy

		Unit	Q0	Q1	Q1.5	Q3	Q6
Head Impact Criterion	HIC_{15}	s	530	497	585	790	1097
Head Acceleration 3ms	A_{3ms}	g	88	75	79	84	92
Upper Neck Tension Force *)	F_z *)	N	498	1095	1244	1555	2101
Upper Neck Flexion Moment	M_y *)	Nm	17	53	61	79	118
Thorax Chest Deflection	D_{chest}	mm	NA	42	40	38	35

AIS3+ 20%LR injury criteria IARVs per dummy

		Unit	Q0	Q1	Q1.5	Q3	Q6
Head Impact Criterion	HIC_{15}	s	523	491	578	780	1083
Head Acceleration 3ms	A_{3ms}	g	85	72	76	81	89
Upper Neck Tension Force *)	F_z	N	498	1095	1244	1555	2101
Upper Neck Flexion Moment *)	M_y	Nm	17	53	61	79	118
Thorax Chest Deflection	D_{chest}	mm	NA	40	38	36	33

AIS3+ 50%CM injury criteria IARVs per dummy

		Unit	Q0	Q1	Q1.5	Q3	Q6
Head Impact Criterion	HIC_{15}	s	631	591	696	940	1306
Head Acceleration 3ms	A_{3ms}	g	97	82	86	92	101
Upper Neck Tension Force *)	F_z	N	546	1201	1364	1705	2304
Upper Neck Flexion Moment *)	M_y	Nm	20	64	74	96	143
Thorax Chest Deflection	D_{chest}	mm	NA	53	51	48	44

AIS3+ 50%LR injury criteria IARVs per dummy

		Unit	Q0	Q1	Q1.5	Q3	Q6
Head Impact Criterion	HIC_{15}	s	671	629	741	1000	1389
Head Acceleration 3ms	A_{3ms}	g	104	88	93	99	109
Upper Neck Tension Force *)	F_z	N	546	1201	1364	1705	2304
Upper Neck Flexion Moment *)	M_y	Nm	20	64	74	96	143
Thorax Chest Deflection **)	D_{chest}	mm	NA	59	56	53	49

Notes:

*) Upper Neck Tension Force (Fz) and Flexion Moment (My) values come from literature scaling and are not specifically associated with CM or LR statistical methods

**) Thorax Chest Deflection larger than 55 mm are considered unrealistic from human point of view and physically impossible to measure with the Q-dummies

3.2 Injury Biomechanics of Head and Neck (UdS)

3.2.1 Head

<u>Type of Injuries</u>

Children and infants have a large, heavy head; cervical ligaments and muscles are weaker than in adults. Given the same deceleration of the body, head and neck trauma is therefore more likely in younger children. Similarly, the resulting brain injury is more severe due to the thin, pliable skull and the yet unfused sutures.

Head injuries are one of the most common causes of disability and death in children. The injury can be as mild as a bump, bruise (contusion), or cut on the head. Or it can be moderate to severe in nature due to a concussion, deep cut or open wound, fractured skull bone(s), or from internal bleeding and damage to the brain.

A head injury is a broad term that describes a vast array of injuries that occur to the scalp, skull, brain, and underlying tissue and blood vessels in the child's head. Head injuries are

also commonly referred to as brain injury, or traumatic brain injury (TBI), depending on the extent of the head trauma. In children some neurologic deficits after head trauma may not manifest for many years. Frontal lobe functions, for example, develop relatively late in a child's growth, so that injury to the frontal lobes may not become apparent until the child reaches adolescence as higher level reasoning develops. Since the frontal lobes control our social interactions and interpersonal skills, early childhood brain damage may not manifest until such frontal lobe skills are called into play later in development. Likewise, injury to reading and writing centers in the brain may not become apparent until the child reaches school age and shows signs of delayed reading and writing skills
There are many causes of head injury in children. The more common injuries are falls, motor vehicle accidents (where the child is either riding as a passenger in the car or is struck as a pedestrian), or a result of child abuse.
We can distinguish:

- **Scalp injuries** which is an external injury
- **Concussion** which is an injury to the head area that may cause instant loss of awareness or alertness for a few minutes up to a few hours after the traumatic event
- **Skull fracture** A skull fracture is a crack or break in one of the skull's bones. We can distinguish:
    - Linear skull fractures - This type accounts for almost 70 percent of skull fractures. In a linear fracture, there is a break in the bone, but it does not move the bone. These children are usually observed in the hospital for a brief amount of time, and can usually resume normal activities in a few days. No interventions are usually necessary.
    - Depressed skull fractures - This type of fracture may be seen with or without a cut in the scalp. In this fracture, part of the skull is actually sunken in from the trauma. Usually, this type of skull fracture requires surgical intervention to help correct the deformity. The bones of the skull of the newborn and nursing infants, in general, possess great malleability. For this reason, the depressed fractures occurring at this age are called “Ping Pong” or “Green Stick” fractures.
    - Diastatic skull fractures - These are fractures that occur along the suture lines in the skull. The sutures are the areas between the bones in the head that fuse with the growth of the child. In this type of fracture, the normal suture lines are widened. These fractures are more often seen in newborns and older infants.
    - Basilar skull fracture - This is the most serious type of skull fracture, and involves a break in the bone at the base of the skull. Children with this type of fracture frequently have bruises around their eyes and a bruise behind their ear. They may also have clear fluid draining from their nose or ears due to a tear in part of the covering of the brain.
- **Epidural hematoma** This is one of the most serious types of bleeding that can occur inside the head as a result of a skull fracture. It happens when a sharp fragment of bone cuts through one of the major blood vessels in the skull or if the skull sustains large deformations. As the injured vessel bleeds, a collection of blood called a hematoma forms in the space between the skull and the outermost membrane (dura) covering the brain. The blood vessel that ruptures is usually an artery, and the hematoma expands rapidly and presses on the brain. This can cause severe injury and even death. Epidural hematomas are especially common after significant injuries to the temple, such being hit by a baseball or baseball bat.
- **Subdural hematoma** This is a collection of blood between the coverings of the brain and its surface. It occurs when a head injury tears any of the large veins that carry blood away from the brain's surface. Subdural hematomas tend to get larger slowly, sometimes over days or weeks, with symptoms gradually worsening. This

type of bleeding leads to serious brain injury and even death if not diagnosed and treated promptly.

- **Intraparenchymal hemorrhages and contusions (bleeding and bruising of the brain).** These injuries involve the brain itself. Both types of injury are caused by either a direct blow to the head or indirectly when the force of an injury to one side of the skull causes the brain to bounce against the other side. This causes an area of damage on the side of the brain opposite from the blow to the head (Figure 3-25).
-

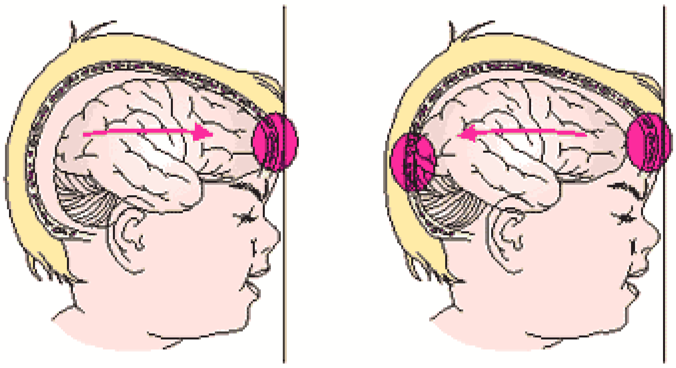


Figure 3-25. Coup and contracoup injuries. Image demonstrates how in a coup injury a blow to the rear of the skull results in an injury to the anterior of the brain. In a contracoup injury (right), the brain recoils and strikes the posterior skull as well, injuring it twice.

- **Diffuse axonal injury.** DAI is one of the most common and devastating types of traumatic brain injury, meaning that damage occurs over a more widespread area than in focal brain injury. DAI, which refers to extensive lesions in white matter tracts, is one of the major causes of unconsciousness and persistent vegetative state after head trauma. It occurs in about half of all cases of severe head trauma and also occurs in moderate and mild brain injury. Vehicle accidents are the most frequent cause of DAI; it can also occur as the result of child abuse such as in shaken baby syndrome. It is well known that this type of injury is due to both linear and rotational accelerations.
- **Retinal Hemorrhage** which are present in nearly all cases of infant abuse in which shaking or shaking impact is documented. This injury mechanism is still poorly known and seems not to be a major issue in road accident.

Injury Criteria

Despite this well accepted distinction in injury mechanisms and the fact that the head is a complex deformable structure, a first set of head injury criteria based on a head model made by one mass only were proposed in the literature (HIC).
Limitation of HIC as a head injury criterion is often discussed as this criterion does not consider the different head injury mechanisms, because it is not considering impact direction and especially because angular acceleration is not taken into account when it is well known that this phenomenon leads to brain shearing.
Even if first injury criterion for Q3 dummy has been proposed in CHILD project, this criterion clearly need improvement. On the other hand head injury criteria for other ages are needed and cannot be fitted with scaling methods only.
Figure 3-26 represents HIC values obtained per AIS score for 61 accidents cases available in CHILD project and we clearly see HIC limitations to predict a head injury.

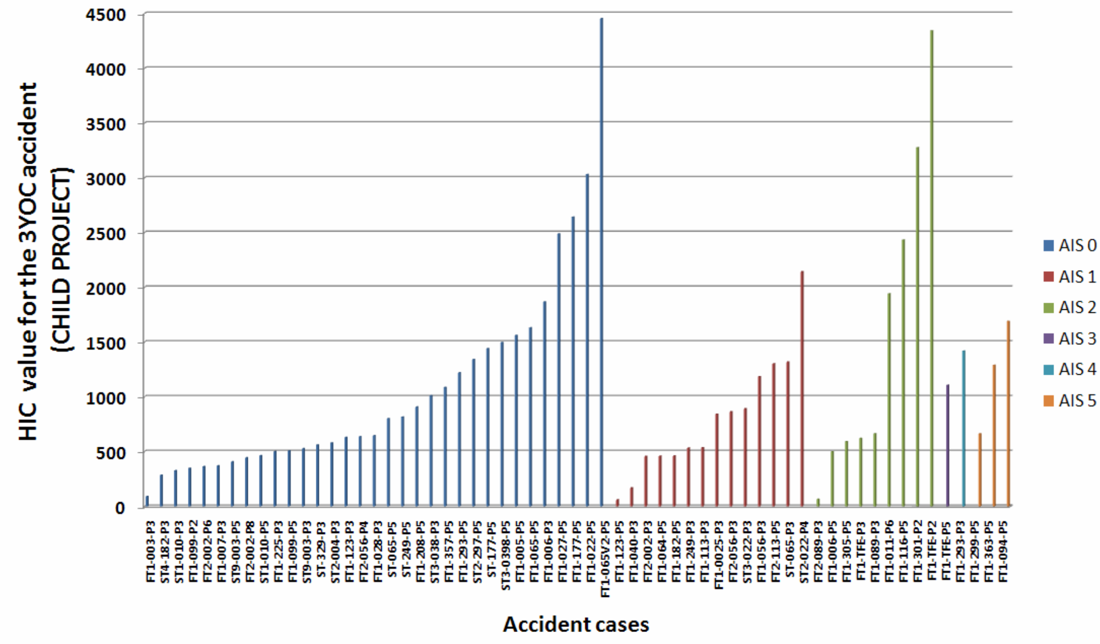


Figure 3-26. HIC value per AIS score obtained for 60 accident cases (CHILD project).

3.2.2 Neck

Neck Injuries Description

There is no difference between the adult and the child cervical spine injuries in a medical point of view. Nevertheless the difference is the frequency of the type injury type. As it was exposed in the previous part there are more Spinal Cord Injuries Without Radiological Abnormality (SCIWORA) and dislocation for the child, the adult have more frequently a fracture (Figure 3-26). The classification proposed is by injury risk level.

For the upper cervical level (C0-C2)

- Dislocation of atlanto-occipital junction followed by the death.
- Atlas fracture
- Rotational dislocation
- Anterio-posterior instability
- Odontoide fracture
- Fracture of the axis process
- SCIWORA

The most frequently observed injuries at the upper cervical level are the C1-C2 dislocation. This lesion is not always due to severe impact and the injury gravity is difficult to estimate.

For the lower cervical spine (C3-C7)

- Fracture of the cervical body
- Dislocation
- Ligamentary instability
- SCIWORA

The spine injuries are rare but 43% of the spine injuries are involved in the higher cervical spine. The upper cervical spine injuries present some characteristics which must be underline. The C1-C2 processes have an anatomical difference and are involved most frequently in the youngest children (Figure 2-9). Finally the mechanisms of the injuries are the very often due to a hyperflexion/hyperextension and/or an axial loading.

Neck Injury Criteria

In contrast to the adult there are no specific neck injury criteria for the child neck. The methodology actually used consists to scale the mechanical parameter such as the force and the flexion moment at the atlanto-occipital joint. For the adult we can list about four injury criteria for frontal impact: MOC (Total Moment about Occipital Condyle); MTO (Total Moment), NIC (Neck Injury Criterion); Nij (Normalized Neck injury Criterion) and for rear impact: NIC (Neck Injury Criterion); Nkm (Neck Criterion rear impact) and LNL (Lower Neck Load Index). Regarding to the literature only the study realized by Palisson et al. (2007) based on CHILD project proposes injury criteria for the Q3 dummy in frontal impact for AIS≥3. This study was also presented at ISO meetings and referenced by the document ISO/TC22/SC12/WG6 N 706. The methodology used is to scale the force and the bending moment recorded during accident reconstruction from the HIII the Q6, P1.5, Q1 and Q0 dummies to the 3 years old child dummy. The scaling method proposed by Irwin and Mertz (1997) takes into account the geometry changes, the stiffness and the failure stress. This method supposes that the body mass density is equal for children and adults. Based to these hypothesis a scale value (from the adult HIII dummy) for the force was fixed at λ=0.41 and for the bending moment at λ=0.33 (Table 3-11).

Table 3-11 Scaling factors from the HIII dummy to the Q3 dummy.

	λ_{FN}	λ_{MN}
HIII	0.41	0.33

Moreover during CREST and CHILD projects, 669 cases corresponding to 1079 children for which 73% were involved in frontal impact and 27 % in lateral impact were physically reconstructed with different dummies. Palisson et al. (2007) have selected 98 accidents reconstructions with the Q0, Q1, Q3, P1,5 and Q6 dummies in order to determine injury risk curves for AIS≥3 and for the Q3 dummy. This method permits to use all the data provide by the child dummies and also increase the statistical analysis. The scale value apply for the Q6, Q1, Q0 and P 1 ½ are summarize in the Table 3-12. Figure 3-26 and Figure 3-27 illustrate respectively injury risk curves and the value recorded during the accident reconstruction in terms of neck tension and bending moment.

Table 3-12. Scaling factors from the Q dummies to the Q3 dummy.

	λ_{FN}	λ_{MN}
Q0	3.12	4.76
Q1	1.42	1.49
P 1.5	1.25	1.3
Q3	1	1
Q6	0.74	0.74

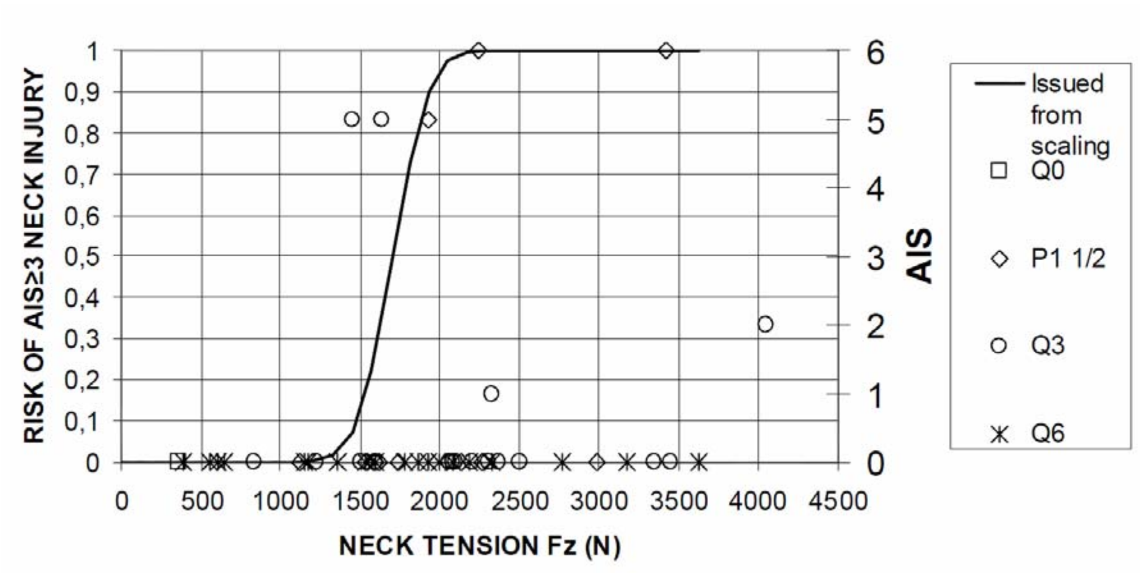


Figure 3-26. Q3 neck injury risk curves in terms of neck tension (Fz) at the atlanto occipital joint (Palisson et al. 2007).

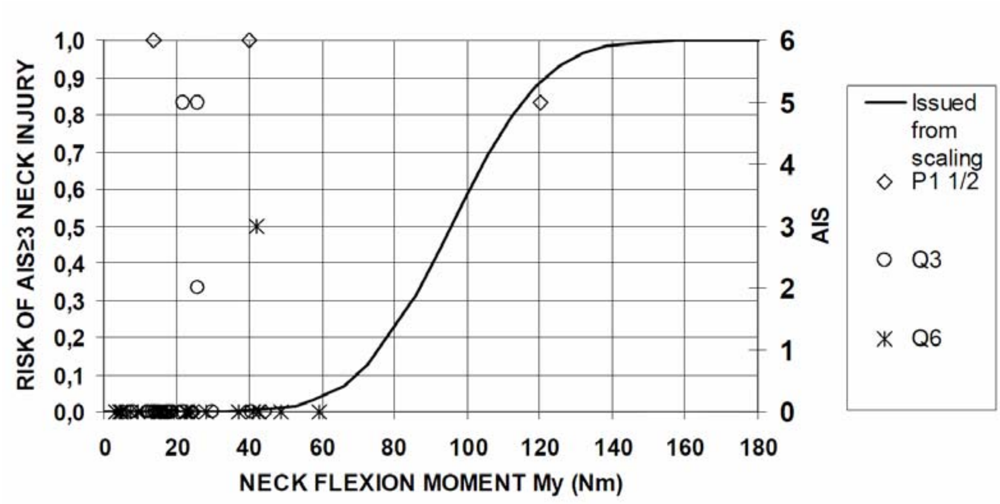


Figure 3-27. Q3 neck injury risk curves in terms of Neck flexion moment tension (My) at the atlanto occipital joint (Palisson et al. 2007).

In regards to the results the neck injury criterion is the tension force it appears that 20% and 50% of risk of an AIS≥3 the tension force is estimated respectively at 1555 N and 1705 N. For the bending moment it seems that there is no adequate correlation between the injury and value recorded. These results show very first attempts which must be improved within CAPSER project (Figure 3-28).

In the child protection field one of the highest difficulty is to obtain the mechanical behavior of the child neck under impact loading, due to ethical reason. No characterization and only very few mechanical properties are available in the literature. As long as dummies are concerned the only method available is the scaling method which supposed that the child is a small adult. Palisson et al. (2007) have used this method in order to obtain a neck injury criterion for the Q3 dummy corresponding to AIS≥3.

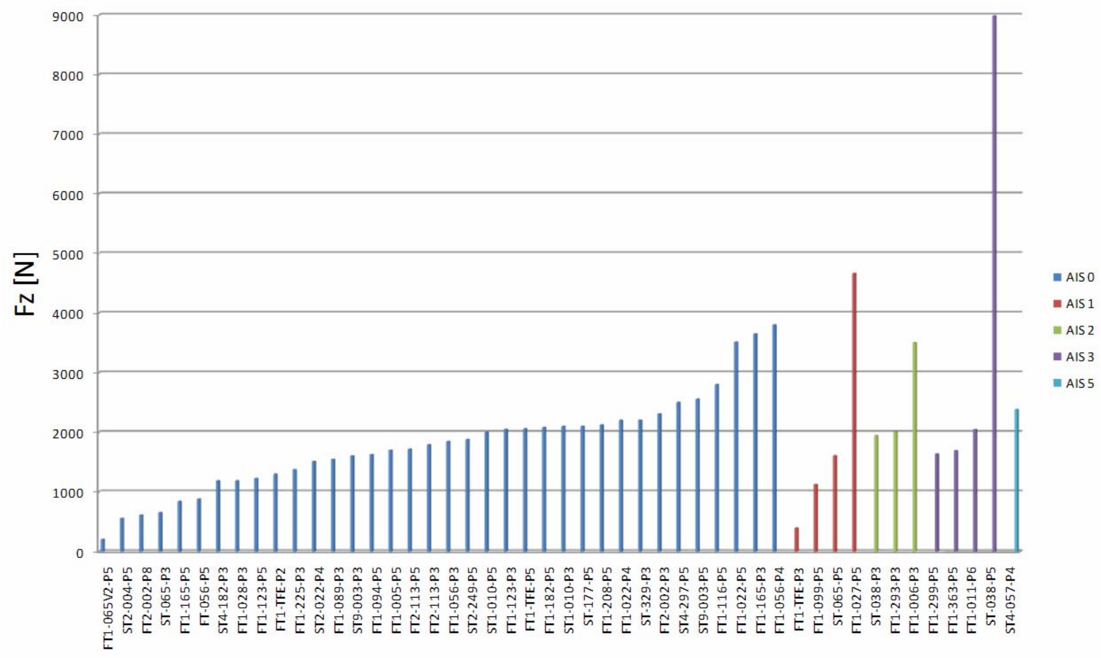


Figure 3-28. Histogram in terms of force tension (Fz) at the atlanto occipital joint (accident reconstruction CHILD Database). Histogram have been performed with the HIII 5°; P 1,5; P10M; P3/4; P3M; P6; P6M; Q1; Q3and Q6 dummies

3.3 Injury Mechanisms of Child Occupants in CRS (TNO)

Both fatal as well as serious injuries sustained by children in car crashes can have various reasons or are caused through various injury mechanisms. Using an appropriate child restraint system (CRS) amongst others prevents the child to impact vehicle interior structures and is hence a key requirement for child protection in cars. However, to ensure proper protection, the CRS needs to be installed properly which is often difficult and can therefore cause potentially dangerous situations (van Rooij, 2005). Additionally, child restraint systems are designed for a specific range of body size and weight. A child seated in a CRS that is inappropriate for either its weight or length may be exposed to potentially hazardous restraint conditions. Prematurely graduated children are more likely to suffer from significant head injuries, abdominal injuries, spinal cord injuries and brain injuries (Vesentini et al. (2007). Additionally it can cause an inappropriate belt fit which may result in submarining during a crash. This means that the lap belt does not engage on the pelvis, as it should, but goes into the abdomen, which can significantly increase the risk of severe abdominal injuries.

In the following chapters several studies and their outcome with respect to injury mechanisms that were carried out either solely by TNO or with contribution from TNO are presented. Please note, that no specific information from the CREST, CHILD or APROSYS projects is listed as these projects were considered to already be fully covered with respect to available information by the WP2 leader during the first work package meeting.

3.3.1 Child Dummy Developments

Lots of research has been done for the development of child dummies. The development of the first series of child dummies started in the late 1960's at TNO. These first dummies from the so called P-series were mainly loading devices consisting of rigid bodies connected by joints. Though the P-series was able to predict child kinematics reasonably well and was improved over the years it still has some mayor discrepancies when it comes to evaluation of modern safety systems. Hence a more biofidelic series of child dummies needed to be developed one would also be able to use for evaluation of for example child-airbag interactions. The development of this latest child dummies, the Q dummy series started in the 1993. Therefore, relevant publications that also include injury mechanism and not mainly biomechanical response corridors or dummy performance are normally 10 years or older. However, most of this data is still considered valid. Most investigations from this time did not only include research on child anthropometry but also focused on biomechanics of and injury mechanisms seen for children in mainly frontal and side impact conditions. One of the problems during the dummy development was that in general only limited biomechanical data on children is available due to mostly ethical reasons. Therefore, most of the established data needed to be derived by means of scaling from adult or animal responses down to the particular child responses. Injury data from accident databases that also includes hints towards the injury mechanism lying beyond is more common. A set of published injury data of traffic accidents including database and found injury characteristics as presented by Beusenberg et.al (1993) is shown in Figure 3-29.

reference	Database characteristics					Injury characteristics									Notes
	years	age (y)	transport mode	restraint type	N	injury severity	body region: head	face	neck	thorax	abd.	extremities: general	upper	lower	
Carlsson [5]	76-'88	0-4	car pass.	rearw. f.	142	MAIS 1-6	++	+			o	o			qualifiers based on injury priority rating
						MAIS 2-6	+								
				booster	130	MAIS 1-6	++	++	++	+	+	+			
						MAIS 2-6	+		o			o			
				unrestr.	228	MAIS 1-6	++	++	o		o	++			
						MAIS 2-6	++	o	o			+			
Langwieder [6]	84-'90	0-14	car pass.	restr.	865	MAIS 1-6	60.4%		15.3%		13.9%				
						MAIS 2-6	+				+	o			esp. 0-2 yrs
				unrestr.	288	MAIS 1-6	55.4%						21.6%	21.0%	
						MAIS 2-6	++				+	+			
Valée [7]	90-'91	0-10	car pass.	restr. (front)	29	MAIS 1-6	52%		21%	31%	24%				excl. fatal.
					10	AIS 3-5	30%		10%	10%	40%				spine: 20%
Agran [8]	80-'85	0-14	car pass.	lap b./rear	141	AIS 1-6	53% (incl. face)			1%	12%	19%			spine: 14%
				3-p.belt/front	88	AIS 1-6	48% (incl. face)			6%	10%	23%			spine: 21%
Lowne [9]	72-'86	0-4	car. pass.	restr.	30	fatalities	80% (incl. face)		33%	7%	10%				
Stürtz [10]	72	0-14	pedestrian		41		++			+	+		+	+	
Lowne [11]	< '74	0-15	car pass.	unrestr.	52	AIS 1-6	73% (incl. face)			8%	13%		33%	46%	pelvis: 6%
			pedestrian		119	AIS 2-6	53% (incl. face)		6%	6%	8%		19%	46%	pelvis: 20%
Agran [13]	81-'87	4-9	car pass.	restr.	143	AIS 1-6	64% (incl. face)		+	6%	17%		11%	11%	
Dejeammes [14](selected cases)	82-'84	0-15	pedestrian		45	AIS 2-6	++							++	
			two wheeler (motorbikes)		23	AIS 2-6	+						+	++	
			car pass.		21	AIS 2-6	++		+					+	

Figure 3-29 Published injury data of children in traffic accidents as presented by Beusenberg et.al. (1993)

The qualifiers "++", "+" and "o" in this Figure indicate whether the body part was injured very frequently, frequently or injured but not frequently, respectively. Though the study from Beusenberg et al (1993) is already quite old, the general findings with respect to obtainable injuries and the underlying mechanisms are still considered valid. The first overall finding was that the use of a CRS in general reduces the risk of sustainable injury for a child. If installed correctly it can keep the child from impacting a hard structure which was found to be the main reason for severely or fatally injured children in traffic causing skull and brain injuries. Furthermore, the study concluded the following:

"As car passengers, the second priority body parts that are injured in crashes strongly depend on the type of restraint. As unrestrained car passengers, children tend to sustain injuries to their extremities while restrained children tend to sustain injuries to their central body parts. A particular difference in injury pattern between restrained and unrestrained children in cars is the occurrence of neck and abdominal injuries. The neck tends to get injured particularly in restrained forwards facing position in frontal and rear impacts, however most authors report low severity neck injuries only (AIS 1). The abdomen is considered an endangered body part in restrained conditions; however these injuries mainly occur in high severity impacts and/or as a result of car intrusion. Detailed data on injuries per body region are barely published."

3.3.2 Seat belt misuse and influence of anchorage locations

In general, the use of a CRS reduces the risk of serious/fatal injuries by a factor of seven (Huijskens et.al. 1993). However, when used incorrectly the CRS cannot protect the child in an optimal way thus increasing the risk of obtainable injuries for its occupant. Therefore, Huijskens et al (1993) performed a study to investigate the influence of several types of CRS misuse including car-interface problems on dummy readings by means of sled testing. The study focused on forward facing systems for children between 9 month and 3 years. In a pre-study, field studies as well as literature was investigated to get an idea on the misuse frequency as well as the misuse itself. It was found, that back then approximately 70% of the systems were used incorrect within the Netherlands. Misuse of the CRS was not only related to faulty installation by the adult installing the CRS, but also due to car-interface problems with the CRS. Though the designs of car interiors might be expected to have changed over the years from 1993 to today with that respect, such problems were still present 8 years later, as stated by Arbogast et. al. (2001).

From more recent studies from all over the world it is found, that such high percentages of misuse as found by Huijkens et al (1993) are unfortunately not long gone history, but still present. O'Neil et al. (2009) for example stated that from recent field studies performed in Indiana for 64.8% of all transported children below 16 at least 1 seat belt misuse was found. Arbogast et al (2001) even stated an estimation of 90-95% of the child safety seats to be used incorrectly.

From the sled test study it was found that the amount of slack in the belt highly influenced the amount of head excursion. Hence, the higher the head excursion, the more likely the child can sustain severe head contact with the interior of the car. The misuse modes studied ranged from unsymmetrical anchorages that provoke a less efficient fixation of the CRS to badly fastened harnesses within the CRS.

In 1992 Jansen et al. presented a study named "Reduction in Seat belt effectiveness due to misuse". Back then the general wearing rate of standard 3-point seat belts by all front seat passengers was assessed at 70 % (in the Netherlands) from which 1/3 was found not to use the belt correctly. Nowadays, seat belt usage has increased and seat belt design has changed since then leading to more effective occupant protection. Nevertheless, the findings of this study shall still be mentioned within this document as misuse of the adult seat belt as well as the CRS are still mayor contributors for severe injuries obtained by children during car crashes. The study consisted of 2 parts. First a field study was performed by the SVOW examining the seat belt use and occurring misuse, secondly a series of sled tests with correctly as well as incorrectly used seat belts was performed to investigate the influence of seat belt (mis-) usage on obtainable injuries. Two types of misuse have been studied: non optimal seat position creating "space" between shoulder and belt as well as incorrect routing of the belt by positioning it for example under the arm-pit or behind the back. It was found, that for the first type of misuse, the ride-down experienced by the occupant was barely affected whereas it seemed to decrease for the second type significantly, thus decoupling the occupant movement from the car movement and increasing the chance of hitting the car interior when the shoulder belt was routed behind the back. Additionally, wrong belt routing was found to be able to result in severe head-to-dashboard impacts and significant reduction of the effectiveness of the belt system.

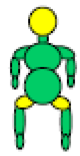
3.3.3 EEVC Working Group 18

EEVC WG 18 “Child Safety” has dealt for some time with the safety of children in cars. One of the group’s first tasks was to review the European accident statistics with respect to child car occupants and injuries in all types of car crashes. From the latest Q-dummy report of this group “Advanced Child dummies and injury criteria for Frontal Impact – Document No 514” published in April 2008, the following general conclusions were drawn:

- An overall positive effect of restraint use by children was observed throughout all databases. Twice as high rates of severe injuries were found for unrestrained children in the most common accident configuration being frontal crashes.
- When correctly restraint, children run very low risk of being severely injured in frontal crashes up to a delta V of 40 km/h.

Please note that this report only focuses on frontal impacts as being the most common impact scenario. Additionally, CRS systems for different age groups according to the UNECE Regulation 44-03 were rated according to the level of protection per body segment. The following findings were reported:

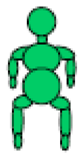
1 Rearward facing infant carrier (ECE-R44 Group 0/0+):



Generally, these CRS were found to provide good protection. Most commonly observed severe injuries were head injuries (60% skull fracture and brain injury, 30% skull fracture only, 10% brain injury without skull fracture). Additionally, a high number of limb injuries was observed, though most times those were less severe and hence considered less important. Three hypothesised injury mechanisms were established for the head:

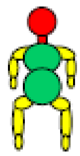
- Impact through the shell with the dashboard
- Direct head impact on supporting objects
- Rebound

2 Rearward facing system with harness (ECE-R44 Group I):



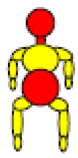
Severe injuries for the head were less frequent, limb (especially arm) injuries were observed. Rearward facing systems were found more effective in frontal impacts compared to forward facing systems.

3 Forward facing system (ECE-R44 Group I):



Head injuries were found most frequently and caused by either direct impact or angular accelerations (brain injuries). The second most frequent injured body part was the limbs. Neck injuries were not frequent, but should be avoided as they are considered to be able to lead to permanent disability or fatality. Chest and abdominal injuries did occur though not frequently

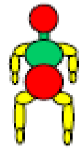
4 Forward facing systems with shield (ECE-R44 Group I) and shield systems (ECE-R44 Group II):



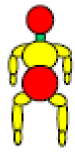
Unfortunately not much information was available on these systems within the databases. But based on observations from experts head contact with the top of the shield, total or partial ejection as well as submarining were considered to be the leading cause for severe injuries.

5 Forward facing seats and adult seatbelt, booster seats (ECE-R44 Group I/II/III):
Children of ECE-R44 Group I run a high risk of obtaining neck injuries.

6 Booster seat and adult seatbelt (ECE-R44 Group II/III):
Head injuries were the most frequent severe injuries found. The relative importance of abdominal injuries was found to increase (injuries of liver, spleen and kidney) compared to the other CRS caused by seatbelt penetration. Chest injuries did occur, but were not very frequent. As injury mechanism no rib fracture but chest compression was recorded. The pelvis was not found a priority body region for frontal impact. Limb fractures were found numerous times.



7 Booster cushion and adult seatbelt (ECE-R44 Group II/III):
The injury causation was in general found to be similar as for booster seats. However, an increased number of chest injuries compared to booster seat was recorded as children using these CRS are generally older and therefore have a less compliant chest



8 Adult seatbelt:
The injury causation was found similar as reported for booster cushions only with worse injury outcome especially in the abdominal region.

For impacts other than frontal impact, a brief compilation of the investigations on the accident databases was provided within the EEVC WG 20 report on Child Safety published in February 2006, as quoted below:

Side impact:
Despite the small sample size, the head still remains the priority, 42 to 62%, even on the non-struck side, and whatever the sample considered (CSFC-96 v. CREST). Chest and abdomen follow (respectively 5-16%, and 19-11%). Finally, in the CSFC-96 sample, upper limb injuries represent 29% of all injuries (all severity).

Rear impact:
The head injuries represent 30% of the total, which is the lowest number compared with other accident configurations, but still remains the most important body area injured. The number of lower limb injuries has increased and tends to be equal to the ones of the head. Injuries to the neck are found for 13%. The sample is not important enough to focus on the severe injures.

Rollover:
Head injuries still remain the highest in number. For the upper limbs, the number is 23%. Neck injuries and abdominal injuries also have to be considered in terms of number and severity.

Non use and Misuse:
The main priority to reduce the number of children killed or severely injured is to get them properly restrained in an appropriate CRS, and to limit misuses. A significant step could be done using education, public information, in combination with law enforcement.

3.3.4 Child Occupant Protection within Euro NCAP

Besides EEVC, also consumer testing is looking at child safety. If you search for child occupant protection on the Euro NCAP website you will find the following statement: "Euro NCAP has carried out a child occupant safety assessment since its very first test to ensure that manufacturers take responsibility for the children travelling in their vehicles. In November 2003, Euro NCAP introduced a child occupant protection rating to provide clearer information for consumers about the results of these tests. As part of this assessment, Euro NCAP uses 18 month old and 3 year old sized dummies in the frontal and side impact tests. As well as studying the results from the impact tests, Euro NCAP verifies the clarity of instructions and seat installation in the vehicle to ensure that the child seat can be fitted safely and securely.”

The dummies used for evaluation are a P1.5, representing the 18 month old child as well as a P3 representing the 3 year old child. The restraints the children are situated in are CRSs that are recommended by the manufacturer of the car and are being installed according to his specifications. However, there are 3 general preconditions a CRS must fulfil for Euro NCAP tests:

1.) It must be recommended by the vehicle manufacturer in all countries of the EU where the vehicle is sold
2.) It must be available for purchase by the public in all countries of the EU where the vehicle is sold
3.) It must be formally approved in UN ECE Regulation 44.03 or later for the vehicle assessed

As these tests provide very controlled conditions without any misuse during restraint installation this test data is considered valuable information. However, it should be noted, that as the manufacturer can choose the CRS to be used within the boundaries stated above, no wide spread of CRS systems can be found. Additionally, the investigated data is of course obtained from crash test dummies and not from actual children. The following data from a couple of recent frontal and side impact Euro NCAP tests was investigated by TNO with consent from Euro NCAP.

In total, data from 51 recently tested cars was reviewed, including several car categories as superminis or mid size family cars. shows the overall star rating including the percentage of achieved points for child safety for some cars tested in 2009 as published on the EuroNCAP website (www.euroncap.com). As the overall rating scheme used by EuroNCAP changed from 2008 to 2009, a direct comparison from the rating provided on the EuroNCAP website cannot be made between 2009 and 2008 tests (and older). However, the raw point score for child safety did not change within the adaption of the general rating. Therefore, it is possible to compare the child occupant protection provided by all cars based on those raw scores.

Make and	model	Overall rating	Adult	Child	Pedestrian	Safety assist
Audi	AUDI Q5	2009 ★★★★★	92%	84%	32%	71%
HONDA	Honda Jazz	2009 ★★★★★	78%	79%	60%	71%
HYUNDAI	Hyundai i20	2009 ★★★★★	88%	83%	64%	86%
KIA	Kia Soul	2009 ★★★★★	87%	86%	39%	86%
PEUGEOT	Peugeot 3008	2009 ★★★★★	86%	81%	31%	97%
SUZUKI	Suzuki Alto	2009 ★★★☆☆	55%	46%	35%	29%

Figure 3-30 Euro NCAP car ratings from several 2009 tests as found on Euro NCAPwebsite

It should be noted, that the child protection score that is considered by Euro NCAP does not only include the dynamic performance of the child dummies (this is maximum 24 raw points out of 49), but also the CRS marking (8 points), CRS to vehicle interface compatibility (4 points) as well as a vehicle based assessment (13 points). So within the new rating a relative score of approximately 49% is theoretically achievable with full score within the dynamic tests and no score in the rest of the assessment. Hence, the overall percentage within the EuroNCAP assessment cannot be directly related to a good or bad performance of the dummy within the tests. However, parameters as CRS marking or CRS to vehicle interface compatibility are important when it comes to avoiding misuse. Therefore a low score within the total rating can indicate potential risk of increased injuries for the child in question within a crash situation.

CRS usage – general:
From the data investigated, it was found, that the P1.5 dummy travelled mostly rearward facing (42 cases) and the P3 dummy forward facing (49 cases). As expected, the variety of the child restraints used is not huge. Only 11 different child seats were used for the P1.5 and only 7 different ones for the P3 coming mainly from 2 manufacturers. One car manufacturer was found that would use self manufactured child seats. All CRSs were approved under UNECE 44.03, available and recommended. For all tests both dummies stayed retained and were neither ejected nor significantly partly ejected during impact. Only one frontal test was found, were the head of the P3 dummy impacted the car interior in frontal impact.

CRS marking and CRS to vehicle interface:
The CRS marking as well as the CRS to vehicle interface score are either granted fully for one CRS (all criteria fulfilled) or not at all (one or more criterion not fulfilled). The CRS marking score awards safety and user instructions on the CRS itself, in the car as well as in the installation manual. With the CRS to vehicle interface score incompatibilities between CRS and belts as well as the car and predictable mislatching that can compromise safety is checked. It was found, that throughout all datasets, all cars scored maximum points on compatibility and only 2 cars lost points on the CRS marking. This indicates, that at least for new cars incompatibility between car and CRS is no longer an issue according to the EuroNCAP protocol, at least if you stick to the child seat recommended by the car manufacturer. With respect to CRS marking, one of the cars lost points as the belt routes were not marked permanent or not colour coded, the other car lost points as instructions on the CRS were missing.

Dynamic performance of the CRS:
The most interesting piece of data to look at for an investigation on possible injury mechanisms is the CRS dynamic performance. Here, an assessment is done based on the following criteria:

- CRS Forward Facing Excursion (forward facing seats, frontal test only)
- Head peak resultant acceleration
- Head Resultant 3 ms exceedence
- Head vertical 3 ms exceedence (referred to as “neck tension”; rearward facing seats, frontal test, P1.5 only)
- Head exposure (rearward facing seats, frontal test only)
- Chest resultant as well as vertical acceleration 3 ms (frontal test only)
- Head side containment (side impact test only)

It should be noted, that points are only awarded for the dynamic assessment if the dummy is not partly or totally ejected by the CRS. In case head contact with any part of the vehicle is found, no points are granted for the head – neck performance.

It is found, that for the P1.5 dummy 12 times and for the P3 dummy 22 times the maximum score of 12 points was obtained. Additionally 24 times (P1.5) and 16 times (P3) the obtained score was higher or equal to 10 points though not maximum (see also Table 3-13). The lowest scores found for the P1.5 and P3 dummy were 6.71 and 4.0, respectively. This indicates that in the majority of cars the protection of the child in his CRS is sufficient for frontal and side impact situations.

Table 3-13 Point distribution of dynamic assessment for investigated cars

Awarded points	P1.5	P3	Sum
12 (max)	12	22	34
≥ 10 < 12	24	16	40
≥ 8 < 10	11	8	19
≥ 6 < 8	4	1	5
≤ 6	0	4	4
Sum	51	51	102

A compilation of where points were lost within the dynamic assessment is provided per dummy in Table 3-14. Please note that one car can be represented within this table multiple times in case for two or more criteria one of the limits was exceeded. The table also indicates, whether points were lost due to exceedence of the upper performance limit (points awarded on a sliding scale) or due to exceedence of the lower performance limit (0 points awarded for sub-category). It can be seen, that only one case was found where points were lost in the side impact. All other cars scored full points for both dummies within this crash scenario. In that one case no points were awarded for the side impact for the P3 at all as the head of the dummy was not contained within the shell of the CRS.

Although in general the P3 was able to score full points in almost twice as many cases compared to the P1.5 (Table 3-13) this does not necessarily mean, that this dummy is in general better protected during impact. For the P1.5 normally a gradual loss of points is found mainly for neck tension based on head vertical acceleration (which is not considered for the P3 score) and / or chest resultant and chest vertical 3ms acceleration. No case is found where exceedence of the lower performance limit occurred. For the P3 dummy the lower performance limit was exceeded in 8 frontal impacts (once for side impact, twice for CRS excursion, once for head 3ms acceleration in the frontal test and five times for either chest resultant or chest vertical acceleration).

Table 3-14 Amount of cases where points for dynamic assessment were lost per criterion and dummy

Points lost with respect to:	P1.5		P3	
	Score > 0 and < max	Score = 0	Score > 0 and < max	Score = 0
Head Peak Resultant Acceleration [g]	1	--	--	--
Head 3msec Exceedence [g]	1	--	1	1
Neck Tension (based on head vertical 3 ms exceedence)	29	--	--	--
CRS forward facing excursion	--	--	--	2
Chest Frontal Resultant Acceleration [3ms]	10	--	23	3
Chest Frontal Vertical Acceleration [3ms]	14	--	5	2

Head Side Containment	--	--	--	1
Head Peak Resultant Acceleration [g] (Side impact)	--	--	--	--
Head 3msec Exceedence [g] (Side impact)	--	--	--	--

From this results it can be concluded, that within new cars assessed by EuroNCAP the head which is found to be one of the most vulnerable body parts within accident databases is well protected in frontal and side impact tests. Only 4% of all dummies lost points within the dynamic assessment due to head accelerations. The most vulnerable part of the P1.5 is found to be the neck (loss of points in approximately 57% of all cases) followed by the chest. For the P3, the chest readings are found to be responsible for the majority of cases where points are lost. This indicates that neck as well as chest should be the body parts were focus should be laid on for children of age 1.5 to 3 years for non-CRS-misuse situations.

3.3.5 Virtual Testing Investigations

Van Rooij et al. (2005) performed a study where child poses in child restraint systems were investigated related to injury potential by means of virtual testing. Focus of this study were children seated in ECE-R44 Group I seats. From a photo study of 10 children in the age group from 1 to 3 years, van Rooij et al. (2005) recorded positions of the children during long as well as short trips and investigated their possible influence on obtainable injuries by means of simulations. One important observation from the photo study was that only few children remained seated in a standard position. In some cases even extreme positions like leaning forward, escaping from the harness or holding feet were observed. Simulations with both, dummy as well as human models in observed relatively common as well as in the extreme positions showed increased risk of injuries. Not only were high lateral neck loads observed in slanted positions, but also large amounts of head excursion were found for correctly restrained children that managed to escape from their harness. This indicates that child models that shall be used for accident reconstruction or for optimization and design of future child restraint systems should not be limited to one distinct position. Models that can not be positioned into different poses will not be able to cover the range of possible hazardous situations a child can put itself into. As children can not be considered to stay situated in their child restraint in a standard initial position and as being “out-of-position” can influence obtainable injuries significantly, models that do not show the possibility for positioning in more than a standard pose can not be considered suitable for accident reconstruction purposes.

3.3.6 Conclusions

From studies presented above the following can be concluded with respect to injury mechanisms:

- Most data is in general available on frontal crashes
- Being situated in a correctly used CRS generally decreases the chance of severe injuries significantly (factor of 7 according to Huijskens et.al (1993)) for children of all age classes
- Misuse of the CRS can significantly increase the risk to sustain severe injuries. The percentage of misuse is still very high and can be considered as one of the main causes of severe injuries.
- Throughout all age classes and restraint systems most severe injures are in general found for the head. With increasing age, abdominal and chest injuries also get more dominant. Limb injuries are found very frequent; however those injuries are normally less severe.

- Frequent injury mechanisms for the head are believed to be related either to direct head contact or to angular accelerations causing brain damage.
- Abdominal injuries are normally found due to too high penetrations of the lap belt
- Chest injuries are in general related to chest compression rather than rib fracture. For older children the frequency for chest injuries increases due to decrease in chest compliance.
- From recent Euro NCAP test data it was found, that within the dynamic assessment hardly any points were lost due to the head, neither in frontal nor in side impact. The main parameters where points were lost on were found to be raised neck tension (P1.5) or raised chest accelerations (both dummies). Almost twice as many P3 dummies were able to score full points within the dynamic assessment (43% compared to 23% for the P1.5). However, no exceedence of the lower performance limit resulting in a 0 sub score was found in any P1.5 readings where such exceedence was found for 8 readings with the P3
- Hardly any severe head injuries were to be expected from the Euro NCAP test results. As head injuries are always stated to be one of the more severe and frequent injuries within literature this might indicate that they are mainly resulting from misuse of the CRS or out of position situations of the child in the child restraint.
- Children are known not to stay in standard positions during a car journey. These “out-of-position” poses can have significant influence on obtainable injuries. Therefore the child models that are to be developed should have the possibility for positioning in different poses to be suitable for accident reconstruction or CRS design and optimization.

3.4 Experimental Biomechanics Data for Children (INRETS-LBMC)

3.4.1 Introduction

If human FE models can be entirely build based on geometrical and material properties, uncertainties on these parameters and the difficulty to simulate the structural response of assembled structures (e.g. organ sliding, etc) still require a validation of the models against relevant physical parameters.

Multiple aspects have to be considered when defining specifications for a numerical model and a dummy. They include the choice of representative geometrical parameters (e.g. size of thorax), positional parameters (e.g. position of shoulder, pelvic angle), mechanical response parameters (e.g. abdominal response to belt loading, overall kinematics), as well as injury assessment reference values (IARV) for relevant injury mechanisms.

While the biomechanical testing data obtained on children is scarce and rarely includes all age ranges, partial data are available in the literature. This data could be of great interest to test the validity of numerical models (and of physical models such as dummies) besides the use of scaled corridors.

Some literature references – with an emphasis on recent papers – are provided hereafter. Corridor data that was used to develop the Q series will not be repeated here. Documents such as the EEVC report Wismans et al. (2008) can be used as a reference if needed. Similarly, the review on pediatric material properties was not included in this report.

3.4.2 Full Body Response: Sled Test Data

Three studies provide Post Mortem Human Subject (PMHS) data in sled configuration (as listed in Brun-Cassan et al, 1993). All three were published prior to 1985. Together, they include tests results on 11 PMHS from 2 to 13 y.o. (Kallieris et al. 1976, Wismans et al., 1979, Dejeammes et al., 1984). While some of the CRS may not be representative of current models, the test results could provide an interesting benchmark for models. The results include the global kinematics, targets trajectories, and some acceleration data. An illustration extracted from Wismans et al. (1979) is provided in Figure 3-31.

Brun-Cassan et al. (1993) compared results from Kallieris et al. (1976) with tests performed with the Crabi 3 and P3 dummies in similar conditions and noted:
“For this series of tests, one observes that the excursion of the cadaver head is greater than the excursion of the head of the dummies […] it is undoubtedly the greater stiffness of the dummies, and in particular the lack of flexibility of their spinal column, which explains this difference.”

A similar analysis was used more recently by Sherwood et al (2003): the authors compared Kallieris data with the response of a 6 y.o. Hybrid III dummy in the same loading setup and reached similar conclusions as Brun-Cassan et al. (1993): “The thoracic spine of the dummy is much stiffer in flexion than the spine of the cadaver.” They concluded that this behaviour may affect the capability of the dummy to predict neck injuries. An illustration is provided in Figure 3-32.

Overall, all comparisons performed between the limited sled data and various dummies suggest that the spines of the dummies were too stiff (Wismans et al., 1979, Brun-Cassan et al., 1993, Sherwood et al., 2003), which could generate incorrect kinematics prediction (head trajectory in particular) or neck load. It is unclear if this could also affect the submarining behaviour.

A similar comparison approach could be used for models.

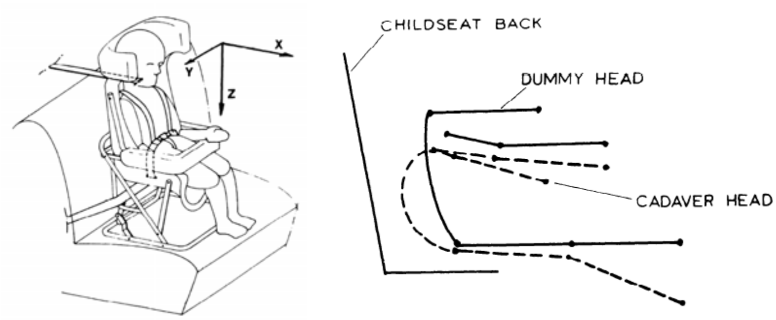


Figure 3-31: Sled test setup and dummy comparison from Wismans et al. (1979). Left: “Overall view of test set-up […]”. Right: “Positions of dummy and cadaver relative to the child seat at 80ms”. Other results from the study include rigid body models with joint properties. The dummy (Part 572 3 y.o.) was found to have a spine that is too stiff.

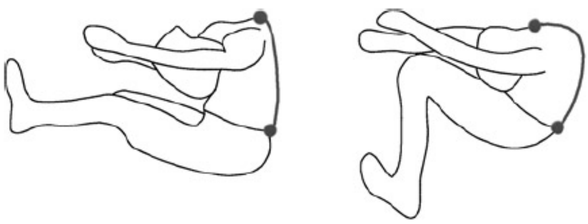


Figure 3-32: From Sherwood et al. (2003) “Schematic of face contact in dummy (left) and cadaver (right) in three-point belt tests. The highlighted spine segment represents the spine from T1 to midlumbar.”

More recently, the team of Children Hospital of Philadelphia started publishing information about non injurious sled tests with volunteers. In their setup, children and adults are subjected to low speed impacts with a pulse peaking at approximately 3g (duration of the order of 100ms). Partial results were published in Balasubramanian et al. (2009) for children age 9 and above. It is likely that supplemental data will be published in the upcoming months. While this data is at much lower intensity, it could provide more detailed results for model validation as it includes numerous targets and 3D motion tracking.

3.4.3 Body Region Response to Loading or Impact

Sources available for the body region response include PMHS data, sub injurious response of live subject, and response obtained in animal studies. For live subjects, the response was obtained by testing volunteers or by observing pre-existing strenuous activities.

PMHS Data

Several studies based on PMHS testing have appeared in the literature in the past few years from either Chinese or US sources They include impacts or dynamic response for the thorax, cervical spine and pelvis (Ouyang et al., 2003, 2005 and 2006, Luck et al., 2008). While limited, this data would be especially pertinent to verify corridor scaling assumptions and to validate modeling assumptions. An example of response for the thorax is provided Figure 3-33.

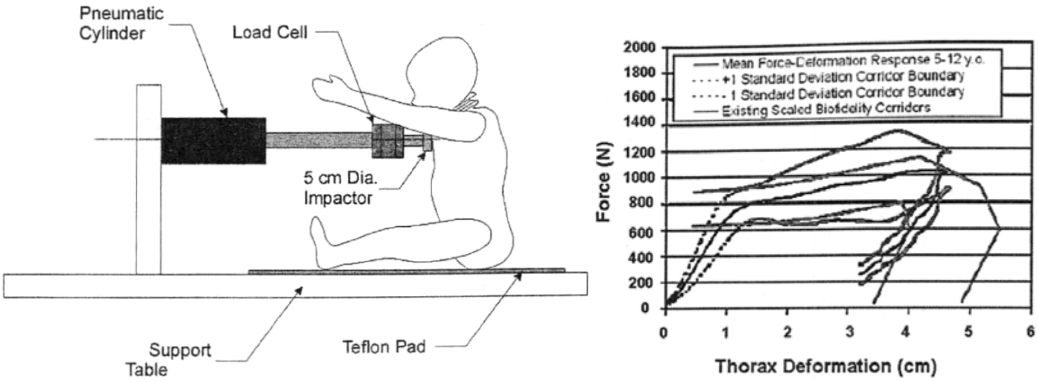


Figure 3-33: From Ouyang et al. (2006). Left: Loading setup. Right: Comparison of between an existing scaled force/deformation corridor and the experimental corridor obtained from 5-12 y.o. tests (impact with 3.5 kg, 75 mm diameter impactor at 6.0 m/s).The study includes 4 subjects between 2 and 4, and 5 subjects between 5 and 12.

Sub Injurious Loading of Live Subjects

Sub injurious loading of live volunteers includes the study of the abdominal response by Chamouard et al. (1996). In the study, 6 children were subjected to quasi static loading of the thighs and the abdomen by a seatbelt (up to 25 daN for the abdomen and 50 daN for the thighs). The results include force deflection response for each loading mode and comparisons with the dummy response. One hypothesis for the study was that the flesh response (and local geometry in this area) may affect the risk of submarining.

More recently, thoracic and abdominal compressions performed during physical therapy were observed in an attempt to characterize the thoracic response across to a wide age range. The principle is to track the hands of the physical therapist in 3D using two video cameras and to measure the reaction force under the patient using an instrumented table (INRETS, Sandoz and al., 2009). An illustration of the setup and force response if provided in Figure 3-34.

Similarly, the team of Children Hospital of Philadelphia has attempted to characterize the thoracic response during resuscitation maneuvers. They have developed two approaches:

- Measurements made using instrumented resuscitation equipment used to apply the thoracic compressions (Maltese et al., 2008);
- the surveying of medical staff practicing these procedures (Arbogast et al., 2009) to rate the thoracic stiffness of dummies.

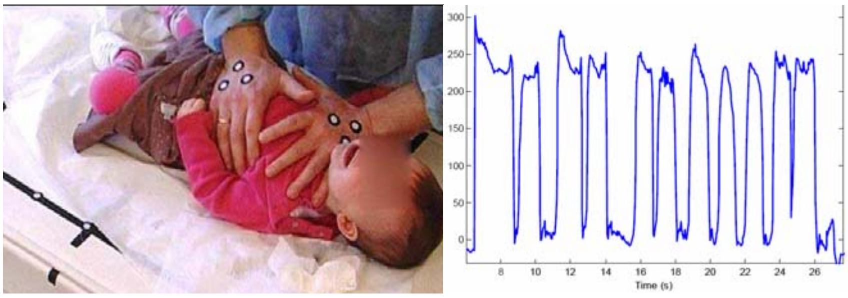


Figure 3-34: Figures illustrating the test setup and typical response for the observation of physical therapy (Sandoz et al., 2009)

<u>Animal Studies</u>

Several studies have used animal models to study specifically a pediatric population. They include a porcine model for the abdomen (Kent et al, 2006, 2008), a goat model for the cervical spine (Pintar et al., 2000, Hilker et al., 2002), a baboon model also for the cervical spine (Nuckley et al., 2006), a sheep model for the lumbar spine (Clarke et al., 2007), etc.

Data can be useful for scaling purpose, for injury criteria selection. In some cases, the animal anatomy and mechanical response may be close enough to the human so that the response curves can be used directly for model validation. This may be the case of the porcine abdomen (at 77 days, 21.4 kg) that was found to be very similar to the abdomen of a 6 y.o. child both in terms of dimensions and quasi-static response (based on Chamouard et al. 1996).

<u>Normal Kinematic / Range of Motion Data</u>

Normal range data can be useful for example to determine joint kinematic prior to failure or to determine the location bony joint stops. A large amount of data is available in the literature, typically for medical application (gait analysis, scoliotic treatment of children, etc).

Data include hip/lumbar/thoracic spine range of motion in various positions (e.g. 5 to 9 y.o. in Haley et al 1986, 11-16 y.o. in Jones et al., 2002, 10.6 y.o. in Kellis et al 2008…).

Some studies were more specifically designed for use in an automotive setting including Arbogast et al. 2007 (normal cervical spine range of motion, 3-12 y.o.) and an ongoing study at UMTRI (Reed et al., 2009). Both are illustrated Figure 3-35.

Figure 3-35: mobility studies. Left: Arbogast et al. (2007) (image from APSN Workshop). Right: UMTRI study (Reed et al. 2009).

3.4.4 Geometrical Data: Dimension, Shape and Posture

Geometrical properties in seated position are especially important regarding the belt path and the submarining risk. Important aspects include the relative positions of the shoulder, neck and the belt, and the relative position of the abdominal belt and pelvis (e.g. Reed et al. 2006, 2008).

The following summary does not aim to be exhaustive – especially considering the basic anthropometric dimension. It will emphasize results from recent studies.

Dimensions and Landmark Positions

Multiple sources of children anthropometry are available including data from the studies of UMTRI in the 1970s (including anthropometry, strength data, inertial properties, etc. available online; Owings et al. 1975, Snyder et al. 1975, Snyder et al., 1977), the CANDAT database (TNO, no clear literature reference found besides a confidential TNO report by Twisk 1994). More recently, Reed et al. (2005) and Serre et al. (2009) proposed updates of children anthropometric dimensions in a seated posture.

Chamouard et al. (1996) provided information about pelvic shape and geometry, and more specifically about the position of the antero superior iliac spines with regard to the flesh of the upper thigh and the belt (see **Figure** 3-36). In fact, it has been proposed that the position of this point is critical for the risk of submarining:

> "*If the belt is placed too high and fails to engage the pelvis, the occupant is likely to submarine, directing belt loads onto the abdominal organs. The optimal position for the lap belt therefore is below or forward of the anterior-superior iliac spines (ASIS) of the pelvis. In both adults and children, the ASIS landmarks lie approximately at the thigh/abdominal junction, so a belt that is below or forward of ASIS landmarks must lie predominantly on the thighs, not on the lower abdomen (Chamouard et al., 1996).*" (Quote from Reed et al, 2008)

Based on their measurements, Chamouard et al. proposed dummy modifications to improve the Q3 dummy response.
Reed et al. (2008) also proposed to use the relative position of the belt and this point to evaluate the performance of CRS (Figure 3-37).

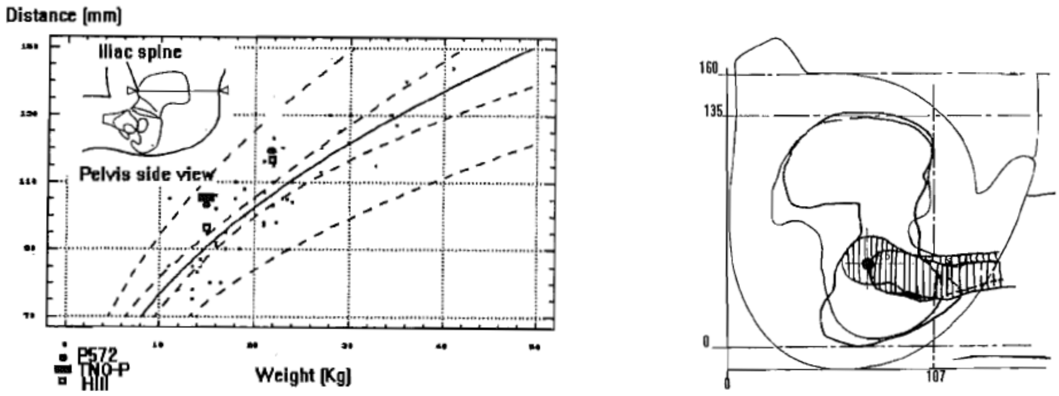


Figure 3-36: illustrations from Chamouard et al. (1996): position of the antero superior iliac spines (left) and example of pelvic geometry vs. P6 dummy (right)

Figure 3-37: Illustrations from Reed et al (2008). Left: The Hybrid III dummy has a gap at the hip making difficult the measurement of the abdominal belt and requiring the use of a flexible “lap form” to prevent the inappropriate belt path. Right: Illustration of pelvic geometry and belt path for the Hybrid III 6 YO.

Shape

While the dimensional data described here above can be used to determine the key dimensional characteristics of dummies and models, it does not necessarily provide shape information that cab be used for belt interaction.

Some shape information has been generated using landmark measurements and interpolation/deformation approaches. An example is the external geometry of a 6 YO in seated position generated for the OCATD study (Reed et al., 2001 and Figure 3-38 left)

Recently, representative (for a given population) anatomical shapes were determined using medical imaging and shape analysis techniques. The work includes characterizations of the pediatric brain geometry using Procrustes Analysis (Danielson et al., 2008) and of the pelvic and thoracic geometry of a 6 YO using Principal Component analysis (Reed et al., 2009). Illustrations are provided Figure 3-38 right. The shape results could be used to verify that the shape of the models and dummies are appropriate.

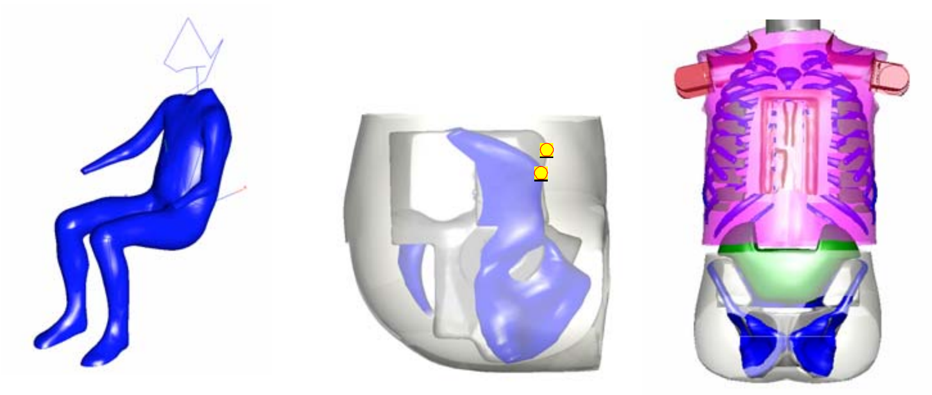


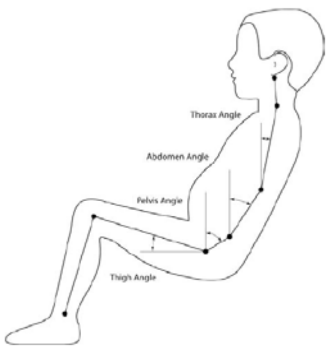
Figure 3-38: UMTRI shapes for the 6 YO. Left: illustration of the shape of a seated 6 YO generated for the OCATD. The shape data is available online in IGES format. Right in blue: shape of the thorax and pelvis of a 6 YO generated by correlation and Principal Component Analysis. The shapes are superimposed on top of the HIII 6 YO dummy.

Postural Data

While there is data regarding the spinal curvature as a function of age in a standing posture (e.g. Cil et al. 2005, Mac-Thiong et al., 2004), limited data is available in the seated posture (including with CRS use).

Chamouard et al. (1996) assumed that the pelvic angles observed by Leung et al (1979) in the adult apply to the children.

Reed et al. (2005) performed external 3D measurements of anatomical landmarks on 62 children selected to represent approximately children between 6 and 10 YO. Measurements were performed in different CRS and without CRS, in a standard posture or a posture selected by the child. The results include angles between various anatomical segments calculated based on the landmarks (illustration Figure 3-39), which could be used for model positioning or dummy verification. They also suggest that postures selected by the children are significantly different from the standard posture – often leading to more tilted pelvis (more “slumped” position).



Means and Standard Deviations of Posture Variables in Conditions 2, 5, 8, and 11

Posture Variable* (degrees)	CRS A		No CRS	
	Sitter-Selected	Standard	Sitter-Selected	Standard
Neck Angle	2.0 (11.1)	3.2 (10.8)	3.5 (11.4)	3.3 (12.5)
Thorax Angle†	5.6 (6.9)	5.8 (6.6)	10.0 (6.8)	9.8 (7.8)
Abdomen Angle††	43.8 (13.4)	39.9 (12.2)	45.0 (12.0)	34.7 (18.2)
Pelvis Angle††	47.2 (13.0)	39.2 (12.4)	47.6 (12.8)	43.5 (11.2)
Thigh Angle†	10.4 (6.0)	11.5 (4.0)	15.8 (6.9)	14.9 (5.8)

* See Figure 11 for variable definitions.
† Values are significantly different across CRS condition (p<0.001)
†† Values are significantly different across posture conditions (p<0.001)

Figure 3-39: illustrations from Reed et al (2005): left: anatomical segments defined in based on the landmarks. Right: results depending on the CRS use and the type of position.

3.5 Summary of Injury Data （TUB）

Based on the input from all partners in Task 2.1, conclusions for body models, separated by age and body segment, were made. It is also important to separate the statements by collision type, certain heavy injuries occur in. Since not enough accident data for each impact type is available, the separation will be made only for frontal and lateral impact.

- [white] **No severe injuries**
- [red] **High risk of injury / high severity**
- [yellow] **No sufficient information available / see remarks**

Frontal impact

	Head	Neck	Chest	Abdomen	Pelvis	Upper Limbs	Lower Limbs
Newborn	[red]	[white]	[white]	[yellow]	[yellow]	[red]	[red]
0,5 YO	[red]	[white]	[white]	[yellow]	[yellow]	[red]	[red]
1 & 1,5 YO	[red]	[red]	[red]	[yellow]	[yellow]	[red]	[red]
3 YO	[red]	[red]	[red]	[red]	[yellow]	[yellow]	[yellow]
6 YO	[red]	[white]	[red]	[red]	[yellow]	[yellow]	[yellow]
10 YO	[red]	[white]	[red]	[red]	[yellow]	[yellow]	[yellow]
Remarks / Injury pattern	Skull and brain injuries, concussion, diffuse axonal injuries and subdural hematomas	Most of the neck injuries are reported for the upper cervical spine (C1 to C4), fracture becomes more important with increasing age. Injury pattern: fraction, dislocation (w.& wo. cord injury) and cord injury.	Flexibility of the thoratic spine has to be considered. 1-3YO organ injuries without rib fracture, 6-10YO organ injuries with rib fracture	Damage of the soft organs (liver, spleen & kidneys) due to penetration of the belt (submarining & oop). No information for 0-1,5YO available	No severy injuries were observed, however detailed pelvis model is essential for realistic lap belt behaviour during frontal crash.	Fractures, especially in rebound. No data for 3-10YO available	Fractures, especially in rebound. No data for 3-10YO available

Side impact

	Head	Neck	Chest	Abdomen	Pelvis	Upper Limbs	Lower Limbs
Newborn	[red]	[yellow]	[yellow]	[white]	[white]	[yellow]	[red]
0,5 YO	[red]	[yellow]	[yellow]	[white]	[white]	[yellow]	[red]
1 & 1,5 YO	[red]	[yellow]	[yellow]	[white]	[white]	[yellow]	[red]
3 YO	[red]	[yellow]	[yellow]	[red]	[yellow]	[red]	[red]
6 YO	[red]	[yellow]	[yellow]	[red]	[yellow]	[red]	[red]
10 YO	[red]	[yellow]	[yellow]	[red]	[yellow]	[red]	[red]
Remarks / Injury pattern		Unclear but seems to be connected with head injuries.	1-3YO organ injuries without rib fracture, 6-10YO organ injuries with rib fracture	Abdominal penetration of of side structure or booster base.	Injuries caused by contacts with penetrating structure, however low injury risk according to the collected data.	Shoulder and arm fractures due to intrusion. No information for 0-1,5YO.	Tibia fractures for 0-1,5YO. Tibia and femur fractures for 3-10YO.

4. SPECIFICATIONS OF CHILD MODELS (UDS AND CHALMERS)

The general specifications were defined to develop child models with the relevant age groups. Within the CASPER project, it is expected to focalize on the models of the head-neck for youngest children (6 weeks, and 6 month, 1 year and 3 years) and on the abdomen and thorax for older children (3 and 6 years). A complete specification of child models with body segments was presented to develop a series of the full body models specified in Table 4-1.

Table 4-1. ***Summary of the models for human body segments and whole body per age and per partner which will be developed in WP2***

	Finite Element Models					MBS (facet) occupant models	Dummy models	DUMMY
Age \ partner	Head	Neck	Thorax	abdomen	Lower L + pelvis	Body	FE	Dummy
1 W	UdS	UdS				TNO (Need geometry)	TUB available	Q0
1 M	UdS	UdS				TNO (Need geometry)		
1 Y	UdS (geometry provided by LMU)	UdS (geometry provided by LMU)	CHA (geometry provided by LMU)	CHA (geometry provided by LMU)	CHA (geometry provided by LMU)		FTSS	Q1
1.5 Y ??	UdS *scale*	UdS *scale*				*TNO available (OK)*	FTSS	Q1.5
3 Y	UdS	*LMS available*	TUB	TUB	CHA (geometry provided by LMU)	*TNO available (OK)*	*FTSS available*	Q3
6 Y	*LMS available*	UdS	INRETS (OK)	INRETS (OK)	INRETS (OK) *Scaling from HUMOS*	*TNO available (OK)*	TUB	Q6
10 or 12 Y ??	UdS *Scale*	UdS *Scale*				*TNO available (10YOC) (OK)*		Q10

Summary of the human segments and whole body models per age and per partner which will be developed in WP2.

Concerning MB (facet) occupant models, 4 models (1.5y, 3y, 6y, 10y) developed in MADYMO are in general available on commercial terms and are included in the standard MADYMO release

According to the results from the literature studies presented in this report, the general specifications for the head and neck models were proposed in the following sections 4.1 and 4.2 in terms of capabilities of injury reconstruction, types of impact, as well as loading conditions at relevant impact speeds.

4.1 Head Models Specifications

Following to this analysis, specifications for head models within CASPER project are:
-Head is the most injured segment involved in car accident. Lots of types of skull failure can occur due to the fact that head child often impact car's structures. A detailed description of child skull, with adequate mechanical properties which take into account rupture, has to be considered.
-Concussions, DAI, and subdural hematomas are principle causes of head injuries so we need detailed models including all anatomical features in order to take into account rotational effect during a crash.

The child head injuries are frequently observed in traffic accidents, which result in skull fractures or brain injuries. The head impact speed and the associated loads are the important physical parameters that caused the either skull or brain damage. It is demonstrated that the head impact speed varies 20 to 60 km/h in different accidents involving children.

The specifications of a child head model should consider the model capability for simulations of child head response in side collisions with proper material properties of and robust model to subject to different loading conditions.

4.2 Neck Models Specifications

In regards to the accident analysis (Figure 2-9, 3-25 and 3-26) and the neck injuries description we can define the model specification.

The higher cervical spine is the mostly involves therefore there is a need of a detailed modelling odontoïde process and axis process as fracture are often observed at this level. In addition the cervical body sustain fractures are often observed at this level. Finally developing neck anatomy implies a detailed facet joint modelling as a function of age.

4.3 Summary of Specifications for Human Body Models

The size of the human body mathematical models was defined in Table 4-2 for each body segments in terms of the anatomical structures for the head, neck, thorax/upper-extremities, and pelvis/lower-extremities.

Table 4-2. Models specifications : ***Summarize of the human segments and whole body models per age and per partner which will be developed in WP2***

Age		Body segment				
		Head	Neck	Thorax + upper L	abdomen	Lower L + pelvis
6W	Institution Name	UdS	UdS			
	Estimation of elements number	*~15 000*	*~15 000*			
6 M	Institution Name	UdS	UdS			
	Estimation of elements number	*~15 000*	*~15 000*			
1 Y	Institution Name	UdS	UdS	CHA	CHA	CHA
	Estimation of elements number	*~15 000*	*~20 000*	*~15 000*	*~15 000*	*~15 000*
3 Y	Institution Name	UdS	*UdS*	TUB	TUB	CHA
	Estimation of elements number	*~15 000*	*~20 000*	*15.000-20.000*	*15.000-20.000*	*15.000-20.000*
6 Y	Institution Name	*UdS*	UdS	INRETS	INRETS	INRETS
	Estimation of elements number	*~15 000*	*~15 000*			*~25 000*
				200 000 - 300 000 (HUMOS ~ 80 000)		

The detailed anatomical and mechanical properties for development of the specified mathematical models will be investigated and defined in the following Task 2.2- Geometrical and mechanical properties.

5. CONCLUSION

In this report the children injury mechanisms for the principals segments and at different ages have been presented. A literature review of injury criteria has been done and a number of limitations have been pointed to be addressed within the CASPER project. Finally this report proposes a child model specification for each age wich must be taken into account in order to reproduce the relevant injury mechanisms.

REFERENCES

Arbogast, K.B., Moll, E.K., Morris, S.D., Winston, F.K. (2001) “Child occupant protection: a summary of current safety recommendations”, Elsevier, Preventive Care Update, Voulme 8, No. 4

Arbogast K.B., Chen I., Durbin D.R. and Winston F.K. (2004) Injury Risks for Children in Child Restraint Systems in Side Impact Crashes, *Proc. Int. Research Council on Biomechanics of Injury*, pp. 25-36.

Arbogast K.B., Ghati Y., Menon R.A., Tylko S., Tamborra N. and Morgan R.M. (2005) Field Investigation of Child Restrains in Side Impact Crashes, *Traffic Injury Prevention*, Vol. 6, pp. 351-360.

Arbogast, K. B., Gholve, P. A., Friedman, J. E., Maltese, M. R., Tomasello, M. F., & Dormans, J. P. (2007). Normal cervical spine range of motion in children 3-12 years old. Spine, 32(10), E309-315. doi: 10.1097/01.brs.0000261542.32649.1f.

Arbogast, K.B., Nishisaki, A., Balasubramanian, S., Nysaether, J., Niles, D., Sutton, R. M., et al. (2009). Expert clinical assessment of thorax stiffness of infants and children during chest compressions. Resuscitation, 80(10), 1187-1191. doi: 10.1016/j.resuscitation.2009.07.005.

Balasubramanian S, Seacrist T, Maltese MR, Arbogast KB, Hopely T, Constans E, Sterner R, Tanji H, Higuchi K. (2009) Head and Spinal Trajectories in Children and Adults Exposed to Low Speed Frontal Acceleration. Paper Number 09-0263. ESV Conference.

Beusenberg, M.C., Happee, R. Twisk, D., Janssen, E.G. “Status of Injury Biomechanics for the Development of Child Dummies”, AAAM/Stapp/IRCOBI Child Occupant Protection Symposium 1993

Brambrink AM, Martin LJ, Hanley DF, et al. Effects of the AMPA receptor antagonist NBQX on outcome of newborn pigs after asphyxic cardiac arrest. J Cereb Blood Flow Metab 1999b;19:927–38.

Brun-Cassan, F., Page, M., Pincemaille, Y., Kallieris, D., and Tarriere, C. (1993). Comparative study of restrained child dummies and cadavers in experimental crashes. SAE Technical Paper 933105. In *Child Occupant Protection (SP-986)*, 243-260. Warrendale, PA: Society of Automotive Engineers, Inc.

Chamouard, F., Tarriere, C., Baudrit, P. (1996). Protection of children on board vehicles: influence of pelvis design and thigh and abdomen stiffness on the submarining risk for dummies installed on a booster. Proceedings of the 15th International Technical Conference on Enhanced Safety of Vehicles. National Highway Traffic Safety Administration, Washington, DC. pp. 1063-1075, SAE Technical Paper, No. 976088. Society of Automotive Engineers, Warrendale, PA.

Ching, R. P., Nuckley, D. J., Hertsted, S. M., Eck, M. P., Mann, F. A., & Sun, E. A. (2001). Tensile mechanics of the developing cervical spine. Stapp Car Crash Journal, 45, 329-336.

Cil A, Yazici M, Uzumcugil A, et al. (2005) The evolution of sagittal segmental alignment of the spine during childhood. Spine 2005;30:93-100.

Clarke, E. C., Appleyard, R. C., & Bilston, L. E. (2007). Immature sheep spines are more flexible than mature spines: an in vitro biomechanical study. *Spine*, *32*(26), 2970-2979. doi: 10.1097/BRS.0b013e31815cde16.

Cramer KE. The pediatric polytrauma patient. Clin Orthop,1995, 125–35.

Danelson, K. A., Geer, C. P., Stitzel, J. D., Slice, D. E., & Takhounts, E. G. (2008). Age and gender based biomechanical shape and size analysis of the pediatric brain. *Stapp Car Crash Journal*, *52*, 59-81.

Dejeammes, M. et al., (1984) Exploration of Biomechanical Data Toward a Better Evaluation of Tolerance for Children Involved in Automotive Accidents, Twenty-Eighth Stapp Car Crash Conference Proceedings, SAE #840530. Oral only ?

Ducrocq SC, Meyer PG, Orliaguet GA, Blanot S, Laurent-Vannier A, Renier D, Carli PA., Epidemiology and early predictive factors of mortality and outcome in children with traumatic severe brain injury: experience of a French pediatric trauma center. Pediatr Crit Care Med. 2006 Sep;7(5):496-7.

EEVC WG18 report – “child safety” – Feb. 2006.

EEVC report - “Q-dummies report – Advanced Child Dummies and Injury Criteria for Frontal Impact” - Working Group 12 and 18 Report, Document No. 514, April 2008.

EuroNCAP home page www.euroncap.com

Haley, S. M., Tada, W. L., & Carmichael, E. M. (1986). Spinal mobility in young children. A normative study. *Physical Therapy*, *66*(11), 1697-1703.

Hilker, C. E., Yoganandan, N., & Pintar, F. A. (2002). Experimental determination of adult and pediatric neck scale factors. Stapp Car Crash Journal, 46, 417-429.

Howard A., Rothman L., McKeag A.M., Pazmino-Canizares J., Monk B., Comeau J.L., Mills D., Blazeski S., Hale I. And German A. (2004) Children in Side-Impact Motor Vehicle Crashes: Seating Positions and Injury Mechanisms, *Journal of Trauma Injury, Infection, and Critical Care*, Vol. 56, No. 6, pp. 1276-1285.

Huijskens, C.G., Janssen, E.G., Verschut, R. “The Influence of Asymmetrical Lower Belt Anchorage Locations on the Crash Performance of Child Restraint Systems”, Ircobi 1993

Huijskens, C.G., Vroman,R. (2003) “Child safety: Who’s move is it?”, ESV conference, paper no. 275

Irwin, A. and Mertz, H. J. Biomechanical basis for the CRABI and hybrid III Child dummies, SAE paper 973317 (1997).

Jager, K., Ratingen, M. van, Lesire, P. et al, “Assessing new child dummies and criteria for child occupant protection in frontal impact”, Paper No. 05-0157, ESV 2005

Jansen, E.G. et al. (1991) “Cervical spine loads induced in restrained child dummies”, Proceedings 35th STAPP Car Crash Conference, San Diego

Janssen, E.G., Huijskens, C.G., Beusenberg, M.C. “Reduction in seat belt effectiveness due to misuse”, Ircobi 1992

Jones, M. A., Stratton, G., Reilly, T., & Unnithan, V. B. (2002). Measurement error associated with spinal mobility measures in children with and without low-back pain. Acta Paediatrica (Oslo, Norway: 1992), 91(12), 1339-1343.

Kallieris D., Barz J., Schmidt G., Heess G., Mattern R. (1976) Comparison between child cadavers and child dummy by using child restraint systems in simulated collisions Paper 760815. Stapp Car Crash Conference, Dearborn, MI.

Kasperk R, Paar O. The polytraumatized child. Pattern of injuries, characteristics of therapeutic management and prognosis. Aktuelle Traumatol 1991;21:1–4.

Keller MS, Vane DW. Management of pediatric blunt splenic injury: comparison of pediatric and adult trauma surgeons. J Pediatr Surg 1995;30:221–4 (discussion 224–225).

Kellis, E., Adamou, G., Tzilios, G., & Emmanouilidou, M. (2008). Reliability of spinal range of motion in healthy boys using a skin-surface device. *Journal of Manipulative and Physiological Therapeutics*, *31*(8), 570-576. doi: 10.1016/j.jmpt.2008.09.001.

Kent, R., Stacey, S., Kindig, M., Forman, J., Woods, W., Rouhana, S. W., et al. (2006). Biomechanical response of the pediatric abdomen, part 1: development of an experimental model and quantification of structural response to dynamic belt loading. Stapp Car Crash Journal, 50, 1-26.

Kent, R., Stacey, S., Kindig, M., Woods, W., Evans, J., Rouhana, S. W., et al. (2008). Biomechanical response of the pediatric abdomen, Part 2: injuries and their correlation with engineering parameters. Stapp Car Crash Journal, 52, 135-166.

Kirk et al. – “Analysis of CHILD data related to frontal impacts” – 4th International conference on protection of children in cars – Dec. 2006

Kokoska E.R.,Keller M.S, Rallo M.C and Weber T.R.” Characteristics of pediatric cervical spine injuries” pp100-105 Journal of pediatric surgery, Vol. 36, N°1, 2001.

Kraus JF, Rock A, Hemyari P. Brain injuries among infants, children, adolescents, and young adults. Am J Dis Child 1990;144:684–91.

Langwieder K., Hell W., Lowne R. and Huijskens C.G. (1996a) Side Impact to Children in Cars–Experience from International Accident Analysis and Safety Tests, *15th Int. Technical Conf. on the Enhanced Safety of Vehicle*, Melbourne, Australia, 1996.

Langwieder K., Hell W. and Willson H. (1996b) Performance of Child Restriant Systems in Real-Life Lateral Collisions, *40th Stapp Car Crash Conference*, Albuquerque, New Mexico, U.S..

Lesire et al. – “Analysis of CREST and CHILD accident data related to side impacts” – 4th International conference on protection of children in cars – Dec. 2006

Lesire et al. – Misuse of CRS in crash situation: danger and possible consequences –AAAM – Melbourne – 2007

Y. C. Leung, C. Tarriere, A. Fayon, and P. Mairesse, A. Delmas, P. Banzet (1979) Comparison Between Part 572 Dummy and Human Subject in the Problem of Submarining. Stapp Car Crash Conference. Paper 791026

Luck, J. F., Nightingale, R. W., Loyd, A. M., Prange, M. T., Dibb, A. T., Song, Y., et al. (2008). Tensile mechanical properties of the perinatal and pediatric PMHS osteoligamentous cervical spine. Stapp Car Crash Journal, 52, 107-134.

Mac-Thiong JM, Berthonnaud E, Dimar JR, et al. (2004) Sagittal alignment of the spine and pelvis during growth. Spine 2004; 29:1642-7.

Maier-Hauff K, Gatzounis G, Borschel M. Pediatric craniocerebral trauma. Special characteristics, therapy and prognosis. Unfallchirurg 1993;96:604–8

Maltese M.R., Chen I.G. and Arbogast K.B. (2005) The Effect of Rear Row Seating Position on the Risk of Injury to Belted Children in Side Impacts in Passenger Car, *19th Int. Technical Conf. on the Enhanced Safety of Vehicle*, Washington D.C:, U.S..

Maltese M.R., Locey C.M., Jermakian J.S., Nance M.L. and Arbogast K.B. (2007) Injury Causation Scenarios in Belt-Restrained Nearside Child Occupants, *Stapp Car Journal*, Vol. 51, pp. 299-311.

Maltese, M. R., Castner, T., Niles, D., Nishisaki, A., Balasubramanian, S., Nysaether, J., et al. (2008). Methods for determining pediatric thoracic force-deflection characteristics from cardiopulmonary resuscitation. Stapp Car Crash Journal, 52, 83-105.

Martin B.W., Dykes E. andLecky F.E. “Patterns and risks in spinal trauma” BMJ Publishing Group Ltd & Royal College of Paediatrics and Child Health 2004.

Maureen S. Durkin, Danielle Laraque, Ilona Lubman and Barbara Barlow, Epidemiology and Prevention of Traffic Injuries to Urban Children and Adolescents, *Pediatrics* 1999; Vol 103; Num 6, DOI: 10.1542/peds.103.6.e74

McCray L., Scarboro M. and Brewer J. (2007) Injury to Children One to Three Years Old in Side Impact Crashes, *20th Int. Technical Conf. on the Enhanced Safety of Vehicle*, Lyon, France.

Mertz et al. – “Biomechanical and scaling bases for frontal and side impact injury assessment reference values” – 47th Stapp Car Crash Conference, 2003-22-0009, October, 2003

NHTSA (2008) 2007 Children Traffic Safety Fact Sheet, National Highway Traffic Safety Administration, U.S. Department of Transportation.

Nuckley, D. J., & Ching, R. P. (2006). Developmental biomechanics of the cervical spine: Tension and compression. Journal of Biomechanics, 39(16), 3045-3054. doi: 10.1016/j.jbiomech.2005.10.014.

O’Neil, J. Daniels, D.M., Talty, J.L., Bull, M.J. (2009) “Seat belt misuse among children transported in belt-pretensioning booster seats”, Elsevier, Accident Analysis and Prevention 41(2009) 425-429

Orzechowski K.M., Edgerton E.A., Bulas D.I., Mclaughlin P.M. and Eichelberger M.R. (2003) Patterns of Injury to Restrained Children in Side Impact Motor Vehicle Crashes: the Side Impact Syndrome, *Journal of Trauma* *Injury, Infection, and Critical Care*, Vol. 54, No. 6, pp. 1094-1101.

Otte D. (1999) Severity and Mechanism of Head Impacts in Car to Pedestrian Accidents, Proceedings of International IRCOBI Conference on Biomechanics Impacts, Barcelona, Spain, pp.329-341.
Scullion P., Morgan R.M., Nagabhushana V., Digges K., Kan C.D., Park S. and Bae H. (2008) Side Impact Risk for 7-13 Year Old Children, *SAE 2008 World Congress*, Detroit, U.S..

Ouyang, J., Zhao, W., Xu, Y., Chen, W., & Zhong, S. (2006). Thoracic impact testing of pediatric cadaveric subjects. The Journal of Trauma, 61(6), 1492-1500. doi: 10.1097/01.ta.0000233711.07823.40.

Ouyang, J., Zhu, Q., Zhao, W., Xu, Y., Chen, W., & Zhong, S. (2003). Experimental cadaveric study of lateral impact of the pelvis in children. Di 1 Jun Yi Da Xue Xue Bao = Academic Journal of the First Medical College of PLA, 23(5), 397-401, 408.

Ouyang, J., Zhu, Q., Zhao, W., Xu, Y., Chen, W., & Zhong, S. (2005). Biomechanical assessment of the pediatric cervical spine under bending and tensile loading. Spine, 30(24), E716-723.

Owings C.L., Chaffin, D.B., Snyder R.G., Norcutt, R.H., (1975): Strength Characteristics of U.S. Children for Product Safety Design. UMTRI Report. Available online at http://mreed.umtri.umich.edu/mreed/downloads.html (Accessed october 2009)

Palisson A., Cassan F., Trosseille X., Lesire P. and Alonzo F. "Estimating Q3 dummy injury criteria for frontal impact using the child project results and scaling reference values". IRCOBI conference pp 263-276. Maastricht 2007.

Pintar, F. A., Mayer, R. G., Yoganandan, N., & Sun, E. (2000). Child neck strength characteristics using an animal model. Stapp Car Crash Journal, 44, 77-83.

Ratingen, M.R. van, Twisk, D., Schrooten, M., Beusenberg, M. (1997) "Biomechanically Based Design and Performance Tagets for a 3-year old Child Crash Dummy for Frontal and Side Impact", Society of Automotive Engineers, Inc. 973316

Reed, M.P., Lehto, M.M., Schneider, L.W., Moss, S., Nghi, T. (2001). Development of anthropometric specifications for the six-year-old OCATD. Technical Paper '2001-01 -1057. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P., Ebert-Hamilton, S.M., Manary, M.A., Klinich, K.D., and Schneider, L.W. (2005). A new database of child anthropometry and seated posture for automotive safety applications. SAE Transactions: Journal of Passenger Cars - Mechanical Systems, 114: 2222-2235.

Reed, M.P., Ebert-Hamilton, S.M., Manary, M.A., Klinich, K.D., and Schneider, L.W. (2006). Improved positioning procedures for 6YO and 10YO ATDs based on child occupant postures. Stapp Car Crash Journal, 50: 337-388.

Reed M.P., Ebert-Hamilton S.M., Sherwood C.P., Klinich K.D., Manary M.A. (2008) Evaluation of the Static Belt Fit Provided by Belt-Positioning Booster Seats. September 2008. IIHS report

Reed M.P., Klinich K.D., Ebert-Hamilton S.M., Manary M.A., Rupp J.D. (2009) Improving Restraints for Older Children: Static and Dynamic Belt Fit Evaluation. SAE Government-Industry 2009. http://www.sae.org/events/gim/presentations/2009/

Rooij, L. van, Harkema, C. Lange, R. de "Child poses in child restraint systems related to injury potential investigations by virtual testing", Paper No. 05-0373, ESV 2005

Schoon, C.C, Huijskens, C.G, Heykamp, A.H. (1992) "Misuse of restraint systems for children in the Netherlands", Proceedings 1992 International IRCOBI Conference on Biomechanics of Impact, Verona

Scullion P., Nix L., Morgan R.M., Nagabhushana V., Digges K.H., Kan C.D., and Lamb T.M. (2009) Injury Mechanism of the Head and Face of Children in Side Impacts, *SAE 2009 World Congress*, Detroit, U.S..

Serre T., Thouvenin S., Brunet C., Lalys L., Bartoli C., Leonetti G. (2009) Comparison between new data on children anthropometry and CRS dimensions. Paper 09-0484. ESV Conference

Sherwood, C. P., Shaw, C. G., Van Rooij, L., Kent, R. W., Crandall, J. R., Orzechowski, K. M., et al. (2003). Prediction of cervical spine injury risk for the 6-year-old child in frontal crashes. *Traffic Injury Prevention*, *4*(3), 206-213. doi: 10.1080/15389580309885.

Snyder, R .G., Spencer, M.L. , Owings C.L., Schneider L.W., (1975): Physical Characteristics of Children as Related to Death and Injury for Consumer Product Safety Design. UMTRI Report UM-HSRI-BI-75-5. Available online at http://mreed.umtri.umich.edu/mreed/downloads.html (Accessed october 2009)

Snyder R.G., Schneider L.W., Owings C.L., Reynolds H.M., Golomb, H. D., Schork A. M. (1977) Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design. UMTRI Report UM-HSRI-77-17. . Available online at http://mreed.umtri.umich.edu/mreed/downloads.html (Accessed october 2009)

TNO (2004) MADYMO Reference Manual, Version 6.2.1, Road-Vehicle Research Institute, Delft, the Netherlands.

Trosseille X, Chamouard F, Tarrière C (1997) Abdominal Injury Risk To Children And Its Prevention. Proceedings of the IRCOBI conference. Hannover, September 1997. p 153-163

Twisk, D. (1994) Anthropometric Data Of Children For The Development Of Dummies. TN0 report 75061275-B (Confidential).

Twisk, D., van Don, B.J.C., Phillipens, M.M.G.M "Frontal Biofidelity and Injury Protection Reference Values for the Q-Series Dummy", Paper No. 323

Vesentini, L., Willems, B. (2007) "Premature graduation of children in child restraint systems: An observational study", Elsevier, Accident Analysis and Prevention 39 (2007) 867-872

Wismans, Maltha, Melvin and Stalnaker (1979) Child Restraint Evaluation by Experimental and MathematicalSimulation, Twenty-third Stapp Car Crash Conference Proceedings, SAE #791017, 1979.

Wismans J; Waagmeester K, Le Claire M., Hynd D, de Jager K, Palisson A, van Ratingen M, Trosseille X (2008) Q-dummies Report Advanced Child Dummies and Injury Criteria for Frontal Impact, Working Group 12 and 18 Report. Document No. 514, EEVC. April 2008

Yang J.K. (2005) Review of injury biomechanics in car-pedestrian collisions, Int. J. Vehicle Safety, Vol. 1, Nos. 1/2/3, pp.100-117.

Yao J.F., Yang J.K. and Otte D. (2007) Head Injuries in Child Pedestrian Accidents–In-Depth Case Analysis and Reconstructions, *Traffic Injury Prevention*, Vol. 8, No. 1, pp. 94-100.

ANNEX 1 – ECE R44 - MASS CLASSIFICATION

GROUP	Lower limit (kg)	Upper limit (kg)
0	/	10
0+	/	13
I	9	18
II	15	25
III	22	36

ANNEX 2 - SYNTHESIS TABLES PER DUMMY SIZE

Q0 – (group 0 /0+)

Age : 3 weeks
(3.460 kg)

FRONTAL IMPACT

Rear Infant Carrier	G0 /G0+	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- brain injuries - Skull fractures - Combination	Neck (fragility – misuse)	/	/	fractures	fractures
	Injury mechanism	- impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
	Meas tfor Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	NONE	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck and possibly data for head (improvement of existing criteria)**
Models should replicate all injury mechanisms

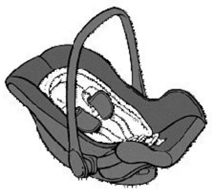
Carritot	G0	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	Few data: Brain injuries	Neck (fragility)	/	/	/	/
	Injury mechanism	Head impact	Head/torso relative movement	/	/	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	NONE	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	NONE	NONE

***Dummy injury criteria works*: neck and possibly data for head (improvement of existing criteria)**
Models should replicate all injury mechanisms

Q0 – (group 0 /0+)

Age : 3 weeks
(3.460 kg)

SIDE IMPACT



Rear Infant Carrier	G0 /G0+	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibly lung contusion	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	TENDENCIES	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	NOT PRIORITY	NONE	NONE

Dummy injury criteria works: head and neck
Models should replicate all injury mechanisms

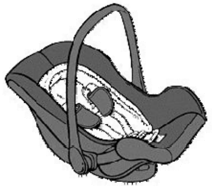
Carritot	G0	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	NO DATA	NO DATA	NO DATA	NO DATA
	Injury mechanism	Impact / door panel through CRS	Head/torso relative movement	/	/	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	TENDENCIES	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	NONE	NONE	NONE	NONE

Dummy injury criteria works: head and neck
Models should replicate all injury mechanisms

Q0 – (group 0 /0+)

Age : 3 weeks
(3.460 kg)

REAR IMPACT



Rear Infant Carrier	G0 /G0+	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	FEW DATA but neck injuries reported	/	/	Some injuries	Injuries commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

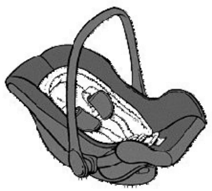
Carritot	G0	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	No data but similar to frontal impact	Neck (fragility)	/	/	/	/
	Injury mechanism	Head impact	Head/torso relative movement	/	/	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q1 – 12 months (group 0+ / I)

(9.6 kg)
(74 cm)

FRONTAL IMPACT



Rear Infant Carrier	G0+	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- brain injuries - Skull fractures - Combination	Neck (fragility – misuse)	/	/	fractures	fractures
	Injury mechanism	- Head impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck and data for head for improvement of existing criteria**
Models should replicate all injury mechanisms

Rearward fac. harness	G0+ or G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- brain injuries - Skull fractures - Combination	Neck (fragility – misuse)	/	/	fractures	fractures
	Injury mechanism	- Head impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck and data for head for improvement of existing criteria**
Models should replicate all injury mechanisms

Q1 – 12 months (group 0+ / I) **FRONTAL IMPACT**

Forward fac. harness	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - brain injuries - Combination	Neck (fragility)	Possibly lung contusion	Rarely, possibility of internal injuries	fractures	fractures
	Injury mechanism	- Head impact - deceleration	Head/torso relative movement	Chest compression by harness	Abdominal compression by harness buckle (shoulders escaping from harness straps)	Not well defined (impacts?)	Not well defined (impacts?)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck, chest. Possibly data for head (improvement of existing criteria) and abdominal area (rarely injured) . Models should replicate all injury mechanisms**

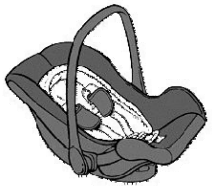
Booster seats	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	Neck (fragility)	Possibly lung contusion	Internal injuries	fractures	fractures
	Injury mechanism	Head impacts	Head/torso relative movement - Seatbelt loading in neck area	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Not well defined (impacts?)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck, chest & abdominal area. Possibly data for head (improvement of existing criteria). Models should replicate all injury mechanisms**

Q1 – 12 months (group 0+ / I)

(9.6 kg)
(74 cm)

SIDE IMPACT

Rear Infant Carrier	G0+	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibility of lung contusion	Rare but possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	NOT PRIORITY	NONE	NONE

***Dummy injury criteria works*: head, neck, & chest. Possibly data for abdominal area (rarely injured).**
Models should replicate all injury mechanisms

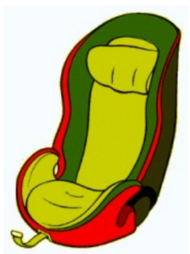
Rearward fac. harness	G0+ or G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibility of lung contusion	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	NOT PRIORITY	NONE	NONE

***Dummy injury criteria works*: head, neck, & chest. Possibly data for abdominal area (rarely injured).**
Models should replicate all injury mechanisms

Q1 – 12 months (group 0+ / I) **SIDE IMPACT**

Forward fac. harness	**G1**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibility of lung contusion	Possibility of internal injuries	No data	Tibia / femur fractures
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NONE	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

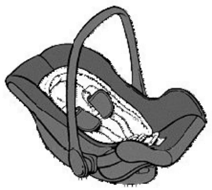
Booster seats	**G1**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibility of lung contusion	Possibility of internal injuries	No data	Tibia / femur fractures
	Injury mechanism	- impact through side wings - Direct impact	- Head/torso relative movement - Seatbelt loading in neck area	Impact on door panel	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	/	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NONE	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q1 – 12 months (group 0+ / I)

(9.6 kg)
(74 cm)

REAR IMPACT

Rear Infant Carrier	G0+	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	/	/	Some injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Rearward fac. harness	G0+ or G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	NO DATA = same as RIC?	NO DATA = same as RIC?	NO DATA = same as FWD in frontal?	/	Some injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Head impact	Chest compression by harness	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q1 – 12 months (group 0+ / I) **REAR IMPACT**

Forward fac. harness

G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Booster seats

G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q1 ½ – 18 months (Group 0+ / I)

(11.1 kg)
(80 cm)

FRONTAL IMPACT

Rear Infant Carrier	G0+ (few children of that age)	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- brain injuries - Skull fractures - Combination	Neck (fragility – misuse)	/	/	fractures	fractures
	Injury mechanism	- Head impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck and data for head for improvement of existing criteria**
Models should replicate all injury mechanisms

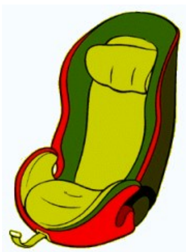
Rearward fac. harness	G0+ or G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- brain injuries - Skull fractures - Combination	Neck (fragility – misuse)	/	/	fractures	fractures
	Injury mechanism	- Head impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck and data for head for improvement of existing criteria**
Models should replicate all injury mechanisms

Q1 ½ – 18 months (group 0+ / I) FRONTAL IMPACT

Forward fac. harness	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - brain injuries - Combination	Neck (fragility)	Possibly lung contusion	Rarely, possibility of internal injuries	fractures	fractures
	Injury mechanism	- Head impact - deceleration	Head/torso relative movement	Chest compression by harness	Abdominal compression by harness buckle (shoulders escaping from harness straps)	Not well defined (impacts?)	Not well defined (impacts?)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Forces ? pressure ?	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck, chest. Possibly data for head (improvement of existing criteria) and abdominal area (rarely injured) . Models should replicate all injury mechanisms**



Booster seats	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	Neck (fragility)	Possibly lung contusion	Internal injuries	fractures	fractures
	Injury mechanism	Head impacts	- Head/torso relative movement - Seatbelt loading in neck area	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Not well defined (impacts?)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Forces ? – pressure ?	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck, chest & abdominal area. Possibly data for head (improvement of existing criteria). Models should replicate all injury mechanisms**

Q1 ½ – 18 months (Group 0+ / I)

(11.1 kg)
(80 cm)

SIDE IMPACT

Rear Infant Carrier	G0+ (few children of that age)	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibly lung contusion	Rare but possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure ?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	NONE	NONE

***Dummy injury criteria works*: head, neck, & chest. Possibly data for abdominal area (rarely injured).**
Models should replicate all injury mechanisms

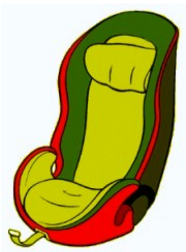
Rearward fac. harness	G0+ or G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibly lung contusion	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure ?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	NONE	NONE

***Dummy injury criteria works*: head, neck, & chest. Possibly data for abdominal area (rarely injured).**
Models should replicate all injury mechanisms

Q1 ½ – 18 months (group 0+ / I) **SIDE IMPACT**

Forward fac. harness	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibly lung contusion	Possibility of internal injuries	No data	Tibia / femur fractures
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure ?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NONE	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

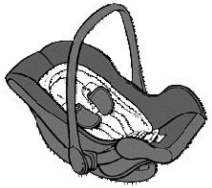
Booster seats	G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Neck (fragility)	Possibly lung contusion	Possibility of internal injuries	No data	Tibia / femur fractures
	Injury mechanism	- impact through side wings - Direct impact	- Head/torso relative movement - Seatbelt loading in neck area	Impact on door panel,	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	/	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure ?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NONE	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q1 ½ – 18 months (Group 0+ / I)

(11.1 kg)
(80 cm)

REAR IMPACT



Rear Infant Carrier	G0+ (few children of that age)	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	/	/	Some injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Rearward fac. harness	G0+ or G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	NO DATA = same as RIC?	NO DATA = same as RIC?	NO DATA = same as FWD in frontal?	/	Some injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Head impact	Chest compression by harness	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q1 ½ – 18 months (group 0+ / I) **REAR IMPACT**

Forward fac. harness	**G1**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Booster seats	**G1**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	NONE	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q3 – 36 months (Group I / II)

(14.6 kg)
(98,5 cm)

FRONTAL IMPACT

Rearward fac. harness: G1	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
Field data	- brain injuries - Skull fractures - Combination	Neck (in case of misuse)	/	/	fractures	fractures
Injury mechanism	- Head impact through shield - Direct impact	Head/torso relative movement	/	/	Loading during rebound phase	Loading during rebound phase
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
Further work necessary	NOT PRIORITY	YES (MORE DATA)	NONE	NONE	To be investigated	To be investigated

***Dummy injury criteria works*: neck and data for head for improvement of existing criteria**
Models should replicate all injury mechanisms

Forward fac. harness: G1 / G2	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
Field data	- Skull fractures - brain injuries - Combination	Rarely but possibly injured	Possibility of internal injuries	Rarely, possibility of internal injuries	fractures	fractures
Injury mechanism	- Head impact - deceleration	Head/torso relative movement	Chest compression by harness	Abdominal compression by harness buckle	Not well defined (impacts?)	Loading on front seatback
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: neck, chest. Possibly data for head (improvement of existing criteria) and abdominal area (rarely injured) . Models should replicate all injury mechanisms**

Q 3 – 3 years (group I/II) **FRONTAL IMPACT**

Booster seats	G1 / G2	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	Rarely injured	Few injuries (internal organs – no fracture)	Internal injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	- Seatbelt loading in neck area	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Loading on front seatback
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED
	***Dummy injury criteria works*: neck, chest & abdominal area. Possibly data for head (improvement of existing criteria).** **Models should replicate all injury mechanisms**						
Booster cushions	G2	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	Rarely injured	Few injuries (internal organs – no fracture)	Liver, spleen and kidney injuries	Numerous fractures	Front seat structure
	Injury mechanism	Head impacts	- Seatbelt loading in neck area	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Loading on front seatback
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED
	***Dummy injury criteria works*: neck, chest & abdominal area. Possibly data for head (improvement of existing criteria).** **Models should replicate all injury mechanisms**						

Q3 – 36 months (Group I / II)

(14.6 kg)
(98,5 cm)

SIDE IMPACT

Rearward fac. harness	G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	Possibly lung contusion	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure ?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NOT PRIORITY	NONE	NONE

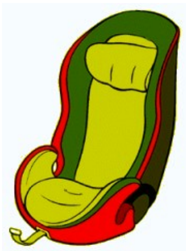
***Dummy injury criteria works*: head, neck, & chest. Possibly data for abdominal area (rarely injured).**
Models should replicate all injury mechanisms

Forward fac. harness	G1 / G2	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	Possibility of internal injuries	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Head/torso relative movement	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure?	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	NONE	NONE

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q 3 – 3 years (group I/II) **SIDE IMPACT**

Booster seats



G1 / G2	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	internal injuries	internal injuries	Fractures	Tibia / femur fractures
Injury mechanism	- impact through side wings - Direct impact	- Head/torso relative movement - Seatbelt loading in neck area	Impact on door panel,	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	Impact	Not well defined
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure?	NONE	NONE
Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Booster cushions

G2	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	internal injuries	internal injuries	Fractures	Tibia / femur fractures
Injury mechanism	- Direct impact	- Head/torso relative movement - Seatbelt loading in neck area	Impact on door panel,	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	Impact	Not well defined
Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	Pressure?	NONE	NONE
Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q3 – 36 months (Group I / II)

(14.6 kg)
(98,5 cm)

REAR IMPACT

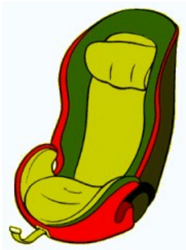
Rearward fac. harness	G1	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	NO DATA = same as RIC?	NO DATA	NO DATA = as FWD in frontal?	/	Some injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	/	Chest compression by harness	/	Not well defined (few data)	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Forward fac. harness	G1 / G2	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q 3 – 3 years (group I/II) **REAR IMPACT**

Booster seats	G1 / G2	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	- kinematics -head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Booster cushions	G2	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- Direct impact with rigid part	- kinematics -head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

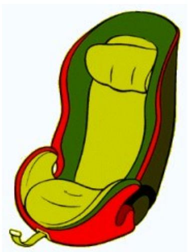
Q6 – 6 years (Group II / III)

(22.9 kg)
(114 cm)

FRONTAL IMPACT

Forward fac. harness	G2 (few children of that age)	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - brain injuries - Combination	Rarely but possibly injured	Possibility of internal injuries	Rarely, possibility of internal injuries	fractures	fractures
	Injury mechanism	- Head impact - deceleration	Head/torso relative movement	Chest compression by harness	Abdominal compression by harness buckle	Not well defined (impacts?)	Loading on front seatback
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	NOT PRIORITY	NOT PRIORITY	NOT PRIORITY	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: few children of that age in such CRS : possibly data for head, neck, chest and abdominal area. Models should replicate all injury mechanisms**



Booster seats	G2 / G3	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	No injury reported	Few injuries (internal organs – no fracture)	Internal injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	/	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Front seat structure
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: chest & abdominal area. Possibly data for head (improvement of existing criteria) and neck (rarely injured at that age). Models should replicate all injury mechanisms**

Q 6 – 6 years (group II/III) **FRONTAL IMPACT**

Booster cushions	**G2 / G3**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	Fractures and brain injuries	No injury reported	Few injuries (internal organs – no fracture)	Liver, spleen and kidney injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	/	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Front seat structure
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: chest & abdominal area. Possibly data for head (improvement of existing criteria) and neck (rarely injured at that age).**
Models should replicate all injury mechanisms

Adult seatbelt	**No group**	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	Fractures and brain injuries	No injury reported	- rare internal organs injuries – few fractures	Liver, spleen and kidney injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	/	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Front seat structure
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	TENDENCIES	EXISTING	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	NOT PRIORITY	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: chest & abdominal area. Possibly data for head (improvement of existing criteria) and neck (rarely injured at that age).**
Models should replicate all injury mechanisms

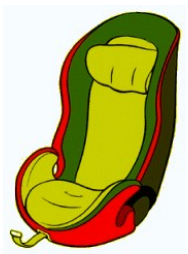
Q6 – 6 years (Group II / III)

(22.9 kg)
(114 cm)

SIDE IMPACT

Forward fac. harness	G2 (few children of that age)	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	Possibility of internal injuries	Possibility of internal injuries	No data	No data
	Injury mechanism	- impact through side wings - Direct impact	Linked with head impact	Chest compression in the shell	Compression of the abdomen in the shell	/	/
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NOT PRIORITY	NOT PRIORITY	NOT PRIORITY	NOT PRIORITY	NONE	NONE

***Dummy injury criteria works*: few children of that age in such CRS : possibly data for head, neck, chest and abdominal area. Models should replicate all injury mechanisms**



Booster seats	G2 / G3	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	internal injuries	internal injuries	Fractures	Mainly femur fractures
	Injury mechanism	- impact through side wings - Direct impact	Linked with head impact	Impact on door panel,	- Compression of the abdomen (door panel / booster horns) - seatbelt penetration	Impact	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q 6 – 6 years (group II/III) SIDE IMPACT

Booster cushions	G2 / G3	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	internal injuries	internal injuries	Fractures	Mainly femur fractures
	Injury mechanism	- Direct impact	Linked with head impact	Impact on door panel,	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	Impact	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Adult seatbelt	No group	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	- Skull fractures - Combined with brain injuries	Very few injuries	- Rib fractures - Internal injuries	internal injuries	Fractures	mainly femur fractures
	Injury mechanism	- Direct impact	Linked with head impact	Impact on door panel, interaction with other occupants	- Compression of the abdomen by door panel - seatbelt penetration	Impact	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	EXISTING	NONE	NONE	NONE	NONE	NONE
	Further work necessary	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	YES (MORE DATA)	TO BE INVESTIGATED	TO BE INVESTIGATED

***Dummy injury criteria works*: head, neck, chest & abdominal area.**
Models should replicate all injury mechanisms

Q6 – 6 years (Group II / III)

(22.9 kg)
(114 cm)

REAR IMPACT

Forward fac. harness	G2	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	FEW DATA but injuries reported	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Due to head impact	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Booster seats	G2 / G3	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	Few injuries	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- impact on seatback - Direct impact with rigid part (intrusion)	Excessive extension	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q 6 – 6 years (group II/III) REAR IMPACT

Booster cushions	G2 / G3	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	Few injuries	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- Direct impact with rigid part	Excessive extension	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Force and moments	/	/	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Adult seatbelt	No group	HEAD	NECK	CHEST	ABDO - & LUMBAR	UP. LIMBS	LOW. LIMBS & PELVIS
	Field data	FEW DATA but HEAD injuries	Few injuries	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- Direct impact with rigid part	Excessive extension	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces - pressure	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	NONE	NONE	NONE	NONE	NONE	NONE

No *dummy injury criteria* work to be done.
Models should replicate all injury mechanisms.

Q10 – 10 years (Group III)

(35.5 kg - *target*)
(144 cm - *target*)

FRONTAL IMPACT

Booster seats and Booster cushions	G3	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	No injury reported	- internal organs – fractures	Liver, spleen and kidney injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	/	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Front seat structure
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development

Adult seatbelt	No group	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	Fractures and brain injuries	No injury reported	- internal organs – fractures	Liver, spleen and kidney injuries	Numerous fractures	Numerous fractures
	Injury mechanism	Head impacts	/	Chest compression by seatbelt loading	Penetration of seatbelt	Not well defined (impacts?)	Front seat structure
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development

Q10 – 10 years (Group III)

(35.5 kg - *target*)
(144 cm - *target*)

SIDE IMPACT

Booster seats and Booster cushions	G3	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Rarely but possibly injured	- rib fractures, - internal injuries	internal injuries	Fractures	Mainly femur fractures
	Injury mechanism	- Direct impact	Linked with head impact	Impact on door panel,	- Compression of the abdomen by door panel or booster horns, - seatbelt penetration	Impact	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development

Adult seatbelt	No group	*HEAD*	*NECK*	*CHEST*	*ABDO - & LUMBAR*	*UP. LIMBS*	*LOW. LIMBS & PELVIS*
	Field data	- Skull fractures - Combined with brain injuries	Very few injuries	- Rib fractures - Internal injuries	internal injuries	Fractures	mainly femur fractures
	Injury mechanism	- Direct impact	Linked with head impact	Impact on door panel, interaction with other occupants	- Compression of the abdomen by door panel - seatbelt penetration	Impact	Not well defined
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development	Dummy + model development

Q10 – 10 years (Group III)

(35.5 kg - *target*)
(144 cm - *target*)

REAR IMPACT

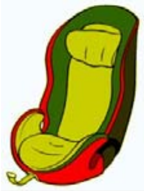
Booster seats and Booster cushions	G3	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	FEW DATA but HEAD injuries	Few injuries	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- Direct impact with rigid part	Excessive extension	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Model development	Model development	Model development	Model development	Model development	Model development

Adult seatbelt	No group	***HEAD***	***NECK***	***CHEST***	***ABDO - & LUMBAR***	***UP. LIMBS***	***LOW. LIMBS & PELVIS***
	Field data	FEW DATA but HEAD injuries	Few injuries	Very few injuries	Few injuries	Few injuries	commonly reported
	Injury mechanism	- Direct impact with rigid part	Excessive extension	/	/	/	Not well defined (few data)
	Meast for Criteria	A 3ms - HIC	Forces and moments	Chest deflection A 3ms	- Forces? - pressure?	NONE	NONE
	Dummy criteria	NONE	NONE	NONE	NONE	NONE	NONE
	Further work necessary	Model development	Model development	Model development	Model development	Model development	Model development

ANNEX 3 – SYNTHESIS TABLE PER TYPE OF IMPACTS (NECESSARY FOR IARV IMPROVEMENT – TO BE COLLECTED)

FRONTAL IMPACT	HEAD	NECK	CHEST	ABDO	LIMBS	DUMMIES (Age of child)
	**X**	**X**	**O**	**O**	**O**	Q0
	**X**	**X**	**O**	**O**	**O**	Q0, Q1
	**X**	**X**	**O**	**O**	**O**	Q1, Q18m, Q3
	**X**	**X**	**X**	**X**	**O**	Q1, Q18m, Q3
	**X**	**X**	**X**	**X**	**O**	Q1, Q18m, Q3, Q6, Q10
	**X**	**X**	**X**	**X**	**O**	Q3, Q6, Q10
	**X**	**X**	**X**	**X**	**O**	Q6, Q10

O	NOT NECESSARY
X	ADDITIONAL DATA COULD BE USEFUL
X	NECESSARY DATA
GREY	NO MEASUREMENT POSSIBILITY AT THIS DAY

SIDE IMPACT	HEAD	NECK	CHEST	ABDO	LIMBS	DUMMIES (Age of child)
	X	X	O	O	O	Q0
	X	X	X	X	O	Q0, Q1
	X	X	X	X	O	Q1, Q18m, Q3
	X	X	X	X	O	Q1, Q18m, Q3
	X	X	X	X	O	Q1, Q18m, Q3, Q6, Q10
	X	X	X	X	O	Q3, Q6, Q10
	X	X	X	X	O	Q6, Q10

O	NOT NECESSARY
X	ADDITIONAL DATA COULD BE USEFUL
X	NECESSARY DATA
GREY	NO MEASUREMENT POSSIBILITY AT THIS DAY