ABDOMINAL INJURY PATTERNS IN REAL FRONTAL CRASHES: INFLUENCE OF CRASH CONDITIONS, OCCUPANT SEAT AND RESTRAINT SYSTEMS

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ABSTRACT

An in-depth study was conducted through the analysis of medical reports and crash data from real world accidents. The objective was to investigate the abdominal injury patterns among car occupants in frontal crashes. The influence of the type of restraint system, the occupant seat, the age and the crash severity was investigated. The results indicate that the risk of abdominal AIS 3+ injuries increased with crash severity and decreased with the introduction of belt retractors. Rear belted passengers were observed to be more likely injured than front belted occupants. The organs injured in frontal crashes for belted occupants were mainly hollow organs especially jejunum, ileum and mesentery.

In France, the recent automobile occupant safety improvements in frontal crashes have reduced the fatality rate from 13.4% to 3.4%. Among the safety devices responsible for these changes, airbags and seat belt load limiters demonstrated a large contribution [Foret-Bruno, 2001]. Foret-Bruno analyzed 100 AIS 4+ injuries sustained in older cars (from 1980 to 1990) and found that 39 were head injuries, 41 were thorax injuries and 20 were abdomen injuries [Foret-Bruno, 2005]. Assuming the identical rate of fatal and MAIS 4+ injuries (13.4%), he calculated an AIS4+ injury frequency of 5.2% for the head, 5.5% for the thorax and 2.7% for the abdomen. Using a population of new cars (from 1996 to 2004) in crashes of comparable severity, Foret-Bruno reported a substantially different injury distribution: among 100 AIS4+ injuries, 13 were head injuries, 25 were thorax injuries and 62 were abdomen injuries. Using the current fatality/MAIS 4+ rate of 3.4%, he found an AIS4+ injury frequency of 0.45% for the head, 0.85% for the thorax and 2.1% for the abdomen. This time trend indicates reductions in the frequencies of AIS 4+ injury to the head, thorax and abdomen. The decrease was larger, however, for the head and the thorax. As a consequence, the abdomen has moved to first in frequency, and thus relative importance.

A focus on the injury typology and an investigation of the influence of parameters such as the type of restraint system, the occupant seat position, the age and the crash severity remains necessary to better understand the injury mechanisms of these abdominal injuries.

Studies regarding abdominal injuries in the U.S. are currently available in the literature. Some of them focused on the adult abdominal injury pattern, and on the abdominal organ injury frequency and severity [Huelke,1993], [Elhagediab,1998], [Yoganandan,2000]. They report a synthesis where the different types of injuries are associated to different contacts (seat-belt, steering wheel, armrest, vehicle interior, etc.).

This paper focuses on the abdominal injury risk based on data from a French database containing cars from 1970 to 2005. The injury pattern is compared to the previous studies from the US where the restraint systems somehow differ from those observed in France. Indeed, in the early 1970's, the front seats of the US cars were equipped with either lap-belts or 3-point belts. In the 1980's, automatic shoulder-belts associated with manual lap belts were developed. In order to protect the unbelted occupants, the cars equipped with manual seat-belts were also equipped with airbags while the cars equipped with automatic seat-belts were not. In 1991, the National Highway Traffic Safety Administration (NHTSA) recommended the use de-powered airbags associated with 3-point manual seat-belts [Page, 1997]. The use of seat-belts became compulsory in several states. In 2002, among the fatally injured front-seat occupants, the percentage of belted occupants was 41%. In 2003, the overall average rate of seat-belt use reached 75% in the US [IIHS, 2003].

In France, the front-seats were equipped with 3-point manual seat belts in 1970. The use of seat-belts became compulsory in 1972. The cars sold in France started to be equipped with airbags in 1980, with pretensioners in 1992 and with belt-load limiters in 1995. In 2002, among the fatally injured front-seat occupants, the rate of belted occupants was 70%. In 2003, the overall average rate of seat-belt use reached 98% in France.

The influence of the type of restraint system on the abdominal injury risk is investigated.

METHOD

DATABASE - For approximately 40 years, Renault and PSA Peugeot Citroën have collaborated through the Laboratory of Accidentology, Biomechanics and Human Behaviour (LAB) to gather information regarding the crash conditions, the car deformations and the injury assessments from real world accidents occurring either in the area under monitoring, or anywhere in France where a car of interest was involved. All the crashes investigated are very accurately documented [Faverjon, 1985]. The information is gathered, stored in the LAB database, and processed with the help of the « Centre Européen d'Etudes de Sécurité et d'Analyse des Risques » (CEESAR). As of today, the database contains 13,765 vehicles, 24,989 occupants and 64,668 injuries.

SELECTION CRITERIA - Six parameters were used to select the occupants from the database. All the non-ejected occupants involved in a frontal crash with an Energy Equivalent Speed (EES) ranging from 40 km/h to 79 km/h were selected. Children younger than 12 years old were excluded since their restraint systems were different. Adult occupants whose restraint system description or medical report were not available in the database, were excluded from the analysis.

ANALYSIS

DATA EXTRACTED FROM THE DATABASE - For each occupant selected from the database, the type of restraint system, the EES, the dashboard intrusion, the seating position, the occurrence of an AIS 3+ abdominal injury, the description of the injury and the age of the occupant were examined.

Restraints were categorized into five categories: no restraint system (unbelted), 3 point static belt (SB), 3 point belt plus retractor (RB), 3 point belt plus retractor and pretensioner (RB+P), 3 point belt plus retractor, pretensioner and frontal airbag (RB+P+AB). Note that for a 3-point belt, the pretensioner is usually located in the stalk. As a consequence, when fired, the pretensioner removes the slack length of both the lap and the shoulder belts. In contrast, the retractor automatically adjusts the length of the shoulder belt only.

Four EES levels were defined: 40-49 km/h, 50-59 km/h, 60-69 km/h, and 70-79 km/h.

For the dashboard intrusion, three classes were defined: lower than 24 cm, between 25 and 45 cm and greater than 45 cm.

The abdominal injury descriptions available in the database included information regarding the organs injured. They were separated into two categories: hollow organ injuries (intestine, colon, duodenum, mesentery, stomach and bladder) and solid organ injuries (liver, spleen, kidneys, and pancreas).

DEFINITIONS

<u>Abdominal injury risk</u> - The abdominal injury risk is defined as the ratio between the number of occupants sustaining AIS 3+ abdominal injuries and the number of occupants involved in investigated crashes.

<u>Abdominal injury frequency</u> - The abdominal injury frequency is defined as the ratio between the number of AIS 3+ abdominal injuries and the total number of injuries occurring in investigated crashes.

<u>Hollow and solid organ injury frequencies</u> - The hollow organ injury frequency is defined as the ratio between the number of AIS 3+ hollow organ injuries and the total number of AIS 3+ abdominal injuries.

The solid organ injury frequency is defined as the ratio between the number of AIS 3+ solid organ injuries and the total number of AIS 3+ abdominal injuries.

<u>Statistical method</u> - Three statistical methods were used in this study to determine whether a difference was statistically significant, namely, the chi-square test, the logistic regression, and the t-test.

The results were said to be significant if the probability was lower than 0.05 (α=0.05).

CORRECTION APPLIED TO THE DATABASE EES - As described above, the database is composed of both collisions collected in a precise area under monitoring and collision cases investigated from anywhere in France where vehicles recently launched by Renault or PSA are involved (spotted cars). These latter are generally severe collisions, since preference is given to investigating crashes that result in severe injuries.

Between 1970 and 2005, an increase of the average crash severity was observed for the spotted cars. This increase likely corresponds to the improvement of the car safety. In other words, the frequency distribution of crash severity for all crashes may have not changed, but the crash severity frequency distribution for injury crashes has shifted to right as vehicle designs have improved. Thus, an overall increase in the crash severity of spotted cars has been observed over time. This is a confounder since the restraint type has also evolved over time. Static seat-belts are installed in old designed cars, while the use of retractors with pretensioners and airbags correspond to recent car design. As a consequence, the cases where sophisticated restraint systems were used have an average EES greater than those where static belts were used, and the vehicles associated with these restraints differ in other respects. To assess the effectiveness of the restraint systems, it is necessary to have sub-samples for the different types of restraint systems where the EES distributions are comparable. As a consequence, prior to computing the overall injury risk, a correction was applied to all the sub-samples such that their EES distributions match an arbitrary EES distribution (Table 1). This method is the direct standardized method.

Table 1 - Reference sample EES distribution

EES	Reference Sample distribution
40-49 km/h	30%
50-59 km/h	30%
60-69 km/h	30%
70-79 km/h	10%

RESULTS

A sample of 5699 occupants was selected using SAS Software and the six selection criteria. Among the 5699, 372 occupants (6.53%) sustained AIS 3+ abdominal injuries. These were mostly perforation and rupture. The number of injuries reported in the sample for each organ is given in Table 2. Injuries coded as “Other” involved the blood vessels, the peritoneal membrane, and the omentum.

Table 2 - Distribution of AIS 3+ abdominal organs injuries

	Organs	AIS 3+ Injuries
Solid organs	Liver	101
	Spleen	141
	Kidneys	21
	Pancreas	17
Hollow organs	Duodenum	11
	Jejunum	102
	Colon	47
	Mesentery	82
	Stomach	6
	Bladder	14
	Others	72
	Total solid	280
	Total hollow	262
	Total	634

An in-depth assessment of the influence of dashboard intrusion, the occupant position, the EES, the restraint system and the occupant age is presented below.

INFLUENCE OF THE CRASH SEVERITY - The distribution of the occupants involved, the distribution of the occupants injured and the injury risks are presented in Table 3 as a function of EES. A chi-square test, performed on this table, shows that EES significantly influences AIS 3+ abdominal injury risk ($p<0.0001$). The risk of AIS3+ abdominal injury drastically increases with EES.

Table 3 - Influence of the crash severity on AIS 3+ abdominal injury risk

EES	AIS 3+	
40-49 km/h	Injured (n)	71
	Involved (n)	2586
	Injury risk (%)	2.75
50-59 km/h	Injured (n)	131
	Involved (n)	1922
	Injury risk (%)	6.82
60-69 km/h	Injured (n)	121
	Involved (n)	992
	Injury risk (%)	12.20
70-79 km/h	Injured (n)	49
	Involved (n)	199
	Injury risk (%)	24.62
Total	Injured (n)	372
	Involved (n)	5699

The hollow and solid organ injury frequencies are reported in Table 4 as a function of EES. A chi-square test was performed on these results. No significant difference in the injury frequencies was observed ($p=0.1$) between the type of organ injured and the different EES classes.

Table 4 - Hollow and solid organ injury frequencies as a function of EES

EES	Hollow organs	Solid organs
40-49 km/h	31(39%)	48(61%)
50-59 km/h	96(52%)	87(48%)
60-69 km/h	67(42%)	94(58%)
70-79 km/h	37(50%)	37(50%)

INFLUENCE OF THE DASHBOARD INTRUSION - The distribution of the occupants involved, the distribution of the occupants injured and the injury risks are presented in Table 5 as a function of the dashboard intrusion. Note that rear passengers were excluded from this analysis (Table 5 and Table 6) because no contact occurred between rear seat occupants and the dashboard. As a consequence, the parameter used to describe the crash severity for the rear seat passengers is EES only. Table 5 shows that the occurrence of an AIS 3+ abdominal injury is linked to the dashboard intrusion ($p<0.0001$). The results show that the risk of AIS3+ abdominal injury increased with dashboard intrusion. For a dashboard intrusion smaller or equal to 24 cm, 5% of the occupants sustained an AIS 3+ abdominal injury. When dashboard intrusion was greater than 45 cm, the AIS 3+ abdominal injury risk was 29%.

Table 5 - Influence of the dashboard intrusion on AIS 3+ abdominal injury risk

Dashboard Intrusion	AIS 3+	
≤24 cm	Injured (n)	202
	Involved (n)	4022
	Injury risk (%)	5
25-44 cm	Injured (n)	63
	Involved (n)	445
	Injury risk (%)	14
45 cm +	Injured (n)	47
	Involved (n)	160
	Injury risk (%)	29
Total	Injured (n)	312
	Involved (n)	4627

Hollow and solid organ injury frequencies are provided in Table 6 as a function of the dashboard intrusion. A chi-square test was performed on this distribution. A significant difference was observed between hollow and solid organ injury frequencies as a function of the dashboard intrusion ($p<0.0001$). For low levels of intrusion, hollow organs were more frequently injured than solid ones. For intrusion levels greater than 25 cm, injuries to the solid organs were predominant.

Table 6 - Distribution of the injured abdominal organs as function of the dashboard intrusion

Intrusion	Hollow organs	Solid organs
≤24 cm	155(55%)	127(45%)
25-44 cm	26(30%)	60(70%)
45 + cm	14(22%)	49(78%)

For a given vehicle, it must be noted that the dashboard intrusion increases monotonically with the crash severity. EES is the indicator of crash severity, thus, EES and the dashboard intrusion are strongly correlated. However, the correlation factor depends on the stiffness of the vehicle structure and thus changes from one vehicle to another especially from a vehicle constructed in 1970 to a vehicle constructed in 2005 (Figure 1).

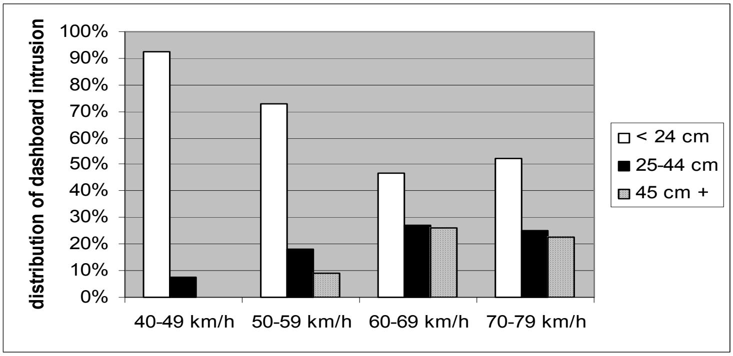

Figure 1: Distribution of dashboard intrusion levels as a function of EES

The sample used in our study contains a large panel of vehicles constructed from 1970 to 2005. The large differences in the car stiffness over time can explain the differences observed in the influence of the EES and the dashboard intrusion on the abdominal injury risk and the injury patterns. Therefore, in this study, both EES and dashboard intrusion are taken into account.

INFLUENCE OF THE TYPE OF RESTRAINT SYSTEM - For each restraint system, the number of occupants involved, the number of occupants injured and the risk of injury are given in Table 7. Note that the rear occupants were excluded from this analysis (Table 7 and Table 8), because the sizes of the sub-samples for each type of rear seat restraint system were too small to draw any robust conclusion. The only evaluation that could be done for rear passengers regarding the restraint system was the influence of being belted versus unbelted.

The results show that the use of belts together with retractors correspond to an abdominal injury risk lower by a factor of 1.6 [CI 95% 1.07, 2.41] relative to static belts. The risk decreased from

16% for static belts alone to 7% for any type of restraint using retractors. No significant difference of AIS 3+ abdominal injury risk was observed between the different combinations of safety devices using belt retractors (p=0.3).

Table 7 - Abdominal injury risk for front seat occupants for different restraint systems as a function of EES. SB = 3 points static belt, RB = 3 points retractor belts, RB+P = 3 points retractor belt with pretensioner and RB+P+AB = 3 points retractor belt with pretensioner and frontal airbag.

Front seat occupant	AIS 3+ injury	Un belted	SB	RB	RB +P	RB+P + AB
40-49 km/h	Injured (n)	33	3	15	2	1
	Involved (n)	781	166	800	148	206
	Injury risk (%)	4.23	1.81	1.88	1.35	0.49
50-59 km/h	Injured (n)	31	15	49	6	10
	Involved (n)	434	99	634	172	226
	Injury risk (%)	7.14	15.15	7.73	3.49	4.42
60-69 km/h	Injured (n)	32	7	30	15	23
	Involved (n)	152	34	329	98	193
	Injury risk (%)	21.05	20.59	9.12	15.31	11.92
70-79 km/h	Injured (n)	11	2	11	1	15
	Involved (n)	23	4	69	13	46
	Injury risk (%)	47.83	50.00	15.94	7.69	32.61
Total	Injured (n)	107	27	105	24	49
	Involved (n)	1390	303	1832	431	671
corrected overall injury risk (%)		14.51	16.26	7.21	6.81	8.31

The hollow organ and solid organ injury frequencies are reported in Table 8 as a function of the type of restraint systems.

The results show a significant difference between belted and unbelted occupant hollow organ injury frequencies (p<0.0001). A significant difference between belted and unbelted occupant solid organ injury frequencies (p<0.0001) is observed as well.

However, for belted occupants, no significant difference was observed between hollow and solid organ injury frequencies (p=0.2) among the belt types. When occupants were unbelted, solid organs were more frequently injured while for belted occupants, injuries to hollow organs were predominant (Table 8).

Table 8 - Hollow and solid organ injury frequencies as a function of the type of restraint system

<table>
<tr><th></th><th>%hollow</th><th>%solid</th><th>%hollow</th><th>% solid</th></tr>
<tr><td>Unbelted</td><td>23%</td><td>77%</td><td>23%</td><td>77%</td></tr>
<tr><td>SB</td><td>63%</td><td>38%</td><td rowspan="4">58%</td><td rowspan="4">42%</td></tr>
<tr><td>RB</td><td>55%</td><td>45%</td></tr>
<tr><td>RB+P</td><td>50%</td><td>50%</td></tr>
<tr><td>RB+P+AB</td><td>62%</td><td>38%</td></tr>
</table>

The influence of both type of restraint system and the dashboard intrusion are examined simultaneously on Table 9 and Table 10. Table 9 shows that for belted occupants (front seat occupants), hollow organ injuries are predominant (68%) in the accidents where the dashboard intrusion is smaller or equal to 24 cm while solid organ injuries are predominant (66% and 77%) when the intrusion is above the threshold of 25 cm. Table 10 shows that for unbelted occupants (front seat occupants), solid organ injuries are predominant (78%, 75% and 78%) even for a dashboard intrusion lower or equal to 24 cm.

Table 9 - Hollow and solid organ injury frequency for belted occupants as a function of dashboard intrusion

Belted	≤24 cm	25-45 cm	> 45 cm
Hollow organs	138 (68%)	17(34%)	6(23%)
Solid organs	66(32%)	33(66%)	20(77%)

Table 10 – Hollow and solid organ injury frequency for unbelted occupants as a function of dashboard intrusion

UnBelted	≤24 cm	25-45 cm	> 45 cm
Hollow organs	17 (22%)	9(25%)	8(22%)
Solid organs	61(78%)	27(75%)	29(78%)

INFLUENCE OF THE OCCUPANT SEATING POSITION - Among the 5699 occupants selected, 3221 were drivers, 1406 were non-drivers in the front seat, and 1072 were in the rear seat. Among the drivers, 205 sustained AIS3+ abdominal injuries, while 107 of the front-seat non-drivers and 60 of the rear-seat occupants sustained abdominal injuries at that severity level. For each seating position, the number of occupants involved, the number of occupants injured and the risk of injury are given in Table 11 for unbelted occupants and in Table 12 for belted occupants.

Table 11 - Distribution of unbelted occupants as a function of their position on the car

Unbelted occupant		Driver	Front seat	Rear seat
40-49 km/h	Injured (n)	24	9	9
	Involved (n)	568	213	415
	Injury risk (%)	4.23	4.23	2.17
50-59 km/h	Injured (n)	29	2	3
	Involved (n)	331	103	273
	Injury risk (%)	8.76	1.94	1.10
60-69 km/h	Injured (n)	28	4	7
	Involved (n)	111	41	137
	Injury risk (%)	25.23	9.76	5.11
70-79 km/h	Injured (n)	6	5	1
	Involved (n)	13	10	18
	Injury risk (%)	46.15	50.00	5.56
Total	Injured (n)	87	20	20
	Involved (n)	1023	367	843
Corrected overall injury risk (%)		14.94	8.64	3.07

Table 12 - Distribution of belted occupants as a function of their position on the car

Belted occupant		Driver	Front seat	Rear seat
40-49 km/h	Injured (n)	10	11	8
	Involved (n)	912	408	70
	Injury risk (%)	1.10	2.70	11.43
50-59 km/h	Injured (n)	44	36	17
	Involved (n)	781	350	84
	Injury risk (%)	5.63	10.29	20.24
60-69 km/h	Injured (n)	46	29	7
	Involved (n)	423	231	49
	Injury risk (%)	10.87	12.55	14.29
70-79 km/h	Injured (n)	18	11	8
	Involved (n)	82	50	26
	Injury risk (%)	21.95	22.00	30.77
Total	Injured (n)	118	87	40
	Involved (n)	2198	1039	229
Corrected overall injury risk (%)		7.48	9.86	16.86

The results from Table 11 and Table 12 show that for unbelted occupants, the abdominal injury risk is the highest for drivers (15%). In contrast, for belted occupants the injury risk is the highest for the rear seat occupants (17%). For any seating position and any restraint system, abdominal injury risk increases as a function of the EES.

The hollow and solid organ injury frequencies are reported in Table 13 for unbelted occupants as a function of the seating position. No significant difference was observed (p=0.6).

Table 13 - Hollow and solid organ AIS 3+ injury frequencies for unbelted occupants as a function of the seating position

Unbelted	Driver	Front seat	Rear seat
Hollow organs	26 (21%)	8(29%)	5(26%)
Solid organs	97(79%)	20(71%)	14(74%)

The hollow and solid organ injury frequencies are reported in Table 14 for belted occupants as a function of the seating position. Significant differences were observed for both hollow and solid organ injury frequencies between drivers and front seat non-drivers, and between drivers and rear seat occupants (p=0.01). However, no significant difference was observed between front and rear seat passengers for hollow or for solid organ injury frequencies (p=0.4).

Table 14 - Distribution of AIS 3+ abdominal injuries for belted occupants as a function of their seating positions.

Belted	Driver	Front seat	Rear seat
Hollow organs	77(52%)	84(63%)	40(69%)
Solid organs	70(48%)	49(37%)	18(31%)

Table 15 and Table 16 show that, for both drivers and front seat passengers, hollow organ injuries are more frequent in the cases where intrusion is smaller or equal to 24 cm while solid organ injuries are more frequent for intrusion greater than 25 cm.

Table 15 - Hollow and solid organ injury frequency for belted front seat occupants as a function of dashboard intrusion

Belted front seat passenger	≤24 cm	25-45 cm	> 45 cm
Hollow organs	83 (67%)	1 (20%)	0(0%)
Solid organs	41(33%)	4 (80%)	4(100%)

Table 16 - Hollow and solid organ injury frequency for belted drivers as a function of dashboard intrusion

Belted driver	≤24 cm	25-45 cm	> 45 cm
Hollow organs	55 (69%)	16(36%)	6(27%)
Solid organs	25(31%)	29(64%)	16(73%)

INFLUENCE OF THE OCCUPANT AGE - In order to estimate the influence of age on the occurrence of AIS 3+ abdominal injury risk, an analysis of the average age was done. The average age of occupants sustaining an AIS 3+ abdominal injury was calculated. The same calculation was done for the occupants with no AIS 3+ abdominal injury. A statistical test was performed to check if there was a significant difference between the two average ages.

Table 17 : Comparison of average age

	Average age
Occupants sustaining AIS 3+ abdominal injury	38.56 [36.84; 40.28]
Occupants without AIS 3+ abdominal injury	35.39 [34.96;35.8]
T Test results	t value = -3.71 p = 0.0002

Results show that the occupant age significantly influences abdominal injury risk. Table 17 reports that the occupants with an AIS 3+ abdominal injury are significantly (p=0.0002) older than the occupants with no AIS 3+ abdominal injury.

MULTIVARIATE ANALYSIS - A logistic regression was performed on the front-seat occupants in order to assess AIS 3+ abdominal injury risk as a function of the explanatory variables: EES, dashboard intrusion, type of restraint system, occupant position, and occupant age. Adjusted odds ratios (OR) were calculated for each of those variables.

The results from the regression are reported in Table 18. Each explanatory variable included in the regression significantly influenced the AIS 3+ abdominal injury risk. It is reminded that the logistic regression requires to chose a reference point of each variable (i.e. one of the values of the variable), which is used to explain the results across the entire variable. The reference points for each explanatory dimension are highlighted in italics in Table 18.

Table 18 – Results of the logistic regression

Number of Observation = 4627			
	Adjusted OR	min	max
EES			
40-49 km/h	-	-	-
50-59 km/h	2.66	1.89	3.75
60-69 km/h	4.75	3.28	6.89
70-79 km/h	11.18	6.83	18.31
Dashboard Intrusion			
< 24 cm	-	-	-
25-44 cm	2.27	1.64	3.16
> 45 cm	4.85	3.21	7.31
Restraint system			
Unbelted	-	-	-
SB	1.21	0.76	1.92
R	0.51	0.38	0.68
R+P	0.46	0.29	0.75
R+P+AB	0.56	0.38	0.82
Position			
Driver	-	-	-
Front seat	1.47	1.13	1.91
Age	1.013	1.006	1.020
Percent concordant pairs: 74.7 Somers'D=0.5 Gamma=0.5 Tau-a=0.06 c=0.75			

Note that the parameters Somers'D, Gamma Tau-a and c give information about the quality of the regression. Somers'D, Gamma, and Tau-a range between -1 and 1, c ranges between 0 and 1. The closer the value is to one, the better the regression.

The values reported for the 95% confidence limits show that each level of EES has a significant influence on the AIS 3+ abdominal injury risk, and that the OR increases with EES.

The same conclusions can be drawn for dashboard intrusion. The OR increases with the dashboard intrusion.

Regarding the type of restraint system, the odds ratios show that the abdominal injury risk is different for the occupants retrained using retractor belts (smaller than one, significant) compared to those unrestrained.

The abdominal injury risk decreased with the introduction of the seat belt retractors. For example, the odd ratio reported for the occupants restrained with retractors and pretensioners is 0.46 [0.29; 0.75] compared to the unbelted occupants.

The odd ratio for occupant position shows that the abdominal AIS3+ injury risk is higher for front seat passengers than for drivers.

The age was used in the regression as a continuous variable. The adjusted OR related to the age is 1.013. The AIS 3+ abdominal injury risk increases with the age by a factor 1.3% per year.

DISCUSSION

SUMMARY OF FINDINGS - Abdominal injury risk increases with crash severity (Table 3 and Table 5). The most vulnerable unbelted occupants are drivers while the most vulnerable belted passengers are rear-seat occupants (Table 11 and Table 12).

For unbelted occupants, solid organ injuries are predominant regardless of dashboard intrusion and occupant seating position (Table 8, Table 10, and Table 13).

For belted occupants, hollow organs are more frequently injured for front seat, non-drivers and for rear-seat occupants than for drivers (Table 14). However, solid organs injuries are predominant when the dashboard intrusion is greater than 25 cm (Table 6). For belted drivers and front seat non drivers, no significant difference was noted on the injury pattern (Table 15 and Table 16).

The introduction of retractor belts significantly decreases the AIS 3+ abdominal injury risk for front seat occupants (Table 7).

INTERPRETATION OF FINDINGS - The largest difference in the abdominal injury risk among the different types of restraint systems was observed between the restraint systems with retractors and those without. In France, when an occupant is reported fatally injured by the first-aid workers at the accident scene, it is very seldom that an autopsy is performed. As a consequence, precise information regarding the severe abdominal injuries is not systematically provided. It is thus highly probable that the frequency of severe abdominal injuries is substantially under-estimated. These cases were more frequent when the occupants were unbelted or in older cars where intrusion is larger and retractors are often not present. As a consequence, the decrease observed regarding the abdominal injury risk due to the introduction of the belt retractor is likely to be underestimated.

Although the results showed an increase (non significant) of the AIS 3+ abdominal injury risk with the use of a static belt compared to non-restraint occupants (Table 7), it must be emphasized that the fatality rate was proved to be significantly decreased by the use of static seat belts [Hartemann, 1985].

Similarly, the results showed that the abdominal AIS3+ injury risk was higher for belted rear occupants (16.86%) than for unbelted ones (3.07%). It must be noted that for rear belted passengers, the lack of intrusion can result in injuries primarily located where the body is in contact with the seat-belt (including the abdomen) while for unbelted occupants the injuries are likely to occur in any body area hitting the interior of the vehicle during the crash (head, thorax, and knees first). Despite the increase of abdominal injury risk, the drop of the fatality rate from 13.4% to

3.4% by means of safety improvements including the restraint systems must be emphasized.

The results reported in Table 7 show that for front seat occupants, for EES between 70 and 79 km/h, the abdominal AIS3+ injury risk was 7.69% for a restraint system composed of a seat belt with retractor and pretensioner while it was 32.61% when an airbag was added. The effectiveness of the airbag to prevent fatalities was previously proved [Foret-Bruno 2001]. This result is thus very likely linked to the under-estimation of the abdominal injuries in the crashes where the occupants are killed (discussed above).

COMPARISON WITH PREVIOUS DATA - Based on NCSS and NASS data respectively, Bondy [Bondy, 1980] and Elhagediab [Elhagediab and Rouhana, 1998] reported the liver, the spleen and the digestive system injuries to be the most frequent abdominal injuries in frontal crashes. Our results are in good agreement with those two studies. Indeed, the spleen (141), the jejunum (102) and the liver (101) are reported in Table 2 as the most frequent injuries in our sample.

The difference in injury order may be attributed to the difference in the ratio between belted and non belted occupants in France versus in the US, where unrestrainted occupants still accounted for a considerable share of abdominal injuries (Yoganandan, 2000). In addition, pretensioners and belt load limiters seem to be more frequent in Europe than in the US.

The steering wheel is assumed, in Bondy and Elhagediab studies, to be responsible for the spleen and liver injuries (Elhagediab, 1998). In our study, the injury source for liver and spleen can not be identified from the results obtained.

According to McElhaney [McElhaney, 1976] and Elhagediab [Elhagediab, 1998], the proximity of the large and small intestine to the lap belt may result in intestine injuries. According to McElhaney, the injuries caused by a 2-point shoulder belt are primarily solid organ injuries (liver and spleen) while the injuries caused by a 3-point belt involved small intestine and duodenum. This observation is in agreement with our results.

Yamada [Yamada, 1970] showed that the tensile strength of the stomach, the large and small intestines, the kidneys, and the urinary bladder decreased with age. This may contribute to the increase of the abdominal injury risk with age.

LIMITATIONS - The principal limitation of the findings of this paper is that all the results were obtained from a French database composed of vehicles from several brands commercially available in France from 1970 to 2005. Since the types of restraint systems were proved to influence the abdominal AIS3+ injury risk, the results may differ from one country to another if the devices used to compose the restraint systems and the ratio of belted / unbelted occupants were not identical.

The cases were drawn from a sample of crashes according to six selection criteria, and therefore the injury risks are representative of the population corresponding to the selected sample and should not be interpreted as representative of the general population involved in crashes.

From the field data analysis, no abdominal injury mechanism was clearly identified. This type of research will be performed using cadaver tests.

CONCLUSIONS

- The abdominal injury risk was observed to increase with EES and dashboard intrusion for front seat occupants.
- The largest difference on the abdominal injury risk among the different types of restraint systems was observed, for front seat occupants, between the restraint systems with retractors and those without.
- The age of the occupant was observed to have statistically significant influence on the abdominal AIS3+ injury risk.
- For unbelted occupants, the abdominal injury risk is the highest for the drivers while for belted occupants the risk is highest for the rear seat passenger.

REFERENCES

Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale (AIS) 1990 Revision. Barrington, IL, 1990.

Bondy N. Abdominal injuries in the National Crash Severity Study. Washington, DC, US DOT NHTSA :80; 1980.

Dischinger P., Ho S., Kerns T. & al. Patterns of injury in frontal collisions with and without airbags. IRCOBI Proceedings, pp 311-319; 1996.

Elhagediab A & Rouhana S Patterns of abdominal injury in frontal automotive crashes. 16th ESV Conference, Windsor Canada, 98-Sl-W-26; 1998.

Faverjon G. Méthodologie des enquêtes sur les accidents réels. Le concours médical 107-30, pp2834-2839 ; 1985.

Foret-Bruno JY., Trosseille X., Page Y. & al. Comparison of thoracic injury risk in frontal car crashes for occupant retrained without belt load limiters and those restrained with 6kN and 4kN belt load limiters. Proc.45th Stapp, p375; 2001.

Foret-Bruno JY. Point sur l'évolution des lesions. Note interne; 2005.

Hartemann F. La ceinture de sécurité. Le concours médical 107-30, pp2841-2847 ; 1985.

Hill J., Parkin S. & Mackay M. Injuries caused by seat belt loads to drivers and front seat passengers. 40th Annual Proceedings American Association For Automotive Medicine, October 7-9, Vancouver, British Columbia; 1996.

Huelke D., Mackay G. & Morris A. Intrabdominal injuries associated with lap shoulder belt usage. Proc., SAE Conf., SAE Paper 930639; 1993.

Insurance Institute for Highway Safety (2003) Washington state sets example for belt use. Status report, 38,1. Arlington, Virginia.

Page Y, Saint Ourens A. Que savons nous de l'efficacité des coussins gonflables de sécurité ? Les cahiers de l'observatoire. Numéro 3. Juillet 1997.

Yamada H. Strength of biological materials. Williams and Wilkins, Baltimore, 1970.

Yoganandan N., Pintar F., Generalli A. & al. Patterns of abdominal injuries in frontal and side impacts. 44th Annual Proceedings Association for the Advancement of Automotive Medicine, Chicago, Illinois, 44:17-36; 2000.