CHILDREN ARE NOT MINIATURE ADULTS

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ABSTRACT

Recent accident research studies confirm on larger samples the specific vulnerable points of children :

. at the neck level for the youngest,

. at the abdominal level for those who, below age 10-12, use the adult seat belt.

Technical solutions are available : "rearward-facing " seats for the youngest, and boosters cushions above age 3 or 4. Dynamic test procedures encounter serious limitations due to dummy shortcomings and the scant data available to determine protection criteria.

A considerable research effort is needed, including research on lateral impacts.

Children differ from adults not only by their size and speed of evolution.

At least until puberty, their structure includes a great many features which means they cannot be reduced to a model of the adult.

And these features must be taken into account in designing protection systems.

In short, the **CHILD IS NOT AN ADULT IN MINIATURE**. This is clearly stated in a 1969 publication by Burdi, Huelke et al. This notion was previously touched on in a 1964 article by Bertil Aldman dealing with the neck and pelvis levels.

At birth, the head represents 25% of the child's total size, while the head of an adult is proportionally twice as small. In 2 years, the volume of the brain grows to 75% of its adult volume (Figure 1).

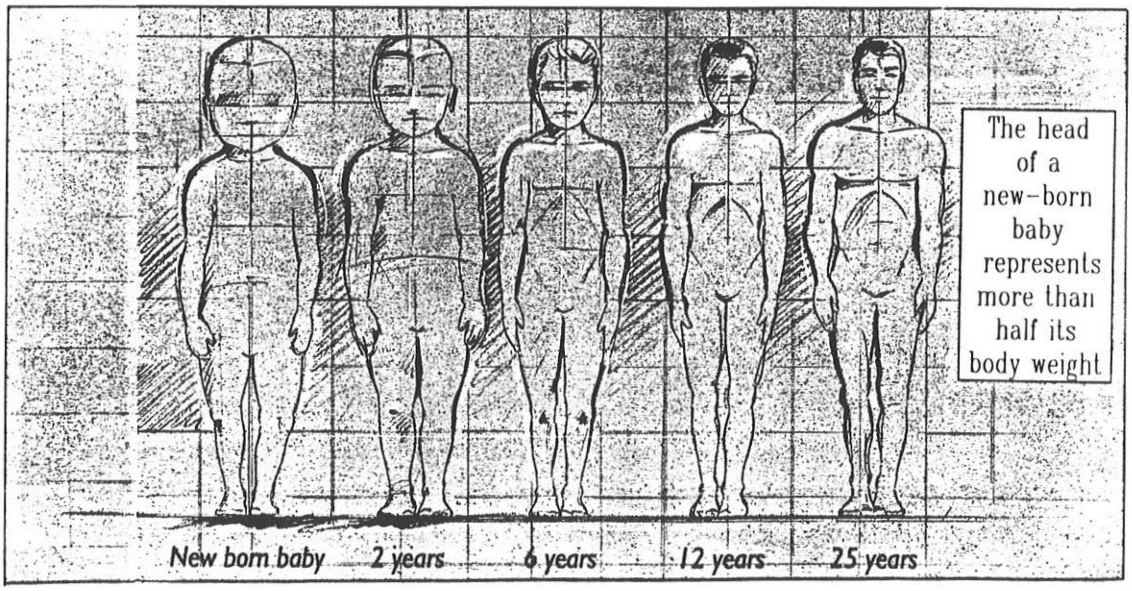


Fig. 1 - Child is not an adult in miniature

The head is not only larger and therefore proportionally heavier, it has a much more developed cerebral stage and a small facial stage (figure 2). This has consequences for the distribution of head injuries. Such injuries will be more often cerebral and hence more severe than in the adult because the brain is more exposed, especially since in addition the child's centre of gravity is located higher than in the adult.

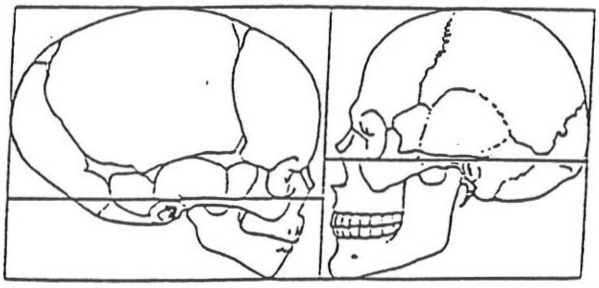


Fig. 2 - A comparison of face-braincase proportions in the child and adult. The horizontal line passes through the same anatomical landmarks on both skulls.

CERVICAL VULNERABILITY

The child's neck seems disproportionately small to support this large head, as suggested by the typical silhouette of a normal child aged 5 (figure 3) :

Small neck muscle and great ligament flexibility give astonishing **cervical mobility**.

Fig. 3 - Typical profile of a 5 years-old child.

On the X-ray of a child bending its head forward, one observes a displacement of the first two cervical vertebraes relative to the underlying vertebraes. This shows the appearance of a luxation.

This displacement can be as much as 4 to 5 mm in a high percentage of young children (figure 4) (Hensinger, 1986).

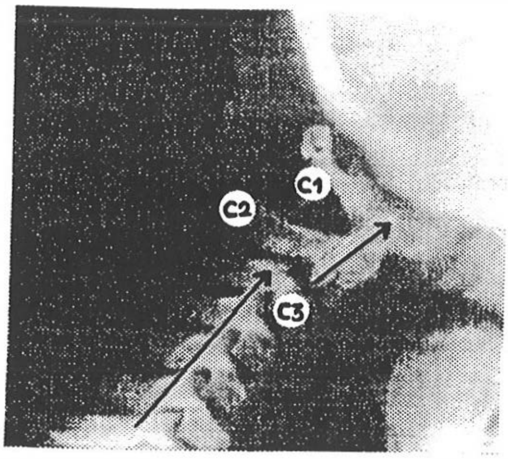


Fig. 4 - Young child normal cervical behaviour during a natural flexion movement.

In figure 5, the first cervical is viewed from above. This is the Atlas which supports the base of the skull. Only the vertebral body (the hatched area) is ossified.

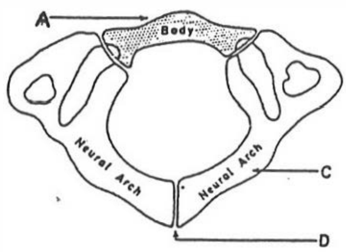


Fig. 5 - Young child first cervical vertebra (view from above).

It will not be until age 7 that the body fuses with the neural arches.

The same is true for_the second cervical vertebra.
The body fuses with the other parts making up the vertebra only between ages 3 and 6 (figure 6).

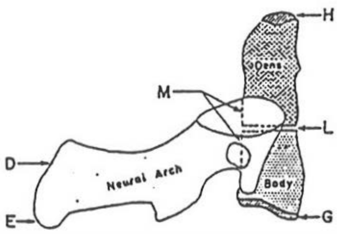


Fig. 6 - Young child second cervical vertebra (view from side).

If we insist on these features, it is of course to emphasize the fragility of the neck of young children.

Moreover, we know clearly that when taking a baby in our arms, we instinctively make sure to support the head carefully in line with the trunk so as to restrict head movement.

What does accident research tell about the distribution of injuries among various body areas (Got, Cuny, 1994) ?

A comparison "with" and "without" restraint system shows that (Table 1) :

. the risk for the head decreases by 48%, which illustrates the overall effectiveness of restraint systems as a whole.
. What is the case for the neck? The small samples available are inadequate to calculate effectiveness. However, neck injuries represent a greater proportion of injuries to restrained children (5.2% of AIS 2+) than to unrestrained children (0.7% of AIS 2+).

For a sample of more severe accidents, the neck risk represents, for all children aged under 10, up to 29% of the overall injury risk. This percentage is probably even higher in the first years of life (Tarrière, 1995).

These figures relating to the neck correspond to a situation in which more than 95% of "restrained" children are "forward-facing". The severity of this risk is confirmed by case studies (Huelke, Mackay and coll., 1992), (Tarrière, 1991), (Trosseille, Tarrière, 1993).

The overall results are fortunately in favour of restraint systems, but the neck risk remains a real problem.

The conclusion is quite obvious: a young child, say between ages 0 and 3, is not made (how true!) to be transported forward-facing.

"Rearward-facing" restraint systems can eliminate head movement relative to the thorax in the main phase of impact. This is essential for the neck. They can also distribute restraint forces over the whole surface of the trunk instead of concentrating them on small surfaces corresponding to the thoracic harness in forward-facing systems.

To the general public, it may be thinking that rearward-facing in a frontal impact means forward-facing in a rear impact.

The public should be reminded that **<u>60%</u>** of collisions are frontal, and that they are considerably more severe than rear impacts, so it is logical that maximum protection should be sought in frontal impact.

Table I : Children - France
Injury Distribution by Body Area and Restraint System

1629 children involved in 1090 accidents in 4 months of 1992-1993

	Harness seat (N=316)		Booster - Seat Belt (2-point / 3-point) (N=624)		Unrestrained (N=613)	
	E = 45%	E = 54%	E = 8%	E = 23%		
	AIS 1+ (N=112)	AIS 2+ (N=30)	AIS 1+ (N=316)	AIS 2+ (N=92)	AIS 1+ (N=332)	AIS 2+ (N=109)
HEAD + NECK + THORAX	78.7	58.3	62.5	45.4	64	54.6
	E = +33%	E = 51%	E = 10%	E = 36%		
ABDOMEN + PELVIS	1.5	2.8	13.7[2]	15.1	6.8[3]	8.6
	E = 89%	E = 86%	E = -87%	E = -38%		

All Restraint Systems (N=992) AIS 1+ (N=442)	All Restraint Systems (N=992) AIS 2+ (N=125)	Unrestrained (N=613) AIS 1+ (N=332)	Unrestrained (N=613) AIS 2+ (N=109)	Severe Accidents PVM 1990[1] – All Restraint Systems AIS 1+ – All configurations (N=41)	Severe Accidents PVM 1990[1] – All Restraint Systems AIS 1+ – Frontal (N=29)
50.4	38.7	51.9	47.4	54%	52%
7.5	5.2	3.9	0.7	29%	21%
8.3	4.5	8.2	6.6	24%	31%
7.5	16.1	10.1	15.1	5%	3%
9.3	9	4.7	5.9	17%	24%
1.7	3.2	2.1	2.6	5%	9%
12.8	19.4	16.1	20.4	7%	10%
A	C	B	D	E	

(PVM = fatal accident police reports)

E = efficiency = % of unrestrained injury victims - % of restrained injury victims / % of unrestrained injury victims

[1] 41 children involved in severe accidents in which at least one adult or child occupant was killed.
[2] The corresponding percentage is 10.8 for the USA (restrained children aged 6 to 12 years - FARS)
[3] The corresponding percentage is 2.6 for the USA (restrained children aged 6 to 12 years - FARS)

Source: C. TARRIERE and C. GOT (December 1994)

At this point in the lecture, it seems appropriate to express our recognition for the work of Bertil Aldman, an enlightened precursor who managed to impose the use of rearward-facing systems in his country, whereas we in the rest of Europe had to wait for the results of accident research before gradually adopting this practice. Thanks to his work, Sweden was about 20 to 25 years ahead of us. Aldman's statement of theory already dates from 1964.

The Swedish statistics show the great effectiveness of such restraints (Tingvall, 1987 ; Carlsson, 1989) : about 90 %.

Moreover, if an impact occurs at the head level, it is indirect and the brain is protected by the structure of the restraint system shell (single-wall or double-wall in the best models) and by shock-absorbent materials. This prospective function can be especially relevant in the case of a side impact. Remember that the mean resultant speed vector is at a 75° (and 255° angle). The reconstitution of a lateral collision in which a child aged 27 months lost its life (BMW/RENAULT 11), when it was in the near-side position and in the centreline of the impacting vehicle, shows this potential utility of a rearward-facing system in a lateral impact (Trosseille, 1996). In this accident, the child was forward-facing in a conventional harness seat. The fatal injuries were skull and brain injuries (right-hand parietal). A second reconstitution was performed with the "Argonaute" rearward-facing seat. The dummy head acceleration forces are halved in this second reconstitution.

This experimental work illustrates the safety potential to be exploited to improve child protection in lateral impacts. This area has been hardly explored and is largely ignored by the current regulations and the CRS makers.

ABDOMINAL VULNERABILITY

I should now like to draw your attention to another feature of children compared with adults. This concerns the morphology of the pelvis in children aged between 3-4 and 12 years.

Let us start with the adult pelvis, shown in profile cross section (figure 7A).

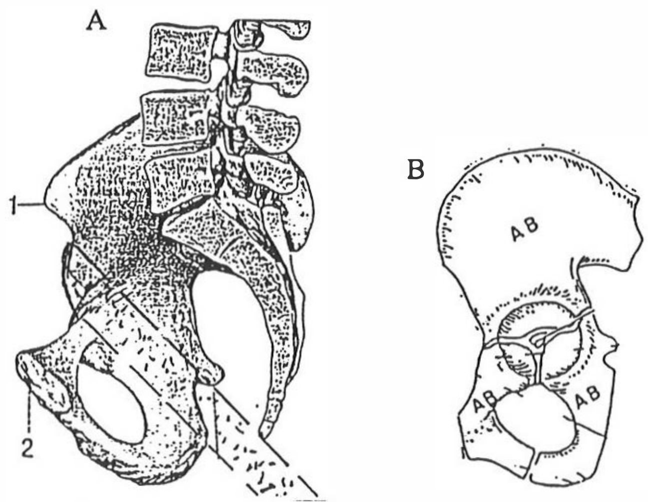


Fig. 7 - Comparison between adult (A) and child (B) pelvises.

For each pelvis, the rear is on the right side with the sacrum which supports the spinal column.

In a sitting posture, the seat-pelvis main contact is with the ischia, and the weight of the trunk tends to make this pelvis tilt toward the rear.

The lap belt also draws the pelvis toward the rear. It normally remains anchored to the pelvis due to these very pronounced shapes to which it remains attached, namely the concave surface in which the muscle "sartorius" is inserted, located just above the anterosuperior iliac spine. The risk is that the belt might pass over the pelvis, above the iliac wings. This phenomenon is called submarining.

What is the case for the child ?

The iliac wing of a child aged less than 8 or 10 years is round and smooth shaped (figure 7B).

It is quite impossible for an adult seat belt to become attached to such a pelvis and stay there during a frontal impact.

It is only at puberty that the shapes and ossification of the child's pelvis will become similar to those of the adult (figure 8) (Hensinger, 1986).

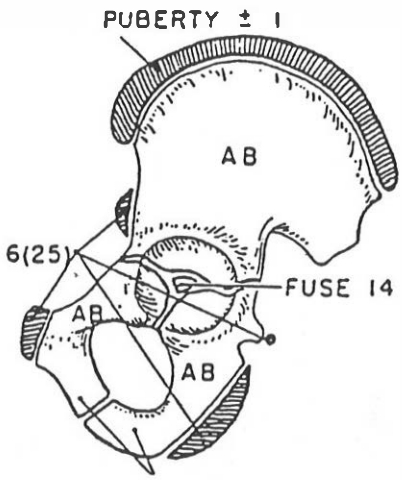


Fig. 8 - The puberty induces the modifications of the pelvic wings (closer to the adult shape).

This feature of children is unfortunately revealed in accidents if they are directly restrained by an adult seat belt (Tarrière, 1995).

As for the neck, the injury risk for the abdomen is higher for restrained children - we ought to say poorly restrained - than for unrestrained children.

The pelvis tilts to the rear, pulled by the seat belt. The belt overpasses the iliac wings and penetrates the abdomen, causing severe internal injuries and, if the impact is severe, luxations or fractures of the lumbar spinal column.

The extra risk involved is 87% (AIS 1+) for all restraint systems used in 1992-93 and 38 % (AIS 2+) that is to say 20% of boosters (good and bad) 40% of adult seat belts.

Here is the kinematics, represented schematically, for a 2-point seat belt:
in addition to abdominal and spinal risks there are brain and neck risks due to impact against the front seat (figure 9).

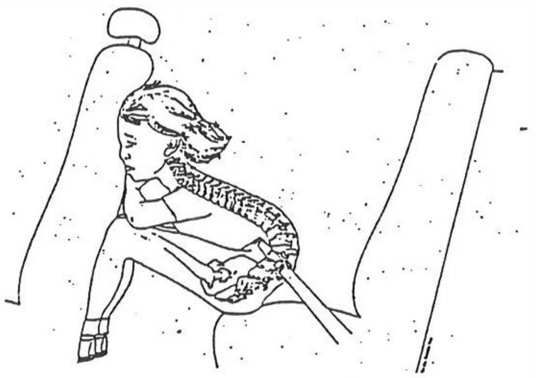
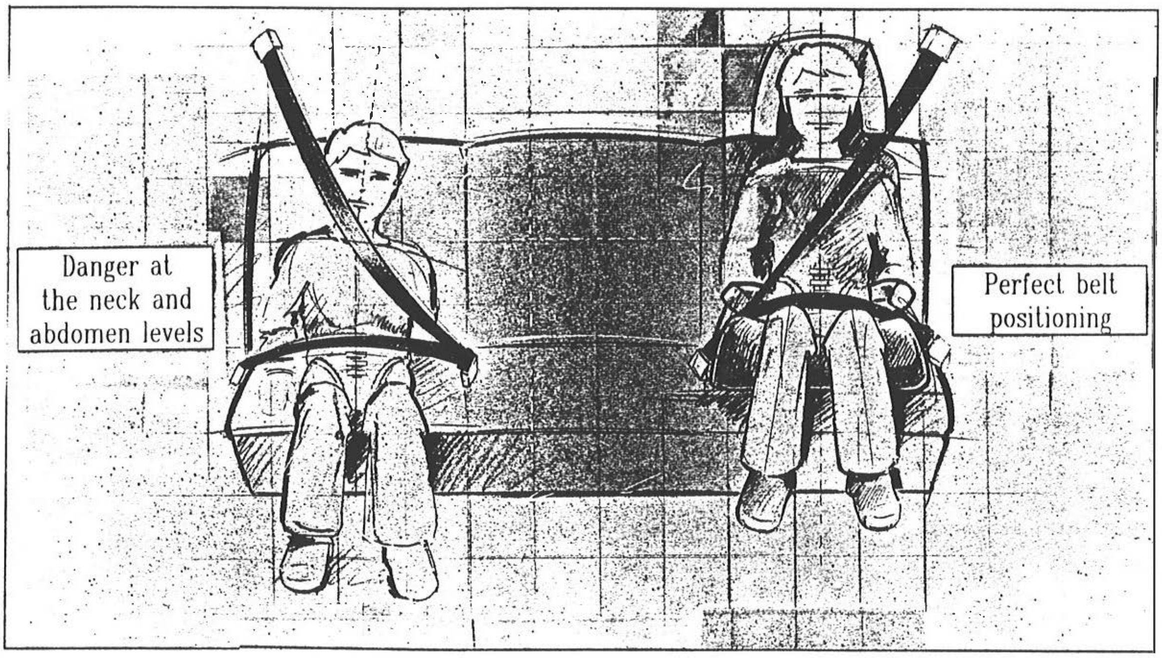


Fig. 9- Children with 2-point seat belt.

For the 3-point seat belt, the risk is mainly focussed on the abdomen and the lumbar column and it is still very real (figure 10).



Without booster (C) **With booster (D)**

Fig. 10- Children with 3-point seat belt.

An adult seat belt should never be regarded as an acceptable restraint system for a child aged less than 12-13.

A booster equipped with side strap guides is a necessary complement to the adult 3-point seat belt. The booster is even more interesting if it is also equipped with a seat back with head restraint to maintain the child's posture and allow it to sleep (figure 11).

Fig. 11 - Passenger booster-cushion.

By way of conclusion, we emphasize that restraint systems should be thoroughly adapted to the specific morphology of the child, taking into account its specific fragile characteristics.

HOW TO SELECT A GOOD BOOSTER

The natural tendency for an adult seat belt is to pass directly over the child's abdomen, or, for the biggest children, to become positioned in the angle formed by the thigh and abdomen, but with a very high risk of submarining.

A good booster is equipped with strap guides at the seat cushion level. The function of these guides is to change the lap strap trajectory so as to position it flat at the base of the child's thighs.

In the survey mentioned above, what are the results concerning the specific protection provided by boosters ? The overall efficiency (29 %) is limited mainly by negative efficiency at the abdominal level (- 9 %).

A question that arises then is **why are certified devices so dangerous.**

Here, the answer is clear. The pelvis design on existing dummies (European and American) is such that it does not at all simulate the child's natural tendency to submarine (Page, 1995). It is therefore understandable that a dynamic test does not enable a distinction to be made between a good and a bad booster. The child dummies for ages 3, 6 and 9 must therefore be improved. This is the sense of resolution N 6 voted unanimously by ISO/TC22/SC12/WG5 which has the task of defining the specifications for dummies used in impact tests (see Appendix 1A).

Another question arises then : **what is to be done until a suitable dummy is available ?**

A proposal has been adopted unanimously by ISO/TC22/SC12/WG6 which brings together the experts responsible for working out protection criteria based on biomechanics considerations (resolution N° 81 outlined in Appendix 1B). This proposal concerns a geometric criterion for positioning of the strap guide relative to anatomical references on the child (Tarrière, 1995).

All of these developments dating from the spring of 1995 are still largely unknown outside the groups of international experts associated with ISO's activities. We should like to emphasize their importance given that the booster is the only solution available for children over the ages of 3 or 4.

CHILD PROTECTION IN SIDE IMPACT

If problems remain for protection of children in frontal impact (dummies, pelvis design, tolerances limits for the different body segments), the situation is even more critical for side impact. Only one dummy claims to be specifically fitted for side impact (SAE Dummy 13 years old).

Child protection systems are designed and certified for operation in frontal impact. Now, more than a quarter of car occupant fatalities and severe injuries are sustained in side impact. A new regulation concerning car performance in side impact should come into application in the coming months in Europe, but it does not concern protection systems for child passengers, a field in which nothing (or so few), has been done yet.

CREST (**C**hild **RE**straint-system **ST**andard), a cooperative project to elaborate New Standard and Measurement Devices for Improved Child Protection Systems has been built associating Car Manufacturers, Universities, CRS Manufacturers and Public Laboratories (see Annex 3).

The main objective is to acquire the necessary knowledge on injury mechanisms and criterion by accident research and experimental reconstructions with instrumented dummies. This methodology has been validated on a small scale by the International Task Force on Child Restraint Systems (Tarrière, 1991 ; Trosseille, 1993 ; Weber, 1993 ; Janssen, 1993) and appears more appropriate than the scaling approach (Fayon, 1974) from adult to child since children are not miniature adults.

The accident analysis shows mortality rate 2.7 higher (0.48) in side impact than in frontal impact (0.17) and the mortality rate is lower at the centre rear (0.21) than for left rear (0.27) or right rear (0.32) (Vallée, 1991). So for the time being, we could at least indicate the **centre rear as the better place and more especially when equipped with an adult three point belt allowing to use every good CRS available on the market.**

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APPENDIX 1A

ISO/TC22/SC12/WG5 - RESOLUTION 6 - 1995

Because the pelvic form of the child is very different from that of the adult, the child dummy pelvis must not be designed in such a way as to allow the masking of the natural tendancy of the child to submarine. In particular, there must be no artificial blocking of the lap belt resulting from poor design of the pelvis-thigh joint.

APPENDIX 1B

ISO/TC22/SC12/WG6 - RESOLUTION N° 81

Concerning the assessment of booster cushion child restraint systems, and given the state of the knowledge (Resolution WG 5 N 6-1995), it is proposed, as a temporary measure, to assess these systems according to the draft procedure in doc ISO/TC22/SC12/WG6 N 424.

APPENDIX 2

CREST

NEW STANDARD AND MEASUREMENT DEVICES FOR IMPROVED CHILD PROTECTION SYSTEMS

Each year, **1000 children are killed** on European roads, and **80,000 are injured**. These figures are especially unbearable in that the great majority of these victims could be avoided. The purpose of this R&DT programme is to create the conditions which will enable very significant progress towards improved standards and measurement techniques as well as more efficient design of protection devices.

Many countries acknowledge that, even if Child Restraint Systems (CRS) are more and more used, accident records tend to show that their performances should be enhanced.
This low effectiveness can partly be explained for the youngest passengers by their greater cervical vulnerability and for the oldest (from 3 to 12 years old) by the morphological immaturity of their pelvis. There is a need to improve the design of dummies as well as the measurement of injury criteria.

The present European regulation ECE 44 focusses only on frontal impact, whereas the few available statistics indicate that **side impacts account for a high rate of severe and fatal injuries for children.**

It is clear that the proposed programme will consider the side impact protection as a priority both for the development of a new standard and for the design of new dummies and CRS.

Objectives :

- Acquire the necessary knowledge on injury mechanisms and criteria by accident research and experimental reconstructions with instrumented dummies.
- Propose test procedures for the assessment of CRS protection effectiveness including improvements of dummies and measurement techniques, which could be used to update the current standard.
- Evaluate prototypes of dummies and CRS in accordance with the new procedure proposals.

Methodology :

- Analyse real-world accidents by detailed medical and technical research (case by case studies) on 400 crashes involving children using CRS. **At least one third of the investigated cases should concern side impacts.**
- Perform experimental reconstructions of selected accidents using fully instrumented dummies, especially at the neck and pelvis level, completed by numerical simulations and sled tests for parametric analysis.

Important Comment : **This methodology has been validated on a small scale by the International Task Force on Child Restraint Systems.**

Programme in four years :

- 400 accident cases will be investigated.
- 40 cases will be selected for experimental reconstruction with fully instrumented dummies and 200 complementary sled tests will be performed.
- Test procedures for improved or new standards will be proposed and prototypes of dummies and CRS will be built and evaluated in order to validate the procedure proposals.

ACCIDENT ANALYSIS, RECONSTRUCTIONS
DUMMIES, MEASUREMENTS, STANDARDS
SIDE IMPACT PROTECTION