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DOES BMI (BODY MASS INDEX) INFLUENCE THE OCCUPANT INJURY RISK PATTERN IN CAR CRASHES?

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ABSTRACT

The influence of BMI on occupant injury risks is studied using Swedish and US car crash data. A clear general trend of increasing BMI over the years is found. No overall differences in MAIS2+ injury risks comparing the different BMI groups were found. However, when stratifying for crash modes and body regions, different relations to BMI were found, although not consistent between the two datasets. As for occupants of different weight, stature and age, occupants of different BMI have specific needs with respect to optimal protection consideration in cars. Knowledge of differences in injury pattern is one necessary area of information.

Key words: BMI, occupants, accident analysis, injury probability, automobiles

IN SOME PARTS OF THE WORLD, the general body constitution of the population is rapidly growing bigger. One way of categorizing body constitution is to use Body Mass Index (BMI), which is based on stature and weight. Only a few studies have evaluated the influence of BMI on injury risk from car crashes. Mock et al (2002) studied the relationship between body weight and risk of death and serious injury in motor vehicle crashes using NASS data. Mock found increased BMI associated with increased risk of mortality and increased risk of severe injuries in automobile crashes. However, when potentially confounding factors were considered, the relationship was less marked. Mock et al. identified that chest injuries were more likely to occur with higher BMI. This is in agreement with a hospital-based study by Boulanger et al (1992) in which injured, hospitalized motor vehicle crash occupants with higher BMI were more likely to have sustained rib fractures, pulmonary contusions, pelvic and extremity fractures and less likely to have incurred head trauma and liver injuries. In the two studies the analyses were not divided by crash mode, thus giving little insight into potential relation to probable injury mechanisms. Arbabi et al. (2003) studied 189 detailed crash cases, separated to some extent by crash mode (frontal and side impacts), but not stratified in body regions and restraint use. Arbabi et al. found a significant increase in risk of fatality with the obese cohort and indications that the severity of abdominal injuries was reduced (the "cushion effect") and the severity of lower extremity injuries was increased. Also, Arbabi et al. emphasized that the overweight cohort includes people with increased muscle mass, who are not classically "overweight", suggesting a classification based on direct morphologic measurements to be more correct. Wang et al (2003) determined the effect of differences in subcutaneous fat depth on injury patterns in car crashes based on 67 adults, all having MAIS 3 or higher injury. Increased subcutaneous fat depth was associated with significantly decreased injury severity to the abdominal region of females, and a similar, but not statistically significant finding for men. In the latter two studies all the occupants were injured, thus giving information regarding injury severity risk only.

The trend of injury risks (MAIS 2+ and AIS 2+ per body region) versus BMI is evaluated in this study, stratified by crash mode when applicable.

METHODS

Data related to 41,914 occupants from Volvo's statistical accident database in Sweden (years 1976-2004) and 4035 occupants from NASS (CDS) in USA (years 1998-2002) were analyzed. The Swedish data set consists of information about Volvo cars only; data were collected based on a repair cost limit (currently 45000 SEK). The selection from NASS is car size (similar to large Volvo models) and general safety performance (within 95% confidence interval of the death rate ranking of Volvo cars, IIHS 2000). Occupants 150 cm and taller were selected. Occupants with BMI<13, age ≤ 13 or sitting in a seat not equipped with seat belt were excluded as well as those with missing weight information. BMI is calculated as weight/stature^2 (kg/m^2). BMI groups according to Centers of Disease Control and Prevention (CDC, 2005) were used; underweight (<18.5), normal (18.5-24.9), overweight (25.0-29.9) and obese (≥30). As an example; a person 170 cm tall is considered normal if weighing 54 kg to 72 kg.

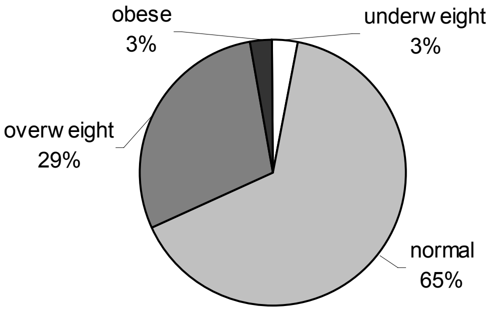

Figure 1a - Distribution of BMI groups in the Swedish Volvo data

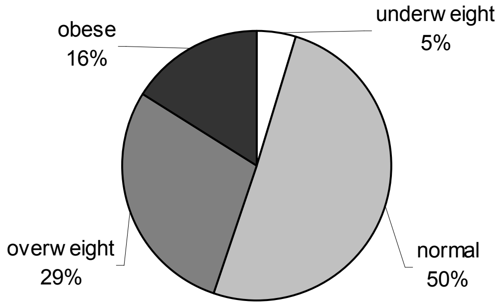

Figure 1b - Distribution of BMI groups in the US NASS data

As seen in Figures 1a and b, 32% of the occupants in the Swedish data are classified as overweight or obese as compared to 45% in the US data. The distribution of BMI groups versus seating position, including percentage of belt usage for each group and position, is shown in Table 1. Seat belt usage is not significantly different between the BMI groups. There is a generally higher seat belt usage in the Swedish dataset as well as a larger number of 3-point seat belts as compared to the US dataset.

Table 1 - Distribution of BMI group versus seating position, belt usage rate for each group and position in brackets.

	Swedish Volvo data			**US NASS data**		
	Driver	Front pass	Rear seat pass	Driver	Front pass	Rear seat pass
Underweight	1% (93%)	5% (93%)	10% (61%)	3% (74%)	8% (62%)	8% (63%)
Normal	62% (93%)	70% (95%)	72% (63%)	49% (80%)	53% (73%)	60% (56%)
Overweight	34% (94%)	23% (95%)	17% (64%)	30% (78%)	26% (76%)	25% (57%)
Obese	3% (93%)	2% (94%)	2% (74%)	18% (73%)	14% (69%)	7% (68%)
Number occ.	**27,670**	**9423**	**4816**	**2942**	**784**	**301**

RESULTS

A general trend of increasing BMI over the years is shown in Figure 2. The Swedish data shows an increase from mean BMI of 23.4 in 1976 to 24.6 in 2004. The US data set shows an increase of 24.5 in 1993 to 25.8 in 2003.

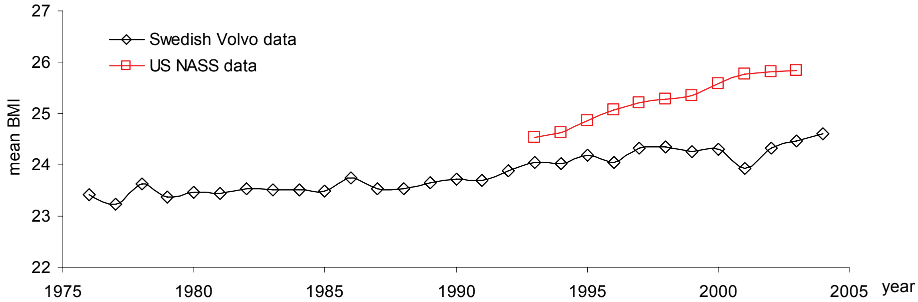

Figure 2 - Mean BMI vs. accident year, the Swedish Volvo data and US NASS data (67,000 occupants in all types of cars in NASS 1993-2003 are included)

There is no general trend between maximum AIS 2+ (MAIS 2+) injury risk and the different BMI groups for all occupants and the subgroups shown for the two datasets in Figures 3a, b. The trend of increased MAIS 2+ injury risk for the unrestrained occupants in frontal impacts in the Swedish data (Fig. 3a) can not be seen in the US data (Fig. 3b). When stratifying this group into body regions, the most obvious relations between AIS 2+ injury risks (per body region) and BMI were seen for chest and lower extremities in the Volvo dataset (increased trend) and for head and face in the US dataset (decreased trend).

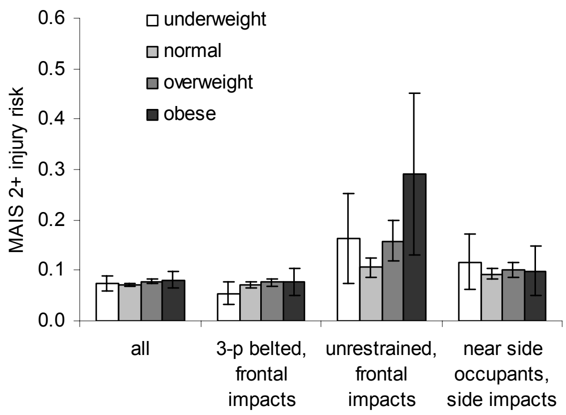

Figure 3a - MAIS 2+ injury risks (incl. 95% conf. intervals) per BMI group in the Swedish Volvo data

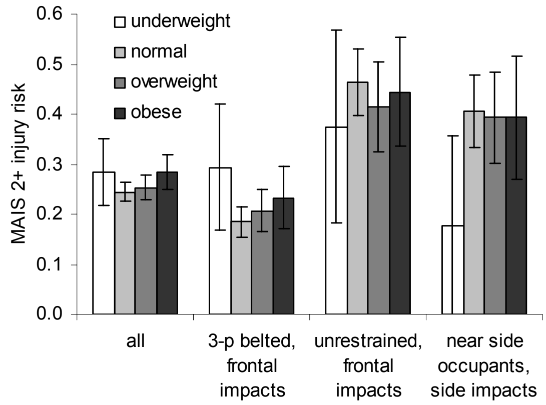

Figure 3b - MAIS 2+ injury risks (incl. 95% conf. intervals) per BMI group in the US NASS data

The AIS 2+ injury risks per body area and BMI group for restrained occupants in frontal impacts are seen in Table 2. No general relationship between MAIS 2+ and BMI can be seen for either of the two datasets (Fig. 3a, b, and Table 2). When stratifying by body parts, different trends can be seen for the two datasets; AIS 2+ chest injury risk being most pronounced, related to increased BMI in the Swedish dataset and AIS 2+ lower extremity injury risk in the US dataset.

Table 2 - AIS 2+ injury risks per body region and overall MAIS 2+ injury risks for 3-p belted occupants in frontal impacts. P-values from logistic regression AIS 2+ injury risks versus BMI, indicating the validity in the regression model.

	Swedish Volvo data					**US NASS data**				
AIS 2+ injury risk	Under-weight	Normal	Over-weight	Obese	p-value	Under-weight	Normal	Over-weight	Obese	p-value
Head + Face	2.7%	2.7%	2.5%	1.6%	0.33	7.5%	8.2%	6.7%	8.7%	0.71
Chest	1.6%	2.4%	2.7%	4.6%	0.00	11.3%	7.3%	7.6%	9.2%	0.20
Abdomen	0.5%	0.5%	0.6%	1.6%	0.15	7.6%	3.3%	2.8%	3.3%	0.46
Spine	1.4%	1.4%	1.4%	1.1%	0.70	5.7%	2.2%	2.8%	2.7%	1.00
Upper extr.	0.1%	1.8%	2.2%	2.2%	0.12	9.4%	8.2%	9.2%	10.3%	0.22
Lower extr. (incl. pelvis)	2.2%	2.1%	2.8%	2.7%	0.02	17.0%	10.2%	10.9%	15.7%	0.02
Maximum	5.4%	7.1%	7.6%	7.6%	0.18	29.4%	18.5%	20.7%	23.3%	0.05
Number occ.	**367**	**8784**	**4024**	**367**		**53**	**645**	**358**	**184**	

Arbabi et al. (2003) and Wang et al. (2003) suggested that abdominal injuries are reduced with increased BMI. In this study, no relationship between AIS 2+ abdominal injury risk and BMI could be seen for the total number of occupants, nor for the unrestrained occupants in frontal impacts. However, in side impact for occupants on the struck side, an increasing trend of AIS 2+ abdominal injury risk for increased BMI could be seen in the Swedish data but not in the NASS data.

DISCUSSION

This study explores the injury risk differences as a function of BMI using real world crash data, involving both injured and uninjured occupants. No general relationship between BMI and MAIS 2+ injury risk was found. When stratifying by frontal and side impacts, a trend was found, suggesting an increase in MAIS 2+ with increased BMI for the unbelted occupants in frontal impacts in the Swedish dataset. Chest AIS 2+ injury risk was found related to increased BMI for restrained as well as unrestrained occupants in frontal impacts in the Swedish data, supporting findings by Boulanger et al. (1992) and Mock et al. (2002), while lower extremities was also found to be related mainly for the unrestrained occupants. A relationship between increased BMI and decreased risk of head and facial injury risk for unbelted occupants in frontal impacts was seen in the NASS data, supporting the observations by Boulanger et al. (1992). The "cushion effect" as suggested by Arbabi et al. (2003) was not found in this study. An effect of BMI on abdominal injury risk was seen in the Swedish data in side impacts, and there with a reverse relation as compared to the hypothesis of Arbabi et al. (2003).

The findings in this study, which are based on two different datasets, suggest partly different trends and emphasize the complexity of understanding the influence of BMI on injury risk. As discussed by Wang et al. (2003); an individual's fat depth can influence his body's ability to tolerate injurious forces, acting both as an energy absorbing material but also increasing the occupant's kinetic energy and thus increasing the loads. BMI might not be the optimal measure of body constitution. Using available datasets, a factor based on occupant stature and weight was the only feasible measure. Wang et al (2003) used subcutaneous fat depth as an indicator of body constitution. However, this information is only available in limited hospital datasets, where all occupants are injured, and will provide another type of information as compared to the data used in this analysis.

The general increase in body size in the population adds a new dimension to occupant characteristics. For this reason it is important to understand the difference in injury occurrence based not only on occupant size, such as stature and weight, but also the aspect of body constitution. Occupants of larger size than normal might have specific needs with respect to occupant protection in cars. A short and heavy driver constitutes a different loading pattern on the restraints as compared to a tall driver of the same weight. Even if the data suggests a "growing population" in some countries, it is suggested that the focus of occupant protection activities should not be moved from normal sized to a larger sized occupant, but rather the scope of these efforts should be expanded to include this dimension of occupant characteristics.

Knowledge of differences in injury patterns is only one area of information needed. Other important areas are knowledge regarding differences in respect to anatomy, ergonomical issues and biomechanical tolerances and mechanisms. Research is strongly encouraged in order to gather more data to be used as a basis for car safety improvements focusing on this dimension of occupant characteristics.

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