ACCIDENT INVESTIGATION AND BIOMECHANICAL RESEARCH: A JOINT APPROACH FOR ROAD USER PROTECTION

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ABSTRACT

Real world crash investigation constitutes the source of all safety research. It gives information on priorities in terms of body segments to protect, crash configurations and impact severities. It can also provide injury tolerances (for instance thoracic injury risk curves) and allows the verification of the efficiency of protective devices.

However, some limitations exist, in particular the precision of information about crash conditions. Experts do good work on defining crash characteristics, using databases, reconstruction software and their own experience. However, even with the best diagnosis, occupant position before the crash is generally still uncertain. This lack of precision can be somewhat compensated by the number of cases which far exceeds the number of biomechanical cases. Furthermore, the data comes from living people, who are after all our subject of interest.

Nevertheless, biomechanical investigations allow compensation of the shortcomings of crash investigations. Probably the most important contribution from biomechanics is the definition of human behavior, without which crash investigations remain only observation. As a matter of fact, human substitutes are needed to provide engineers with tools for improving safety. Only biomechanical research is able to give specifications for the development of such substitutes. Both behavior and injury criteria are important to define. Information on Human behavior is needed in order to mimic injury mechanisms, criteria are needed to measure them. If one or the other is missing, injury protection cannot be evaluated. The next step is the definition of injury risk curves. In this case, either crash investigation or biomechanics can contribute to their definition, the precision and the control of boundary conditions being the strength of biomechanics, the number of cases and the type of subject (living people) being the strength of crash investigation.

So, the use of the two disciplines together provides tools for developing safety systems and allows the evaluation of their efficiency. They allow also highlighting mechanisms which are different from those experienced in standard procedures with current dummies and the improvement of the behavior of these dummies in order for them to be more humanlike. It also shows that dependence on rating systems is not enough and that in some cases looking at real life is necessary to improve protection.

KEYWORDS

Accident investigations – Biomechanics – Cadavers – Injury Criteria – Safety devices

REAL WORLD CRASH INVESTIGATION

Crash investigation is the basis of safety research. It allows the characterization of occupant exposure, focusing the attention of designers on main problems and providing feedback on the real-world performance of solutions.

As an example, analysis of data in the 80's show that 50% of deaths or severe injuries were due to intrusion, while 25% of them were due to overloading of the body by restraint system. It was then concluded that structures had to be stiffened and restraint systems had to be softened. But the equilibrium should take into account the distribution of exposure, in terms of crash severity as well as occupant characteristics, especially as a function of age. Indeed, a stiffer car offers a better protection to young persons at a higher velocity by reducing intrusion, but kills older occupants at a lower velocity by a higher loading of the thorax. Now if the restraint system limits body loading, it can protect senior citizens, but it decreases the potential of protection for the young.

This statement belongs to the field of perfection and needs to know the exposition and the tolerances as a function of age. Then a policy has to be defined. Should the number of people protected be maximum, irrespective to the age, or should the weakest be protected, even if finally more people are killed as a whole?

Finally, reality was quite different and somehow more pragmatic because we don't know for sure the tolerances before the improvements are proposed. As a consequence, the policy is at least to improve the protection of one part of the population, without decreasing the safety of an other one.

Thoracic protection is a good illustration of an improvement process thanks to accident investigation. In the 70's, looking at biomechanical results (Kallieris, 1978), it was clear that limiting belt loading was a good way to reduce chest injuries. Textile load limitors were, therefore, introduced in French cars. At the same time a survey was made, and 167 accident cases were analyzed. As a result, a belt load threshold was found as a function of age (Foret Bruno, 1978). Because of the introduction of retractors, the possibility of using these belt loading limitors disappeared and they were not seen on new cars until 95 when the increasing of car stiffness required to introduce again belt load limiting. At that time, this limiting of loads to 6kN didn't decrease performances for young people (who could sustain at least 8 kN) because it was coupled with pretensionners and belt locking devices. Indeed, this arrangement decreased belt slack and body excursion remained the same. The youngest occupants were less likely to be killed by intrusion while the oldest occupants were better protected.

Some examples below show the improvement of performances, but also the limitations of the 6 kN limit. All following cases have an EES of 55 to 60 km/h.

- Case 1 is a 52-year-old man who sustained no injury. He tor 200 mm of the force limiting device. He would have sustained 9,5 kN without load limiting and would have probably died.
- Case 2 is a 63-year-old man who sustained 7 rib fractures. He tor 140 mm of the force limiting device. He would have sustained 8,5 kN without load limiting and would have also probably died.
- Case 3 is a 85-year-old woman who died with 160 mm of 6 kN force limitation. In this case, the level of limitation was too high.

It is clear that although the 6 kN force limit is an improvement, it not sufficient to protect weaker people. The analysis of 256 accident cases with shoulder belt load limitors (Foret Bruno, 1998) allowed the definition of the probability of chest injury as a function of belt tension and demonstrated the need for a further load reduction (figure 1).

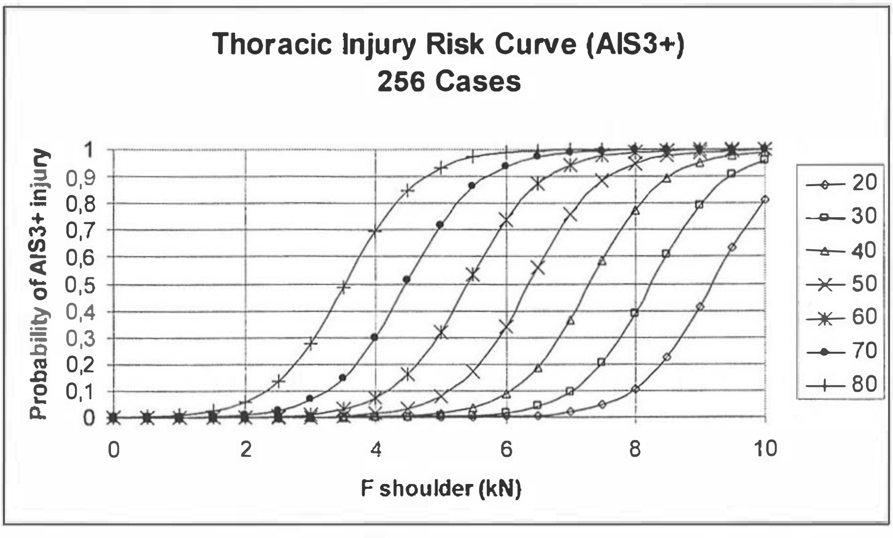

Fig. 1: Probabilities of AIS3+ risk as a function of belt tension at the shoulder depending on the age groups for the 256 cases.

As a consequence, 4kN limitors were introduced in 1998. In this case, though, excursion would be too large and the belt system requires a purpose designed airbag. At this time it was not sure that the additioin of an airbag would not change the tolerance to belt loading. Indeed, no accident data were available. The airbag was therefore designed to keep the same excursion as with 6 kN limiting. Then the accident survey was continued. Up to now, 65 cases with 4kN and airbag were analyzed in addition to the 80 cases with 6 kN (see table 1). The analysis of these accident cases has shown that, while the risk of death or severe injury was decreased by 18% with the 6 kN limit, the use of the 4 kN limit restraint system with airbag results in a 60% reduction in the same risk. It is to be noted, however, that regulation or rating tests with the Hybrid III dummy cannot see any difference between the two systems.

Table 1. Potential benefits of 4kN belt load limit with purpose designed airbag

Load limitation	AIS2+	AIS3+	AIS4+
6kN	15%	18%	39%
4kN + airbag	38%	60%	74%

Of course, crash investigations have some limitations: In the best case, we will have information on the occupant loading (for instance belt load limiting), but these are external loads, related to injuries through boundary conditions. Biomechanical criteria should be disconnected from external conditions and only associated to a measurement device like a dummy. How, though, can a criterion be established on a dummy which cannot discriminate between two devices with such different efficiencies on the road? At this stage, biomechanical research is needed to improve human surrogates which were not developed for such restraint systems or for all loading conditions.

BIOMECHANICS

As described before, dummy behavior is a key point for the development of criteria. Initially, biomechanical investigations were needed to develop dummies and to give initial specifications. Then, crash investigations allowed the evaluation of protection solutions and validating criteria. But it cannot afford for new solutions. Here is the need for biomechanical investigations.

A first example is chest behavior. Accident investigation gives belt loading limits as a function of age. But it doesn't give information on the combination of belt and bag before the introduction of such systems on the road. Limits in terms of belt load were transferred to the dummy by Mertz (1991) in terms of sternal deflection. But we can see today that this measurement is not appropriate for combined loading. Indeed, HIII sternal deflection doesn't discriminate between 6 kN limit and 4 kN with airbag restraint systems (Trosseille, 1999). However, as shown previously, accident investigation demonstrates a clearly improved efficiency of the second solution. Biomechanical data are still missing in terms of behavior and in terms of injury criteria and tolerances. In this case, the distribution of loading and the velocity are of utmost importance. The knowledge of behavior and of injury criteria is the main objective of biomechanics. Indeed, with a humanlike dummy, it is possible to relate accident statistics to a pertinent criterion, in order to issue injury risk curves, as defined by Korner (1989). If, however, the dummy is not humanlike or if one doesn't look at the correct criterion, wrong results can be issued.

Improvements from biomechanical research can be integrated in a numerical model of the human being. A model presented by Lizée (1998) was validated against more than 100 corridors, in particular under shoulder belt or distributed loading. Baudrit (1999) made a comparison between HIII and human body model responses. He founded the same tendencies, but in some cases some differences. In particular, the HIII model, as with the dummy itself, didn't demonstrate any difference between 6kN shoulder belt load limiting and a combination of 4kN limiting and airbag. The Human Body model, though, shows that this combination can be efficient on decreasing the deflection (figure 2). In the same way, preliminary results from tests on the THOR dummy demonstrate a decrease of deflection with the 4kN and airbag system. It is to be noted that measurements are not the same on the three substitutes : HIII measures a sternal deflection at a moving point (rod-pot), the human body model gives a maximum sternal deflection and THOR measures the chest deflection at four points (two on each side of the sternum).

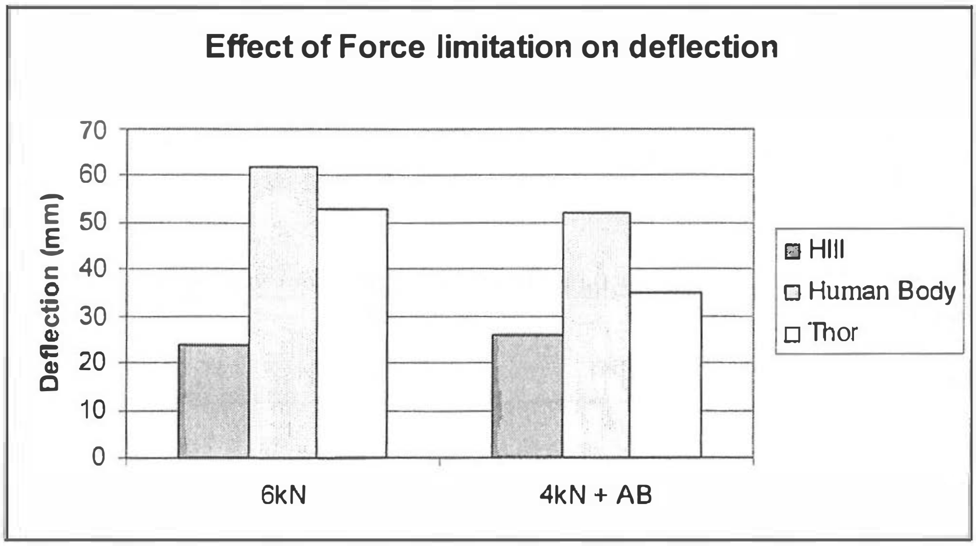

Fig. 2: Effect of belt and airbag on the thoracic deflection

This example demonstrates that improvements in dummy behavior or selected criteria can allow the detection of differences between safety devices. However, this doesn't mean that the criterion is the good one. Still a lot of work is needed to understand the different modes of injury generated by belt or distributed loading and to find a criterion which is able to discriminate between them.

Airbag loading and belt loading do not correspond to the same injury mechanism. Although deflection is produced by both types of restraint, the scale is certainly different. In that case, how is it possible to evaluate the injury risk with this criterion alone if the loading is combined ? For the same force applied to the thorax, the deflection is more sensitive to concentrated loading (belt). As a consequence, the decrease of belt loading will have more effect on the deflection than the increase of airbag loading for the same applied force. However, the decrease of deflection will underestimate the benefit of decreasing the belt load. Studies intending to differentiate between the kind of loading (Morgan, 1994) can assess this problem. Nevertheless, they still need more validation and understanding of injury mechanisms.

An other example is the behavior of the foot and ankle. In 1995, Portier (1995) showed that Achilles' tendon force generates moments at the ankle level of the same order of magnitude as moments sustained by the ankle joint itself. Missing this information cannot permit the development of dummies with a good behavior and the loading of the vehicle on the foot cannot be pertinent. With the help of data from Petit (1996) and Crandall (1996) it was then possible to define characteristics for a humanlike dummy leg. This tool is now available to evaluate loading of the foot in cars and to develop protective devices. A point still missing is injury tolerances as a function of age.

EXPERIMENTAL RULES

As we can see, experiments on anatomical subjects are of importance. Without this knowledge, improvement, progress and creativity are frozen. But in order to keep this possibility to continue anatomical research, common ethical principles should be defined. This point should be discussed at international level in order to define at least fundamental rules. In our opinion, the following items must be discussed:

- Transparency: in France, cadaver tests are performed on bodies donated to the science, which is an official way of working.
- Respect : cadavers must be treated with caution and with respect to the body
- Anonymity : the name and identity of cadavers have to remain unknown

- Dissemination: results have to be published at the end of the study. If studies can be carried out on cadavers for the evaluation of new protection systems, scientific issues must be included for the benefit of the whole community.

In the same way, protection of laboratory personnel and of the environment should be assured. For instance some precautions should be taken:

- serology of cadavers
- vaccination of exposed personnel, individual protections
- control of residuals (liquid and solids)

These points are only a few items and are an illustration of what should be discussed between research teams in order to ensure the future of biomechanical research.

A LINK BETWEEN ACCIDENT RESEARCH AND BIOMECHANICS

In 1992, Norin (1992) presented a method to predict the safety potential of a safety design feature. He included crash severity and occupant size parameters in his analysis. It seems, when looking at chest data from crash analysis, that age is also a first order parameter which can be addressed now with new data.

Here is, for illustration, an example of global evaluation for the thorax, using crash severity and age as main parameters. The first step is to start from involvement. Table 2 gives the distribution as a function of age and velocity. Then, it is necessary to transfer this involvement into consequences. It is in one side the tolerance of people and in the other side the loading of them by restraint systems. Table 3 gives the parameters of injury risk curve as a function of age for a logistic distribution. Table 4 gives test results as a function of velocity. Values provided here correspond to a mean for all overlapping configurations, since this parameter was not considered in the crash distribution. Considering this parameter would be of importance to account for intrusion or pulse level effects.

Test results are given in terms of shoulder forces since injury risk curves as a function of age are only known for this parameter. It could be argued that injury risk as a function of shoulder belt force depends on the restraint system geometry. This is probably true up to a certain extent, but it is, in any case more significant that dummy measurements cannot discriminate between 6 kN and 4 kN with airbag.

This step points out the importance of biomechanical research in defining good criteria. Indeed, if this key point is not achieved, the global evaluation is meaningless.

It is then possible to calculate a global risk for each class of age and velocity by multiplying the involvement by the risk of injury occurring for the measurement made at the considered velocity for the considered age. The sum of all classes gives an overall risk of a given level of injury.

Table 5 gives the risk of AIS3+ for each class and figure 3 gives the overall risk for each level of injury.

All these overall risks can then be compared for each technical solution. This allows the determination of whether one solution is better than another at a global level.

Figure 4 gives a comparison of several systems: no load limiting, 6kN limiting and 4kN limiting with an airbag.

Table 2: Distribution of involvement for frontal impact

		EES			
		0-25 km/h	26-45 km/h	46-65 km/h	>65 km/h
Age	18-30 years	0,085	0,194	0,089	0,015
	31-45 years	0,09	0,167	0,101	0,008
	46-60 years	0,052	0,086	0,047	0,007
	61 + years	0,013	0,021	0,023	0,002

Table 3: Injury risk curves

	Cst (constant)	A (Age)	F (Force)	
AIS2+	18,3	6,2	0,573	Values from [1]
AIS3+	19,9	5,9	0,557	Values from [1]
AIS4+	21,5	5,6	0,541	Extrapolation from AIS2+ and 3+

Risk of AIS = 1/(1+exp(Cst+Age*A+Force*F)

Table 4: Test results: Shoulder force

	EES			
	0-25 km/h	26-45 km/h	46-65 km/h	>65 km/h
No limitation	3,5	5	6,5	8
6 kN limitation	3,5	5	6	6
4 kN + AB	3,5	4	4	4

Table 5: risk of AIS3+ for each classes (No limitation)

		EES			
		0-25 km/h	26-45 km/h	46-65 km/h	>65 km/h
Age	18-30 years	6,1E-06	2,0E-04	1,4E-03	2,8E-03
	31-45 years	6,9E-05	1,9E-03	1,4E-02	5,7E-03
	46-60 years	5,0E-04	1,1E-02	3,2E-02	6,8E-03
	61+ years	1,9E-03	1,5E-02	2,2E-02	2,0E-03

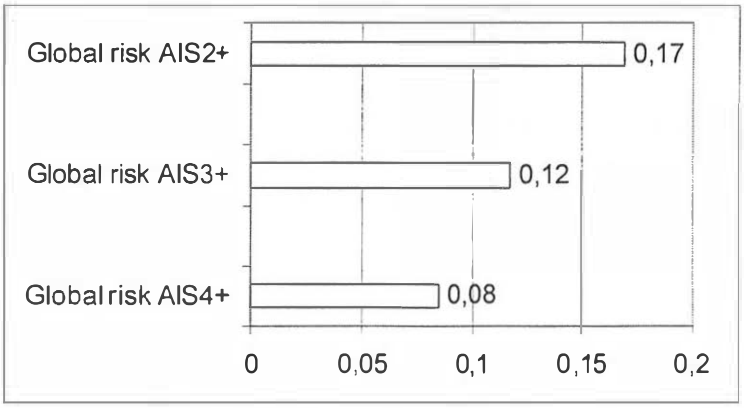

Fig. 3 : overall injury risk for 4 kN and Airbag restraint

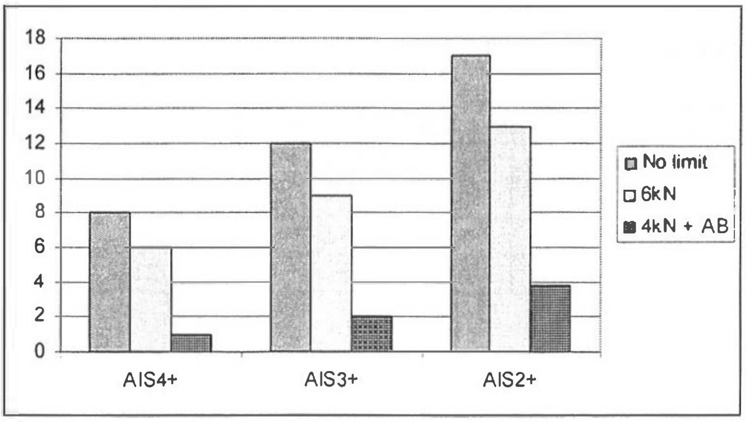

Fig. 4 : comparison of different systems.

It can be noticed that the decrease in serious injuries and death (AIS3+) is of the same order of magnitude as that shown by accidentology (25% for 6kN and 83% for 4kN and airbag).

Only chest evaluation was presented here as an example. For a complete evaluation, it would be necessary to include all body segments and crash configurations, including frontal and lateral impacts, as well as geometrical parameters like the height and weight of occupants.

SUMMARY AND CONCLUSIONS

As a summary, we can define as follow the contribution of each discipline to a complete approach as follows:

- crash investigation provides data on involvment in terms of severity, typology of accidents and distribution of ages. It also provides wide data on crash consequences related to crash conditions.
- Biomechanics provides information on human behavior, criteria and injury risk curves as a function of age. The former is necessary to measure properly the loading of occupants and to have access to the pertinent parameters. The latter is necessary to address the right injury mechanisms.

Both disciplines can contribute to the definition of injury risk curves and are always usefull to validate results from each other.

Then vehicle engineers are able to develop protective devices where these seem to be appropriate. They can olso develop these devices to give the best overall efficiency. For instance, it is more appropriate to give priority to the oldest occupants in the configuration where they are likely to be and not, for instance, at the highest velocity. Too much attention paid to one point which is not necessary can lead to wors solutions on other points which can be of major importance. For this purpose, it is still necessary to get data on all body segments, for all ages, configurations and injury severities.

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