Motorcycle Crashes into Road Barriers: the Role of Stability and Different Types of Barriers for Injury Outcome

Matteo Rizzi, Johan Strandroth, Simon Sternlund, Claes Tingvall, Brian Fildes

Abstract This research focused on motorcycle crashes into road barriers and addressed two research questions: the first to assess if injury risk for motorcyclists is affected by collisions with different types of barriers, and the second, to examine if injury outcome in these crashes can be affected by being in an upright position during the collision. Police-reported motorcycle crashes into road barriers in Sweden between 2003 and 2010 were analyzed across different barrier types, using the Fatal-Serious-Injury Ratio (FSI). In addition, 55 in-depth interviews with Swedish motorcyclists who had crashed into road barriers were included to measure threat-to-life and medical disability.

The analysis of police records showed no statistically significant difference between the FSI-ratios for wire rope barriers, Kohlswa-beam and W-beam barriers, although these FSI-ratios were generally very high. The small number of in-depth case findings, however, showed that injury severity was lower in crashes in which the motorcyclists were in an upright position during the collision. The proportion of subjects with ISS 16+ was 24% lower in those crashes compared to those who slid into the barrier. In addition, AIS 2+ and AIS 3+ injuries were 22% and 12% lower, respectively. The mean Risk for Permanent Medical Impairment 10% (RPMI) was 51% lower, and leg injuries were more common although these results were not statistically significant. While the implementation of Anti-lock Brakes on motorcycles may improve stability during critical situations, further development of integrated leg protectors might still be needed.

Keywords Crash, Injury Risk, Motorcycle, Road Barrier, Stability.

I. INTRODUCTION

Every year approximately 50 motorcyclists are killed and almost 400 are severely injured on the Swedish roads [1]. Motorcycles are becoming increasingly popular in Sweden – the number of motorcycles on the road has doubled during the past decade [1]. While motorcycles may meet important transport needs for their users, due to the growing congestion in urban areas and the demand for more energy-efficient transport, they may also meet important future needs for the whole society. However, a disadvantage associated with motorcycles is their shortfall in safety, compared to passenger cars. Previous studies [2] have shown that during the last 25 years the risk of being killed or severely injured when an injury crash occurred in Sweden has been quite constant for motorcyclists. Motorcycle crashes into road barriers, in particular, represent an increasing problem as well as an area of great concern to the motorcycle community. Previous studies have shown that these crashes have a higher injury risk, compared to all motorcycle injury crashes in general [3] – [4], and the likelihood of being fatally injured as a motorcyclist in a collision with a road barrier was reported to be 80 times higher for motorcyclists than for passenger car occupants in the USA [5]. While different road barriers may have different injury risks for motorcyclists in the event of a crash [5] –[6], the issue of whether the motorcyclist collides with the barrier in an upright position or slides into it is also of relevance, as the injury mechanisms may change [7].

This research set out to investigate these issues by addressing two research questions:

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1. to investigate if motorcyclists' injury risk differs in collisions with different types of road barriers;
2. whether the injury outcome in motorcycle crashes into road barriers can be reduced when the motorcyclist is in an upright position prior to collision.

II. METHODS

This research involved an analysis of police reported crash data and a small sample of in-depth interviews with motorcyclists who had crashed into road barriers. While the first research question was investigated using police reports, the second one analyzed interviews with motorcyclists. Both analyses compared motorcyclists' injury outcomes, as described below.

Police reported crashes

This research used the STRADA database (Swedish Traffic Accident Data Acquisition) which contains all police reported road crashes in Sweden since 2003. However, this database does not automatically keep records of collision partners. As each crash includes a brief description written by a police officer attending the crash scene, text search was used to find keywords related to motorcycle crashes into road barriers. Crashes containing the word "barrier" ("räcke" in Swedish) in the crash description were then merged with the National Road Database (NVDB) to get further information regarding the type of barrier, type of road and other infrastructure details. Crashes without a match between the STRADA and NVDB databases were excluded. Cross-checks were also performed through Google Street View to get a better understanding of how the crash site may have looked. After this process, 160 motorcycle crashes into any kind of road barrier that had occurred in Sweden during the period 2003 to 2010 were available for analysis. Some examples of road barriers [8] are shown in Appendix I.

TABLE I

Road barriers in police -reported motorcycle injury crashes in Sweden 2003-2010

Type of barrier	n	%
Concrete	4	3%
Pipe-beam	8	5%
Kohlswa-beam	36	23%
W-beam	45	28%
Wire rope	35	22%
Other	2	1%
Unknown	30	19%
SUM	160	100%

The injury outcome in motorcycle crashes into different types of road barriers was analyzed by grouping crashes depending on speed area, type of road and annual average daily traffic (AADT). As mentioned above, police records do not include diagnoses and therefore injury outcomes were analyzed using the Fatal-Serious-Injury Ratio (FSI) for each group, as shown below.

$$FSI\ ratio = \frac{number\ of\ fatally\ and\ severely\ injured\ motorcyclists}{number\ of\ injured\ motorcyclists} \quad (1)$$

In order to identify crashes that had occurred on roads with similar standards, FSI-ratios were separately calculated for roads with speed limit 90 km/h or above, for divided roads (with median barrier or median reserve) and roads with at least 4000 AADT.

As noted in other studies [9], police data are generally known to suffer from a number of data quality problems. However, it was assumed that this limitation would equally affect all groups and therefore was not expected to affect this analysis. The difference between the two groups´ proportions of FSI was tested by a two proportion z-test for independent observations.

Interviews with injured drivers

Police records do not normally include the level of information needed to answer the first research question; therefore it was decided to expand this material by carrying out telephone interviews with motorcyclists involved in these crashes. Crashes that had occurred in 2010 were excluded from this process because of possible sensitivity issues for the participants. Subjects' personal information for 105 cases was obtained from the Swedish Transport Agency. Before being contacted, the participants were informed about this project with an explanatory statement sent to their home address. Those who were willing to participate were asked a number of questions regarding their motorcycling habits, use of protective equipment, injuries sustained in the crash as well as the pre-crash and crash phases. The following guide was used:

- General description of the crash
- Description of injuries sustained in the crash
- Crash site, weather and road conditions
- Critical factors at the crash site (i.e. heavy traffic, poor road conditions etc)
- Driving speed before crash
- Reaction before crash (i.e. hit the brakes, swerved, accelerated, no reaction etc)
- Collision phase (i.e. type of barrier hit, how it was hit etc)
- Motorcycle characteristics (i.e. make, model, year of manufacture, ABS-fitment etc)
- Previous motorcycling experience
- Previous experience with the motorcycle involved in the crash
- Use of protective equipment (i.e. helmet, back protector, motorcycle boots etc)

The interviews were made on evenings or weekends and normally took 20 minutes. While the STRADA database includes hospital records as well, these were available for only 35% of cases. The injuries were then coded according to the AIS 2005 system [10], based on the participants' description. Cross-checks were also made in those cases with an available hospital record to identify possible discrepancies in the diagnoses. Cases with unclear diagnoses were excluded (n=4). Further 10 cases were excluded due to insufficiently detailed information (see Appendix III). Finally, material from 55 participants was available for analysis. Age and gender of participants are shown in Table II while the distribution of injuries (n=119) per body region and AIS level is presented in Fig 1.

TABLE II
Age and gender of participants in interviews

Age	Male	Female	SUM	%
18-24	10	1	11	20%
25-34	15	2	17	31%
35-44	10	2	12	22%
45-54	6	5	11	20%
55-64	1	1	2	4%
65+	2	0	2	4%
SUM	44	11	55	100%

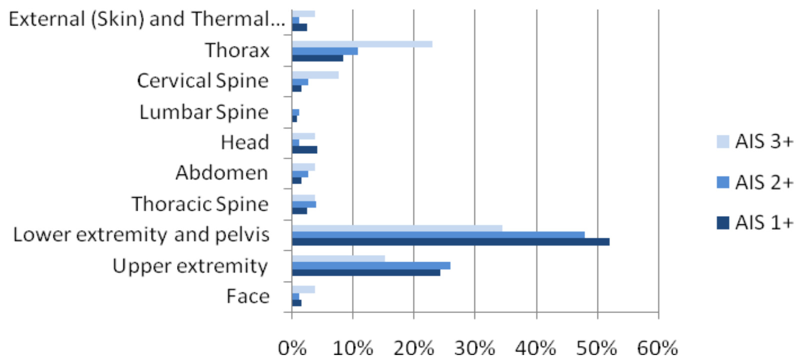

Fig. 1. Injury distribution per body regions and AIS level, n injuries=119.

Analysis of interviews

Injuries among motorcyclists who crashed into the road barrier in an upright position were compared with injuries among other motorcyclists who fell to the ground before the collision and slid into the barrier. Other factors that could affect injury outcome (i.e. driving speed and use of protective equipment) were analyzed. The overall injury outcome in terms of fatality risk was analyzed using a number of measures, based on the 2005 Abbreviated Injury Scale (AIS) [10] that measures the threat-to-life after sustaining an injury. The Injury Severity Score (ISS), a measure of overall injury severity comprising the sum of the squares of the highest AIS scores in three different body regions, MAIS (Maximum Abbreviated Injury Scale) and the distributions of AIS 2+ and AIS 3+ injuries were analyzed. The difference between the two groups' proportions of AIS, MAIS and ISS was tested using chi-square statistics.

In addition, each subject's injury scores were also converted to a Risk for Permanent Medical Impairment (RPMI) which shows the risk of long-term disability, given the severity and location of the injuries sustained. The mean value of RPMI for the two groups was then compared. The difference between two groups' mean value of RPMI was tested by an independent two sample t-test which was conducted for unequal sample sizes and variance.

Risk for Permanent Medical Impairment (RPMI)

As mentioned above, RPMI is an estimation of the risk for a patient to suffer from a certain level of medical impairment, based on the diagnosed injuries. As a reference, amputation of a foot or tibia is set to an impairment of 9 and 19%, respectively. The risk is derived from risk matrices for 1%, 5% and 10% medical impairment which have been presented in a previous empirical study [11]. In the present study, AIS values from the three most injured body regions on motorcyclists were applied on these risk matrices to obtain values for risk1, risk2 and risk3, respectively. These risks were selected from the matrices depending on the location and AIS level of the injury. RPMI was then calculated according to the equation below, as shown in [11].

$$RPMI = 1 - (1 - risk_1) \times (1 - risk_2) \times (1 - risk_3) \quad (2)$$

III. RESULTS

Police reported crashes

As shown in Table I above, in 19% of all available crashes the type of barrier was unknown. Among the remaining 81% of crashes, 73% involved wire rope, Kohlswa-beam and W-beam barriers. It was therefore decided that the material including pipe-beam and concrete barriers was too limited and was excluded from the analysis.

Comparisons were carried out to identify possible discrepancies in the remaining material. The FSI-ratios were calculated for different speed areas, road widths, road types, barrier positions and AADT. While police data do not include information on driving under influence of alcohol or use of protective equipment, driver characteristics such as age and gender were also checked without finding major variations.

The FSI-ratios are presented below with statistical significance between each type of barrier and the others included in the analysis. An attempt to identify further trends was also made by grouping crashes involving Kohlswa-beam and W-beam barriers, as their structure was considered to be similar.

The findings for speed areas 90 km/h or above showed no statistically significant difference between wire rope, Kohlswa-beam and W-beam barriers (see Table III). While the material was limited, wire rope barriers had a 52% FSI-ratio which was slightly lower than for Kohlswa-beam and W-beam barriers together (55%). Similar results were found for divided roads, as no statistically significant difference was found between the analyzed types of barriers (see Table IV). With regard to roads with AADT larger than 3999, Kohlswa-beam barriers were found to have a FSI-ratio lower than in the previous calculations (35%). The only statistically significant difference was found between Kohlswa-beam and W-beam barriers (p<0.04, see Table V).

TABLE III
Comparison of FSI-ratios for road barriers in speed areas >90 km/h

			p values			
90 km/h or above	n	FSI-ratio	Wire rope	Kohlswa-beam	W-beam	Kohlswa and W-beam
Wire rope	29	52%	-	*0.71*	*0.57*	*0.79*
Kohlswa-beam	9	44%	*0.71*	-	*0.44*	*0.58*
W-beam	20	60%	*0.57*	*0.44*	-	*0.74*
Kohlswa and W-beam	29	55%	*0.79*	*0.58*	*0.74*	-

TABLE IV
Comparison of FSI-ratios for road barriers on divided roads

			p values			
Divided roads	n	FSI-ratio	Wire rope	Kohlswa-beam	W-beam	Kohlswa and W-beam
Wire rope	34	59%	-	*0.43*	*0.41*	*0.92*
Kohlswa-beam	17	47%	*0.43*	-	*0.16*	*0.37*
W-beam	23	70%	*0.41*	*0.16*	-	*0.45*
Kohlswa and W-beam	40	60%	*0.92*	*0.37*	*0.45*	-

TABLE V
Comparison of FSI-ratios for road barriers on roads with AADT>3999

			p values			
AADT > 3999	n	FSI-ratio	Wire rope	Kohlswa-beam	W-beam	Kohlswa and W-beam
Wire rope	21	57%	-	*0.16*	*0.46*	*0.72*
Kohlswa-beam	20	35%	*0.16*	-	0.04	*0.20*
W-beam	22	68%	*0.46*	0.04	-	*0.23*
Kohlswa and W-beam	42	52%	*0.72*	*0.20*	*0.23*	-

Interviews with injured drivers

The initial response rate was 62%, although 10 interviews were excluded from the analysis due to insufficiently detailed information (see Appendix III). The response rate among slightly injured motorcyclists included in the analysis (51%) was very similar to the one for severely injured motorcyclists (54%). Furthermore, the distributions of slightly and severely injured among the initial sample for interviews (n=105) and the analyzed interviews (n=55) were very similar (see Appendix III).

The analysis of interviews with 55 motorcyclists who sustained injuries in a crash into a road barrier showed that 20 (36%) of them had fallen off the motorcycle prior to collision. In the other 35 cases (64%) the participant reported being on the motorcycle in an upright position during the collision. The groups were named as A and B, respectively, to distinguish them more easily (see Table VI).

TABLE VI
Collision type into the road barrier

Group	Description	n	%
A	Fell off the motorcycle prior to collision	20	36%
B	Crashed in an upright position	35	64%

Only 6 participants drove a motorcycle equipped with Anti-lock Brakes (ABS). All of them had crashed into the road barrier in an upright position.

Comparisons were carried out to ensure that the two groups were comparable in terms of injury risk. The results showed similar distributions of factors that may affect injury risk in a crash, such as reported speed compliance, use of protective equipment and run-off angle. The average age of motorcyclists in group A (fell off the motorcycle) and group B (crashed in an upright position) was 33 and 37, respectively. While the distributions of types of barriers were similar, the average speed limit in groups A and B was 76 km/h and 82 km/h, respectively. Also, the distributions of crashes in speed areas 90 km/h or above were 57% for group B and 40% for group A (see Figure 2), thus indicating that crashes in group B had generally higher speed limits. Further results are presented in Appendix III.

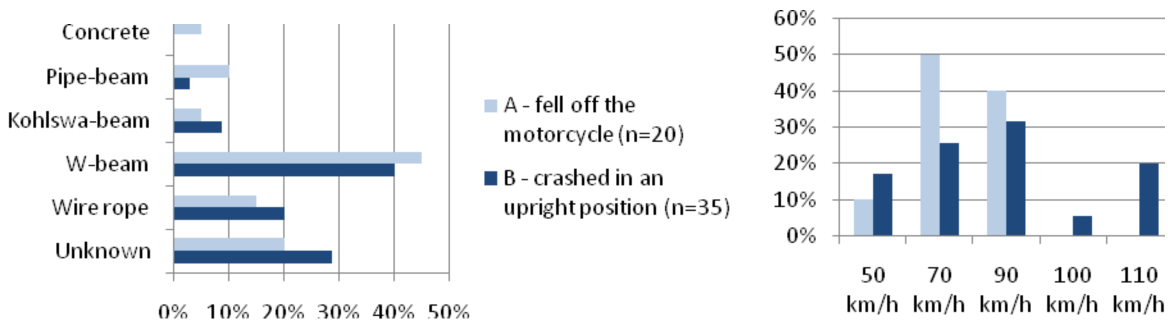

Fig. 2. Road barriers and speed limits involved in the 55 interviews.

While hospital records were available for 35% of cases (n=19), crosschecks were made to compare the reported diagnoses with the ones based on self-reported injuries. A comparison of ISS values is presented in Appendix III. The findings of the analysis of injury outcomes in groups A and B are showed in Table VII. The shares of AIS 2+ and AIS 3+ injuries in group B (crashed in an upright position) were respectively 22% and 13% lower than in group A (fell off the motorcycle prior to collision). These results were statistically significant at the 99% level ($p<0.01$). The shares of MAIS 2+ and MAIS 3+ were also lower in group B (9% and 12%, respectively), although these results were not statistically significant at the 95% level.

The overall injury outcome was also analyzed using ISS (Injury Severity Score) and RPMI (Risk for Permanent Medical Impairment). While the shares of participants with ISS 1-8 and 9-15 were higher in group B, the share of ISS 16+ subjects was 24% lower than in group A, thus indicating that the overall injury outcome among participants who were in an upright position during the collision was milder. However, the results were statistically significant at the 95% level for ISS 16+ only ($p=0.02$).

Analysis of RPMI showed lower values of mean risk for permanent medical impairment for participants within Group B on 1%, 5% and 10% levels. The mean values of RPMI 1%+, 5%+ and 10%+ in group B were 7%, 26% and 51% lower, respectively. The difference was increasing with higher medical impairment which is consistent with other studies based on RPMI [12], although these results were not statistically significant at the 95% level.

Table VII
Comparison of injury outcomes among groups A and B

	A fell off the motorcycle		B crashed in an upright position		Difference B-A	
AIS 2+	33	(75%)	40	(53%)	-22%	p<0.01
AIS 3+	13	(30%)	13	(17%)	-13%	p<0.01
MAIS 2+	16	(80%)	25	(71%)	-9%	*p=0.48*
MAIS 3+	7	(35%)	8	(23%)	-12%	*p=0.33*
ISS 1-8	11	(55%)	25	(71%)	+16%	*p=0.22*
ISS 9-15	2	(10%)	6	(17%)	+7%	*p=0.23*
ISS 16+	7	(35%)	4	(11%)	-24%	p=0.02
mean RPMI 1%+	57.2%		53.2%		-7%	*p=0.60*
mean RPMI 5%+	33.5%		24.8%		-26%	*p=0.30*
mean RPMI 10%+	19.9%		9.8%		-51%	*p=0.21*

Injuries were also compared depending on the AIS level and body region. The most common AIS 2+ injuries in both groups were in the upper and lower extremities, even though the share of leg injuries in group B (55%) was higher than in group A (39%). While the total number of AIS 3+ injuries was quite limited (n=26), their distribution suggested that AIS 3+ injuries in the lower extremities were more common in group B than in group A (46% and 23%, respectively). Thorax injuries, on the other hand, accounted for 31% of AIS 3+ injuries among group A.

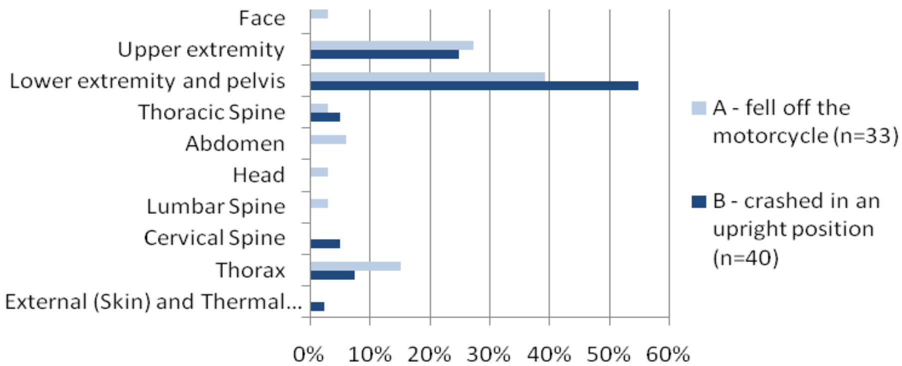

Fig. 3. Injury distribution per body regions for AIS 2+ injuries, n injuries=73.

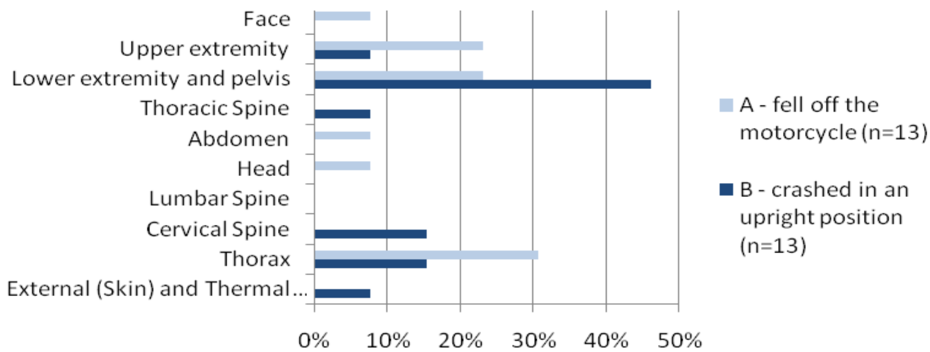

Fig. 4. Injury distribution per body regions for AIS 3+ injuries, n injuries=26

IV. DISCUSSION

While road barriers were originally used to protect from something hazardous, like rocks, trees, heights etc, today they are used more and more for protection against oncoming traffic as well. However, they might pose a risk for motorcyclists as they were originally developed to protect passenger car occupants. This study investigated this issue by analyzing motorcyclists' injury risk in collisions with different types of road barriers. Also, the injury outcome in crashes in which the motorcyclists collided into the road barrier in an upright position was compared to those who slid into the barrier.

Research Question 1 – Type of Road Barrier

The first research question was addressed by analyzing the injury outcome among motorcyclists who had crashed into wire rope, Kohlswa-beam and W-beam barriers from police records. Relevant crashes were identified through text search in the police description of the crash. Even though all police records for the period 2003 to 2010 were used, concrete barriers were excluded from the analysis due to the limited material. The proportion of fatally and severely injured motorcyclists among all injury crashes (FSI-ratio) was analyzed and compared for these three types of barriers. While the limitations of analyzing injury outcome with police data are clear, there is no reason to believe that injury outcomes would be under- or overestimated by police officers for a particular type of barrier.

The analysis showed in almost all cases no statistically significant difference at 95% level between FSI-ratios for wire rope, Kohlswa-beam and W-beam barriers. Kohlswa-beam and W-beam barriers were also grouped and compared with wire rope barriers alone. This was based on the assumption that Kohlswa-beam and W-beam barriers have a similar structure. Another critical assumption was that roads with speed areas of 90 km/h or above as well as divided roads and roads with AADT bigger than 3999 would have similar standards and would therefore be suitable for comparison. Crashes in 50 km/h and 70 km/h speed areas were excluded because only 2 injury crashes involving wire-rope barriers in those speed areas were found in the STRADA database (see Appendix II). Normally the speed limit on a Swedish road is a function of its standards which also depend on the AADT. In most cases, a road with high AADT needs to be divided (with median barrier or median reserve) in order to have at least a 90 km/h speed limit. It was therefore argued that by applying these criteria roads with similar injury risks for motorcyclists would be selected. While controls were made without finding any major discrepancies (see Appendix II), further research in other countries where wire rope barriers are widely used should be carried out, possibly with other methods depending on the data quality.

While the Swedish motorcycle community has raised concerns regarding the safety implications of the large implementation of wire rope barriers during the last years, the present study suggests that such barriers do not imply higher injury risks for motorcyclists than other steel guardrail barriers. However, it should be noted that all FSI-ratios were quite high, in general above 50% or more. As mentioned above, previous studies [2] based on similar material have shown that the average FSI-ratio in all motorcycle crashes in Sweden is around 35%, thus confirming that road barriers constitute a higher injury risk for motorcyclists per se. Further research and testing should therefore be aimed at developing safer barriers for motorcyclists in general.

It should be noted, though, that current wire-rope road barriers have led to fewer crashes for motorcyclists in Sweden. After the installation of median wire rope barriers on 2+1 Swedish roads, the number of fatal and severe motorcycle crashes was reduced by 65%-70% on those roads [15], with no other major infrastructural improvements. This was based on the assumption that motorcycle mileage was constant after rebuilding those roads. While it could be argued that such results could be due to the fact that motorcyclists simply avoided 2+1 roads with wire rope barriers, the authors explained that the effect would still be considerable (32%-35%) even under the assumption that motorcycle mileage was decreased by 50% on those roads.

Research Question 2 – Upright vs Sliding Impact

The second research question was addressed from interviews with 55 motorcyclists who had sustained injuries in a crash into a road barrier. The final response rate was 52% which should be more than acceptable for a telephone survey [16], although a higher response rate could have been expected as road barrier design is an area of increasing concern to motorcyclists in Sweden. However, a comparison with the initial sample including all police reported crashes in Sweden 2003-2009 with personal information (excluding fatal outcomes) suggested that the analyzed material was still representative.

Participants were then grouped depending on how they collided with the road barrier: sliding on the asphalt (group A) or in an upright position (group B). While interview studies are generally known to have limitations [13], it could be argued that this issue should not largely affect the findings of this study as the response rate did not seem to be affected by the injury outcome.

Self-reported injuries were AIS-coded by the research team and the overall injury outcome was analyzed with MAIS, ISS and RPMI. While this method has clear limitations, as it relies on the participant's accurate memory of diagnosed injuries, comparisons were made in those cases with an available hospital report. The results indicated that the diagnoses made by the research team generally agreed quite well with the hospital records, although minor differences were found for AIS 1 injuries. However, it should also be noted that possible discrepancies would probably be spread randomly throughout the material and would therefore equally affect both groups, even though the material was limited. The level of detail given by the participants about the injuries sustained in the crash was normally sufficient to assign AIS levels. As shown in Figure 1, approximately 76% of all injuries were to the upper or lower extremities. The AIS level of such injuries is relatively easy to code, as for instance a fracture could range from AIS 1 to AIS 3 (i.e. finger or open tibia fracture, respectively). While head injuries require much more detailed information (e.g. time of unconsciousness, depth of brain contusion etc) it could be argued that such injuries accounted for 4% of the analyzed material.

A critical step was ensuring that any difference in injury outcome between groups A and B was due to the crash configuration itself. Comparisons were made to analyze any difference between the groups with regards to age, reported use of protective equipment, speed limit, reported speed compliance, run-off angle and type of barrier hit (see Appendix III). Participants who crashed in an upright position were on average older, reported similar use of protective equipment and reported slightly worse speed limit compliance. Besides, crashes included in group B generally occurred on roads with higher speed limits. All these aspects could suggest that crashes in group B should have somewhat higher injury risk than the crashes in group A. The results of this study, however, show a generally lower injury outcome among group B which would indicate that this might be an underestimation.

The analysis showed statistically significant differences between groups A and B in the shares of AIS 2+ and AIS 3+ injuries and the share of subjects with ISS 16+. Other interesting trends were found, although non-statistically significant at a 95% probability level. In particular, the mean value of RPMI 10% for motorcyclists who collided with a road barrier in an upright position was 51% lower than for those who fell off the motorcycle prior to collision. No previous research on RPMI in motorcycle crashes could be found and therefore caution may be needed, as this was a first attempt to analyze the risk for permanent medical impairment for motorcyclists. These findings seem promising and further research needs to be carried out to more exactly quantify this issue. Other methods could be tested too, for instance, multiple logistic regression. It should also be noted that the risk matrices for permanent medical impairment [11] were initially developed for passenger car occupants. While there is reason to believe that a certain injury should have a certain risk for permanent medical impairment regardless of how that injury was sustained (i.e. different road users), further research should confirm this.

Even though the material in the present study was too limited to draw general conclusions, the findings may contribute to further understanding of the mechanisms of injury among motorcyclists. Previous research on real-life crashes has shown that the risk of suffering a critical MAIS 4+ injury would double when a motorcycle rider falls prior to a collision against a passenger car [14]. Crash tests using Hybrid III dummies against steel guard rail and concrete barriers at 60 km/h have shown more survivable loads when the dummy was in an upright position, compared to a sliding crash configuration at the same speed [7]. The results of the present study seem to be in line with this previous research, as they suggested that the overall injury severity as well as the risk for medical impairment were generally lower in crashes in which motorcyclists were in an upright position during the collision. A speculative explanation for this is that the final moments of the chain of events leading to a sliding crash into a road barrier differed from the one in which the motorcyclist crashed in an upright position. While the crash still occurred, more favorable conditions may be provided by the upright position itself. In this case, the motorcycle could absorb part of the impact energy and, to some extent, protect the motorcyclist in the initial impact. However, it is evident that further research should investigate this issue.

These findings also showed that in crashes in an upright position AIS 2+ and AIS 3+ injuries in the lower extremities were more predominant, as they accounted for 55% and 46% of injuries, respectively. While the material was limited, these results may seem reasonable as legs would probably be more exposed to the road barrier in a crash in an upright position with small run-off angles. Further research is warranted to investigate this issue.

In conclusion, the present research found no significant differences in terms of injury risk for motorcyclists between wire rope, Kohlswa-beam and W-beam barriers. Indications were also found that the overall injury outcome and the risk for medical disability could be lower in crashes in which the motorcyclists were in an upright position during the collision. However, AIS 2+ and AIS 3+ injuries to the lower extremities were more common. While further research is needed, there might be reason to believe that improving stability in critical situations may change the chain of events leading to a crash, thus preventing or mitigating injuries. Previous studies have shown that Anti-lock Brakes (ABS) on motorcycles have great safety benefits [17] – [18], probably because of improved stability during hard braking [2]. Interestingly, none of the 6 participants riding ABS-equipped motorcycles included in the present study had slid into the road barrier. Other countermeasures aimed at improving stability, such as Traction Control systems or scooters with two front wheels (i.e. Piaggio MP3) have been implemented and may have positive effect, although no real-world evaluations have been carried out yet. However, the concept of motorcycle crashworthiness could be further developed. For instance, based on the findings of the present study, leg protectors may have an important impact on motorcyclists' injury risk in the future. Today's motorcycles are not as compatible with road barriers as passenger cars are, but the development of integrated rider protectors could be promising and therefore should be further investigated.

V. CONCLUSIONS

- No statistically significant difference at $p<0.05$ between the FSI-ratios for motorcycle crashes into wire rope, Kohlswa-beam and W-beam barriers was found.
- The FSI-ratios for wire rope, Kohlswa-beam and W-beam barriers were in general above 50%.
- Among motorcyclists who collided into road barriers in an upright position, the shares of AIS 2+ and AIS 3+ injuries were significantly lower, 22% and 13% respectively, compared with similar crashes in which the motorcyclist fell off the motorcycle prior to collision.
    - The share of ISS 16+ subjects was 24% lower, statistically significant at 95% level.
    - The mean RPMI on 10% level was 51% lower, although this result was not statistically significant at 95% level.
    - AIS 2+ and AIS 3+ leg injuries were the most common.

VI. ACKNOLEDGMENTS

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VIII. APPENDIX

Appendix I – the most common road barriers in Sweden. Pictures are taken from [8].

W-beam barrier

Pipe-beam barrier

Kohlswa-beam barrier

Concrete barrier

Wire rope barrier

Appendix II – Type of Road Barrier

TABLE A.
Comparison of FSI-ratios for crashes into different types of road barriers

	Cable		**Kohlswa-beam**		**W-beam**		**Kohlswa and W-beam**	
	n	FSI-ratio	n	FSI-ratio	n	FSI-ratio	n	FSI-ratio
Speed area								
50 km/h	1	0%	3	33%	3	67%	6	50%
70 km/h	1	100%	17	35%	18	67%	35	51%
90 km/h	11	64%	6	50%	14	50%	20	50%
100 km/h or more	18	44%	3	33%	6	83%	9	67%
Road type								
Single carriageway with 2 lanes	1	0%	19	37%	21	57%	40	48%
2+1 roads	17	65%	0	-	1	100%	1	100%
Single carriageway with 4 lanes	0	-	4	75%	4	75%	8	75%
Dual carriageway	8	75%	1	0%	0	-	1	0%
Motorway	9	33%	12	42%	18	67%	30	57%
AADT								
0-499	1	100%	3	0%	3	100%	6	50%
500-1999	1	0%	5	40%	9	44%	14	43%
2000-3999	12	58%	5	80%	9	67%	14	71%
4000-5999	8	50%	1	100%	4	75%	5	80%
6000-7999	4	75%	4	50%	7	43%	11	45%
8000-	9	56%	15	27%	11	82%	26	50%
Barrier position								
Side barrier, right	1	0%	7	43%	7	71%	14	57%
Side barrier, left	0	-	5	80%	7	43%	12	58%
Median barrier	29	59%	10	60%	8	75%	18	67%

Appendix III – Upright vs Sliding Impact

TABLE B
Material used for the interviews

Material based on police records	160

Material excluding killed motorcyclists and 2010 cases	121
Material including personal information	105
Explanatory statements sent	105
Participants successfully contacted	65
Participants who did not remember falling off or crashing upright	6
Participants who could not give detailed information on injuries and therefore with unclear diagnoses	4
Analyzed interviews	55

TABLE C
Comparison between police records and analyzed interviews

	Police records with personal information excluding 2010 cases		Analyzed interviews		Response rate
Slightly injured	55	52%	28	51%	51%
Severely injured	50	48%	27	49%	54%
Total	105	100%	55	100%	52%

TABLE D
Crosschecks between calculated ISS and reported ISS

Individual	Calculated ISS	Reported ISS	Difference
93	1	1	0
113	1	1	0
71	4	4	0
12	9	9	0
32	34	34	0
78	38	38	0
91	4	4	0
3	4	4	0
95	22	22	0
97	2	2	0
82	2	2	0
38	4	5	1
55	8	9	1
100	19	18	1
50	4	5	1
58	4	5	1
89	3	2	1
87	4	5	1
116	13	10	3

TABLE E
Comparison between groups A and B

	A - fell off the motorcycle (n=20)	**B - crashed in an upright position (n=35)**
Age		
18-24	20%	20%
25-34	40%	26%
35-44	20%	23%
45-54	20%	20%
55-64	0%	6%
65+	0%	6%
SUM	100%	100%
Back protector		
Used	90%	80%
Not used	10%	20%
Unknown	0%	0%
SUM	100%	100%

Other protective equipment		
All available	75%	83%
MC-jacket, gloves and boots	10%	6%
MC-jacket and gloves	5%	3%
Not used	5%	9%
Unknown	5%	0%
SUM	100%	100%
Speed area		
50 km/h	10%	17%
70 km/h	50%	26%
90 km/h	40%	31%
100 km/h	0%	6%
110 km/h	0%	20%
SUM	100%	100%
Run-off angle		
<20 degrees	35%	46%
21-45 degrees	0%	9%
46-65 degrees	10%	3%
>65 degrees	5%	11%
Unknown	50%	31%
SUM	100%	100%
Reported driving speed		
Within the speed limit	70%	57%
10-30 km/h over the speed limit	25%	17%
>30 km/h over the speed limit	5%	17%
Unknown	0%	9%
SUM	100%	100%