Cyclist Injuries Leading to Permanent Medical Impairment in Sweden and the Effect of Bicycle Helmets

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Abstract Cyclist injuries leading to long-term consequences are common and therefore important to identify in order to design a more sustainable road transport system. The aim of this study was to apply impairment scaling to those injuries to reflect long-term consequences. The Risk of Permanent Medical Impairment (RPMI) was measured for cyclist injuries and compared with the Injury Severity Score (ISS). Type and location of the crash as well as injury distribution were analyzed. The effect of the bicycle helmet was also calculated using induced exposure techniques. The material was Swedish hospital records for the period 2003-2012.

In total 77% of all bicycle crashes in Sweden were single bicycle crashes, most of which were not police-reported. The number of impaired cyclists was more than 3 times larger than those with ISS 9+. Of all impairing injuries, almost 70% were to the upper and lower extremities. Furthermore, almost 10% were head injuries. The most common injuries to the upper extremities were to the shoulder and the wrist (AIS 2). Bicycle helmets were found to reduce head-impairing injuries by 62%, and severe impairing injuries by 68%. The effectiveness in reducing face injuries was lower (37% and 49%, respectively).

Traditional prevention of cyclist injuries has been focused on helmets. However, the findings of the present study indicate a need for other strategies to also prevent other injuries, especially to the upper extremities.

Keywords *bicycles, head injury, helmets, motor vehicle collisions, single bicycle crashes*

I. INTRODUCTION

The popularity of cycling has increased and during the last years more attention has been given from stakeholders to create a safer environment for cyclists. Especially in big cities cycling is an important complement to reduce vehicle congestion and CO2 emission, and to encourage health benefits. According to hospital reported crashes, cyclists account for a higher proportion than any other road user in Sweden [1]. During 2011 cyclists represented 41% of all severe injuries (medical impairment) and car occupants 34%. The injury consequences of bicycle crashes are primarily correlated to non-fatal injuries [2, 3], as cyclists statistically represent around 3% of all road fatalities in Sweden [1].

Based on hospital data for all different bicycle crash types, Juhra et al [4] found that the most frequently injured body region was upper extremities (37%) followed by lower extremities (30%). Also injuries to the head and the skull were common and represented 26% of all injuries. Fractures were the most frequent injury type in bicycle crashes (18%). Less than five percent of all the cyclists suffered a traumatic brain injury.

Previous research has shown that there are different injury patterns in single bicycle crashes and bicycle-car crashes [4, 5]. Head injuries are most common in collision with a motor vehicle, while fractures of the upper extremities are more frequent in collisions with other cyclists or in single bicycle crashes. Cyclists injured in a collision with a motor vehicle are generally the most seriously injured [3]. The most frequently injured body region in fatal crashes is the head.

Previous studies have shown that the effectiveness of helmets in preventing head injuries is 65-88% [6-8]. Also, helmets have been found to protect the part of the face that is near the edge of the helmet [8, 9]. Cyclists, however, are still minimally protected road users. In the best case scenario the cyclist is wearing a helmet. While the use of helmets in Sweden has increased during the last decade [10], this differs on a regional level. For children under the age of fifteen the use of bicycle helmets has been mandatory since 2005 [11]. During

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the time when this study was conducted the use of bicycle helmets ranged from 18% to 32% [10].

There are several ways of describing injuries and measuring loss of health. The collection of injury data and the description and assessment of injury severity play an important role in legislation, research and development of countermeasures. Quality of data, both in terms of reliability and coverage, are important aspects, in particular if underreporting is skewed towards certain types of road users or situations. While police reports are still the main source of information presenting traffic injury outcome, several studies have shown that police records do not reflect the true injury outcome [12, 13]. Injuries to cyclists are even more under-reported than other road users since single bicycle crashes are dominating and often unknown to the police [12]. Therefore, hospital data are more relevant to use to analyse bicycle crashes.

Aside from the collection of injury data the grading of the injury severity might influence the injury picture. The immediate diagnosis following trauma is the main source for assessing the severity and coding of injuries. The Abbreviated Injury Scale (AIS) [14] is one of the most commonly scales used in the traffic injury epidemiology field. The AIS only assesses the severity of a single injury while the ISS (Injury Severity Score) is a method of describing the overall severity of injuries and is calculated by using the highest AIS values for three body regions that are squared and summed, measuring threat-to-life. Another method to measure the injury outcome is to focus on long-term consequences, injuries leading to impairment. Traffic crashes are one of the leading causes of impairment and reduction of productive years among the population [15]. The Swedish Transport Administration (STA) has therefore broadened the definition of serious injuries and since 2008 the definition also includes injuries predicted to lead to permanent medical impairment. To the authors´ knowledge no previous study has been published regarding long-term health consequences to cyclists.

The objective with the present study was to use different methods to classify injury severity to compare how the bicycle injury outcome is affected, as well as the effectiveness figures of bicycle helmets. Based on hospital-reported injuries occurring in bicycle crashes in Sweden the aims of the present study were to:

- analyze type of crash and location of hospital-reported bicycle crashes in Sweden;
- compare injuries leading to medical impairment and ISS 9+ for different crash types;
- analyze injuries leading to medical impairment and ISS 9+ for different body regions and severity levels;
- estimate the effectiveness of bicycle helmets in reducing impairing injuries as well as injuries among cyclists with ISS 9+.

II. METHODS

Material

The STRADA database (Swedish Traffic Accident Data Acquisition) [16], which contains police and hospital records of road crashes in Sweden, was used. The data collection started in 2003 with a gradually increasing national coverage. In 2013 all (but one) hospitals in Sweden are reporting injuries. Hospital reports normally include a number of parameters describing the crash (brief description of the crash, crash type, location etc), personal information about the cyclist (age, gender, use of protective equipment etc) and full diagnoses classifed according to the AIS 2005 scale [14].

All cyclists who were involved in a road traffic crash and received medical treatment at emergency departments of Swedish hospitals during the period 2003-2012 were included in this study; all fatally injured cyclists were excluded. A total of 55,220 records were available for analysis. The age distribution ranged from 1 to 98 years, and the average age was 36 years; 55% of the cyclists were male (n=30,559).

The hospital records were grouped by crash type and location of the crash. The injury data were further analyzed for different body regions by using two injury classification methods: RPMI, Risk for Permanent Medical Impairment [17], and ISS, Injury Severity Score.

Risk for Permanent Medical Impairment (RPMI)

Cyclists' initial diagnoses were converted to the Risk for Permanent Medical Impairment (RPMI) scale which indicates the risk of long-term impairment, given the severity and location of the injuries sustained. RPMI is an estimation of the risk for a person to suffer from a certain level of medical impairment, based on the diagnosed injuries. A medical impairment is considered permanent when no further improvement in physical and/or mental function is expected with additional treatment. The assessment impairment degree is independent of cause and without regard to occupation, hobbies or other special circumstances of the injured person. The injury is given a degree of medical impairment between 1% and 99%. Some general examples are as follows: limited motion of shoulder 1-20%, amputation of tibia is set to an impairment of 19%, total loss of hearing 60%.

The risk is derived from risk matrices for least 1% medical impairment (PMI 1+, see Table I) as well as at least 10% medical impairment (PMI 10+, see Table II), as presented in a previous empirical study [17]. As an example, AIS 2 injuries at the upper extremities have a 35% risk for at least 1% permanent impairment (see Table I) and 3% risk for at least 10% permanent impairment. While PMI 1+ includes all levels of impairments, a PMI10+ results in persistent symptoms affecting activities of daily living of a person.

The scale of permanent medical impairment is based on judgments made by physicians following a nationally applied Swedish model [18]. In the present study, AIS values from hospital records were applied on these risk matrices to obtain risk values for each injury. These risks were selected from the matrices depending on the location and AIS level of the injury. The combined RPMI for each cyclist was calculated based on a product of the risks of not being injured, described by Gustavsson et al [19], see Eq. 1, where *n* is the number of injuries sustained by each cyclist.

$$RPMI = 1 - (1 - risk_1) \times (1 - risk_2) \times (1 - risk_3) \times (1 - risk_n) \tag{1}$$

TABLE I

RISK OF PERMANENT MEDICAL IMPAIRMENT (PMI 1+). NUMBERS IN PERCENT.

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Head	8.0	15	50	80	100
Cervical Spine	16.7	61	80	100	100
Face	5.8	28	80	80	n.a.
Upper Extremity	17.4	35	85	100	n.a.
Lower Extremity and Pelvis	17.6	50	60	60	100
Thorax	2.6	4.0	4	30	30
Thoracic Spine	4.9	45	90	100	100
Abdomen	0.0	2.4	10	20	20
Lumbar Spine	5.7	55	70	100	100
External (Skin)	1.7	20	50	50	100

TABLE II

RISK OF SEVERE PERMANENT MEDICAL IMPAIRMENT (PMI 10+). NUMBERS IN PERCENT.

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Head	2.5	8	35	75	100
Cervical Spine	2.5	10	30	100	100
Face	0.4	6	60	60	n.a.
Upper Extremity	0.3	3	15	100	n.a.
Lower Extremity and Pelvis	0.0	3	10	40	100
Thorax	0.0	0	0	15	15
Thoracic Spine	0.0	7	20	100	100
Abdomen	0.0	0.0	5	5	5
Lumbar Spine	0.1	6	6	100	100
External (Skin)	0.03	0.03	50	50	100

The total number of impaired cyclists (PMI 1+) was calculated by adding the calculated risk for medical impairment (RPMI 1+) for each cyclist. The same process was used to calculate the total number of severely impaired cyclists (PMI 10+).

The ISS is a measure of overall injury severity comprising the sum of the squares of the highest AIS scores in three ISS body regions injured. By calculating PMI 1+ and 10+ for each cyclist a direct comparison between the threat-to-life of the sustained injuries and their long-term consequences was possible. For this analysis the ISS threshold was set at 9 since the number of ISS 16+ cases would be too limited. While ISS 16+ is normally used [20], ISS 9+ is not an uncommon approach for analysis of cyclist injuries in Sweden [21].

The injury distributions were also analyzed by body regions. This was done for all impaired (PMI 1+) and severely impaired (PMI 10+) cyclists as well as for cyclists with ISS 9+.

Further analysis was also carried out to investigate which injuries were the most common within the same body regions for different AIS levels.

Effectiveness of bicycle helmets

An analysis using induced exposure can be used when true exposure is not available [22-24]. With this approach, the key point is to identify at least one crash or injury type in which the countermeasure under analysis can be reasonably assumed (or known) not to be effective. In the present study, injuries to cyclists with and without helmets were compared. If the only noteworthy difference in terms of injury risk is wearing a helmet, the relation between injuries not affected by helmets would be considered as the true exposure relation. This means that any deviation from the relation between non-sensitive injuries is considered to be a result of bicycle helmets. The effect of bicycle helmets is therefore considered to be zero if R in Equation 2 is equal to 1.

$$R = \frac{A_{HELMET}}{N_{HELMET}} \div \frac{A_{NO-HELMET}}{N_{NO-HELMET}}$$
(2)

A_{HELMET} = number of injuries sensitive to bicycle helmets, involving cyclists with helmets
$A_{NO-HELMET}$ = number of injuries sensitive to bicycle helmets, involving cyclists without helmets
N_{HELMET} = number of injuries non-sensitive to bicycle helmets, involving cyclists with helmets
$N_{NO-HELMET}$ = number of injuries non-sensitive to bicycle helmets, involving cyclists without helmets

The effectiveness in terms of injury reduction can be expressed as:

$$E = 100 \times (1 - R)\%$$
(3)

The standard deviation of the effectiveness was calculated on the basis of a simplified odds ratio variance, according to Equation 4. This method gives symmetric confidence limits but the effectiveness is not overestimated.

$$Sd = \sqrt{\sum_{i=1}^{4} \frac{1}{m_i}}$$
(4)

where *m* is the number of injuries of each type. The 95% confidence limits are given in Equation 5.

$$\Delta E = 100 \times R \times Sd \times 1.96$$
(5)

In the present study, all impairing injuries (PMI 1+) as well as severe impairing injuries (PMI 10+) were analyzed. The effectiveness of helmets was also evaluated based on injuries sustained by cyclists with ISS 9+. In order to control for crash severity, only cyclists who sustained at least one AIS 2+ injury in body regions other than the head and face were included. Cases in which bicycle helmet use was unknown were excluded.

To minimize the influence of no causal mechanisms the analysis was limited to single bicycle crashes as well as bicycle-motor vehicle crashes. Injuries to the head and face were considered sensitive to bicycle helmets. All other injuries were considered non-sensitive (see Eq. 2). Head injuries in this study were defined as skull fractures and brain injuries. Soft tissue injuries, e.g. bruises, abrasions and lacerations of the scalp and forehead, were classified as external (see Table I). The same was made for facial injuries except from large laceration (AIS-code 216006.3). Controls were made on other factors that could possibly affect injury risk (i.e. age, crash location etc) to ensure that the only difference in terms of head and face injury risk was the helmet itself. Tables III and IV show an overview of the material as well as the age distributions with and without bicycle helmets.

TABLE III
NUMBER OF INJURIES INCLUDED IN THE STUDY

	PMI 1+	PMI 10+	ISS 9+
Helmet	3355	387	1877
No helmet	5671	770	4921
Unknown use of helmet	2585	393	2072

TABLE IV
DISTRIBUTION OF INJURIES BY AGE GROUP, WITH AND WITHOUT BICYCLE HELMETS

	PMI 1+		PMI 10+	
	helmet	no helmet	helmet	no helmet
0-6	4%	0%	3%	0%
7-15	25%	8%	20%	6%
16-24	2%	9%	2%	8%
25-44	24%	23%	25%	23%
45-64	30%	37%	33%	37%
65+	15%	23%	18%	25%
Total injuries	100%	100%	100%	100%
n injuries	3355	5671	387	770

III. RESULTS

Crash type and location

The analysis of STRADA hospital reports during 2003-2012 showed that 77% of the bicycle crashes in Sweden were single bicycle crashes. In only 1% of those single bicycle crashes the police were known to be present at the crash scene, see Table V. Bicycle crashes involving a motor vehicle, generally a passenger car, accounted for 13% of all crashes. While the police were known to be at the crash scene in only 7% of the analyzed cases, no information was available in 33% of the reports.

TABLE V
DISTRIBUTION OF INJURED CYCLISTS BY TYPE OF BICYCLE CRASH AND PRESENCE OF THE POLICE AT THE CRASH SCENE

	Police not at crash scene	Police at crash scene	Unknown	Total
Bicycle - bicycle	5%	0%	2%	7%
Bicycle - pedestrian	1%	0%	0%	2%
Bicycle - motor vehicle	4%	5%	4%	13%
Single bicycle	49%	1%	26%	77%
Other	1%	0%	0%	1%
Total injured cyclists	60%	7%	33%	100%
n injured cyclists	32990	3864	18366	55220

In total 77% of hospital-reported bicycle crashes in Sweden occurred in urban areas, see Table VI. Among urban crashes, approximately 38% occurred on a street, while 29% occurred on a bicycle path. Only 2% of crashes were reported to have taken place in roundabouts.

TABLE VI

DISTRIBUTION OF INJURED CYCLISTS BY LOCATION OF BICYCLE CRASHES IN URBAN AND RURAL AREAS, ALL BICYCLE CRASHES

	Urban	Rural	Unknown	Total
Street, intersection	10%	1%	-	11%
Street, non-intersection	28%	6%	4%	37%
Bicycle path	29%	3%	2%	34%
Sidewalk	4%	-	-	4%
Roundabout	2%	-	-	2%
Other	3%	1%	-	4%
Unknown	3%	-	6%	9%
Total injured cyclists	77%	11%	12%	100%
n injured cyclists	42689	6127	6404	55220

Long-term consequences

It was found that the number of impaired cyclists (PMI 1+ and 10+) was more than three times larger than those with ISS 9+, Table VII. The number of cyclists with ISS 16+ was quite limited (n=551).

TABLE VII

NUMBER OF CYCLISTS WITH IMPAIRMENT (PMI 1+), SEVERE IMPAIRMENT (PMI 10+) ISS 9+ AND ISS 16+ IN SWEDEN 2003-2012

	n injured cyclists
PMI 1+	9287
PMI 10+	1268
ISS 9+	3074
ISS 16+	551

The analysis of injury distributions showed that 46% of the impairing injuries (PMI 1+) were to the upper extremities. 22% were to the lower extremities, while only 9% of all impairing injuries were head injuries. On the other hand, head injuries were the most common among severe impairing injuries (42% of PMI 10+), although injuries to the upper and lower extremities accounted for a slightly lower share of PMI 10+ injuries (38%).

When cyclists with ISS 9+ were taken into account, external injuries (i.e. scratches, bruises etc) were the most common (35%), followed by head injuries (19%). Table A in the Appendix shows the distribution of injured body regions in single bicycle crashes as well as crashes involving motor vehicles.

TABLE VIII

DISTRIBUTION OF IMPAIRING INJURIES (PMI 1+), SEVERE IMPAIRING (PMI 10+) INJURIES AND INJURIES AMONG CYCLISTS WITH ISS 9+

	PMI 1+	PMI 10+	ISS 9+
Head	9%	42%	19%
Cervical Spine	5%	6%	3%
Face	5%	8%	11%
Upper extremity	46%	25%	7%
Lower extremity and pelvis	22%	13%	11%
Thorax	1%	0%	9%
Thoracic Spine	2%	2%	2%
Abdomen	0%	0%	2%
Lumbar Spine	2%	1%	1%
External (Skin)	10%	1%	35%
Total injuries	100%	100%	100%
n injuries	11717	1557	10065

Injuries to the shoulder and to the wrist were the most common among injuries to the upper extremities, Table IX. Further analysis showed that clavicle fractures accounted for approximately 40% of all injuries to the shoulder.

TABLE IX

DISTRIBUTION OF INJURIES TO THE UPPER EXTREMITIES, BY AIS LEVEL

	AIS 1	AIS 2	AIS 3	Total
Shoulder	5%	24%	0,0%	29%
Upper arm	0%	1%	0,0%	2%
Elbow	5%	12%	0,1%	17%
Forearm	0%	5%	0,0%	5%
Wrist	6%	21%	0,1%	28%
Hand, excluding fingers	1%	6%	0,0%	7%
Finger	12%	0,0%	0,0%	12%
Total injuries to upper extr.	30%	70%	0,2%	100%
n injuries to upper extr.	5415	12428	35	17878

A similar analysis of the injuries to the lower extremities and pelvis showed that ankle and knee injuries were the most common (31% and 25%, respectively), Table X, although pelvic and upper leg fractures were also common.

TABLE X

DISTRIBUTION OF INJURIES TO THE LOWER EXTREMITIES AND PELVIS, BY AIS LEVEL

	AIS 1	AIS 2	AIS 3+	Total
Pelvis and upper leg	2%	8%	14%	24%
Knee	9%	16%	0,5%	25%
Lower leg	0%	8%	1%	8%
Ankle	11%	19%	0,3%	31%
Foot	4%	7%	0,0%	10%
Unknown	1%	1%	0,3%	1%
Total injuries to lower extr.	27%	58%	15%	100%
n injuries to lower extr.	1591	3416	912	5919

Effectiveness of bicycle helmets

Table XI shows the basis for the calculations of the effectiveness of bicycle helmets. Injuries to the upper extremities were somewhat more common among cyclists with helmets. Tables B and C in the Appendix show the injury distributions in single bicycle crashes and bicycle-motor vehicle crashes.

TABLE XI

DISTRIBUTION OF INJURIES BY BODY REGIONS, WITH AND WITHOUT BICYCLE HELMETS (ALL BICYCLE CRASH TYPES)

	PMI 1+		PMI 10+		ISS 9+	
	helmet	no helmet	helmet	no helmet	helmet	no helmet
Head	2%	6%	12%	29%	12%	21%
Cervical Spine	6%	5%	14%	8%	4%	3%
Face	2%	3%	4%	6%	8%	13%
Upper extremity	56%	45%	41%	28%	9%	7%
Lower extremity and pelvis	22%	30%	17%	19%	11%	10%
Thorax	2%	1%	2%	2%	12%	7%
Thoracic Spine	5%	4%	7%	5%	3%	2%
Abdomen	0%	0%	1%	1%	2%	1%
Lumbar Spine	2%	3%	2%	2%	1%	1%
External (Skin)	3%	3%	0%	0%	37%	35%
Total injuries	100%	100%	100%	100%	100%	100%
n injuries	3355	5671	387	770	1877	4921

Analysis of age distributions (see Table IV) showed that cyclists with helmets included more youngsters than those without helmets. Controls were then carried out to ensure that the effectiveness would not be overestimated, showing that the overall effects were the same (if not identical) as for younger age groups. Further analysis of gender, crash locations, road conditions, type of transport to the hospital (own, ambulance, helicopter) showed no discrepancies from the overall results.

All reductions of head and face injuries were statistically significant at the 95% level, excluding two (PMI 1+ and 10+ face injuries in bicycle crashes into motor vehicles), Table XII. In all bicycle crashes, helmets were found to reduce all impairing head injuries (PMI 1%+) by at least 58%, while the effectiveness in reducing severe impairing injuries (PMI 10+) was even greater (64%). Head injuries among cyclists with ISS 9+ were also reduced by 52% +/- 4%. The effectiveness in reducing face injuries was lower, ranging from 37% for all impairing injuries to 49% for severe impairing injuries. The effectiveness in reducing head injuries was generally higher in crashes involving motor vehicles than in single bicycle crashes. However, this was not found to be the case for face injuries.

TABLE XII

EFFECTIVENESS OF BICYCLE HELMETS IN REDUCING HEAD AND FACE INJURIES IN DIFFERENT CRASH TYPES, WITH 95% CONFIDENCE LIMITS. NON-SIGNIFICANT RESULTS WITH CONFIDENCE LIMITS LARGER THAN 100% ARE INDICATED WITH *NS*

		PMI 1+			PMI 10+			ISS 9+		
Single bicycle	head injuries	57%	+/-	6%	63%	+/-	6%	44%	+/-	6%
	face injuries	56%	+/-	8%	76%	+/-	5%	45%	+/-	6%
Bicycle - motor vehicle	head injuries	70%	+/-	4%	75%	+/-	4%	67%	+/-	3%
	face injuries	*-27%*	+/-	*85%*	*-101%*	+/-	*ns*	45%	+/-	12%
Single and motor-vehicle	head injuries	62%	+/-	4%	68%	+/-	4%	52%	+/-	4%
	face injuries	37%	+/-	12%	49%	+/-	15%	47%	+/-	5%

IV. DISCUSSION

Many databases, as well as national road crash statistics, are often based on police reported data. It is well known that injured vulnerable road users such as cyclists are underreported in police data [12]. Furthermore, single bicycle crashes are even less likely to be reported. In the present study hospital-reported crashes were analyzed and few of these were police reported. The results showed that bicycle crashes without any other party involved accounted for almost 80% of all bicycle crashes. It is therefore important to use hospital-reported crashes as a source of information for city planning and evaluations of road safety actions.

Most of the crashes included in the present study took place in non-intersections on a street or bicycle path (71%). Since most of the injuries occurred in single bicycle crashes there is a need to better understand the dynamics of non-intersectional crashes in order to improve prevention strategies. Based on data from insurance claims Isaksson-Hellman [25] showed that most collisions involving a motor vehicle (77%) occurred in a intersection. The most frequent conflict was when a cyclist was approaching the intersection from a bicycle lane from the right just before the intersection. These crashes in intersection could be addressed by changes in the infrastructure, by speed reducing measures as well as protection systems of the cars [26]. Fredriksson et al [27] found that fatal cyclist injuries were most often caused by impact to the windshield frame area. Pedestrian countermeasures have been proven effective in reducing pedestrians injuries [28] and these should be further developed to address cyclists as well.

Depending on whether the injury classification is made by the police or from medical sources and which scaling method (e.g. MAIS2+, MAIS3+ or medical impairment) is used, the injury picture varies to such an extent that completely different strategies for prevention would be developed [13]. This was also shown in the present study when comparing hospital and police-reported injuries as well as in the comparison between injuries leading to medical impairment and ISS 9+. In the present study there were 3 times more injuries when all injuries causing medical impairment were compared to ISS 9+. The AIS and ISS predict risk of death and have been found to have a limited correlation with the development of impairment [29, 31]. Some low severity injuries according to AIS (AIS 1 and 2), where there was no interaction with other injuries, often lead to permanent impairment. Out of all road traffic crashes resulting in injuries, the non-fatal injuries dominate and few of them are potentially life-threatening. This is particularly true for injuries to cyclists. Therefore it is urgently necessary to consider long-term consequences when targeting prevention actions for bicycle safety.

The analysis of injury distribution showed that the upper and lower extremities injuries were the most common. In total 46% of the all impairing injuries (PMI 1+) were to the upper extremities followed by the lower extremities, 22%. However, head injuries were the most common among more severe impairments (PMI 10+), although injuries to the upper and lower extremities accounted for a slightly lower share of PMI 10+ injuries (42% and 38%, respectively, see Table VIII). Likewise, other studies have showed that injuries to the upper extremities were more frequent in single bicycle crashes than in collisions with a motor vehicle [4, 31]. However Bambach et al [7] found that among hospitalised cyclists, injured in collisions with motor vehicle involvement, the upper and lower extremity injuries were dominant, while head injuries were the most common among severe injuries. Head injuries are most frequent in the case of life-threatening injuries among cyclists [5, 31]. The broad panorama of different impaired body regions shows that the prevention of serious bicycle injuries cannot be accomplished through helmet use alone; further prevention strategies are necessary in order to reduce the injury outcome. One way could be to include energy-absorbing material in clothes. Cycling is a relatively unstable way of travelling which means that cyclists may fall off their bicycles even if effective infrastructure measures are introduced.

The present study showed a first evaluation of the long-term consequences of bicycle crashes in Sweden as well as an evaluation of the effectiveness of bicycle helmets in reducing impairing head and facial injuries. While the results seemed impressive, no previous research was found on this specific issue and therefore caution must be executed. Further research should investigate the long-term benefits of bicycle helmets as well as other protective equipment. It should also be noted that the risk matrices for permanent medical impairment [17] 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 acquired (i.e. different road users), further research should confirm this.

Several studies have shown that bicycle helmets are effective in preventing head injuries for all cyclists of all ages [6-9, 32]. Most of the previous studies have used a case-control design [6-9, 32]: the cyclists with head injuries were compared with cyclists with injuries to other body regions. This analysis was based on an induced exposure approach, as shown in other studies [22-24], as true exposure is often difficult to obtain and may contain many confounding factors. While previous research has suggested that helmeted cyclists may change their riding behaviour [7], the present study found no actual evidence of higher crash risk among cyclists with helmets. Furthermore, while it is possible to control for these factors, an induced exposure method analyzes the relative differences between the two groups (helmet and non-helmet), which automatically compensates for possible confounders.

A limitation of the present evaluation of bicycle helmets is that no information on helmet type was included in the hospital reports. It could be argued that the majority of helmets on the Swedish market are micro-shell types, which consist of a thin shell incorporated with the rest of the helmet. However, during the last years the proportion of skate-helmets with hard shell has increased. In the present study, no distinction between different types of helmets could be made. Future research should be aimed at understanding the influence of helmet design in reducing injuries in real-life crashes. Interestingly, a recent helmet test [33] in Sweden showed that hard shell helmets generally provided lower protection than micro-shell helmets. Furthermore, an airbag bicycle helmet showed three times lower g-forces than conventional helmets. Further testing and research is therefore needed to quantify the benefits of this innovative technology. In general all helmets did not absorb angular acceleration effectively. The reason for this is that angular acceleration is disregarded in legislation testing of helmets [34]. This is very alarming since angular acceleration is the dominating cause of brain injuries [35].

In the present study hospital-reported crashes were studied and therefore the included cyclists are more likely to have been involved in a more severe crash. A database that includes all cyclist who experienced a crash, not only those who seek medical care, would provide the best estimate of helmet effectiveness. The effectiveness is probably an underestimation of the true protective effect. Many cyclists wearing a helmet who are involved in a crash and hit their helmet/head may not seek medical care unless other types of injuries are serious enough. The data were not limited to crashes where the cyclists hit their heads. It was assumed that both cyclists with and without head injuries and cyclists with and without helmets had the same probability of striking their heads. The data were not adjusted for age, gender, alcohol intoxication or crash type.

V. CONCLUSIONS

- 77% of all hospital-reported bicycle crashes in Sweden were single bicycle crashes. Most of them occurred in urban areas.
- The number of impaired cyclists (PMI 1+) was 3 times larger than those with ISS 9+.
- The most common impairing injuries were to the upper and lower extremities (46% and 22%, respectively).
- Bicycle helmets reduce impairing head and face injuries (PMI 1+) by 62% and 37%, respectively.
- Prevention of serious bicycle injuries cannot be accomplished through helmet use alone. Further prevention strategies are necessary in order to reduce the injury outcome.
- Few of the analyzed crashes were police reported and therefore hospital data should be used to analyse bicycle crashes and suggest relevant countermeasures.

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APPENDIX

TABLE A

INJURY DISTRIBUTIONS BY BODY REGIONS IN SINGLE CRASHES AS WELL AS BICYCLE-MOTOR VEHICLE CRASHES

	Single bicycle			Bicycle - motor vehicle		
	PMI 1+	PMI 10+	ISS 9+	PMI 1+	PMI 10+	ISS 9+
Head	8%	38%	19%	14%	53%	18%
Cervical Spine	3%	5%	3%	11%	10%	4%
Face	5%	9%	13%	5%	6%	7%
Upper extremity	50%	30%	7%	23%	10%	7%
Lower extremity and pelvis	22%	14%	13%	23%	10%	8%
Thorax	1%	0%	7%	2%	1%	13%
Thoracic Spine	1%	1%	1%	4%	4%	4%
Abdomen	0%	0%	2%	0%	0%	2%
Lumbar Spine	1%	1%	0%	6%	3%	3%
External (Skin)	9%	1%	35%	12%	2%	35%
Total injuries	100%	100%	100%	100%	100%	100%
n injuries	8860	1092	6185	1442	242	2271

TABLE B

INJURY DISTRIBUTIONS BY BODY REGIONS, WITH AND WITHOUT BICYCLE HELMET, IN SINGLE BICYCLE CRASHES

	PMI 1+		PMI 10+		ISS 9+	
	helmet	no helmet	helmet	no helmet	helmet	no helmet
Head	2%	4%	10%	21%	14%	21%
Cervical Spine	4%	5%	11%	9%	3%	3%
Face	1%	3%	2%	8%	9%	15%
Upper extremity	66%	52%	54%	36%	9%	7%
Lower extremity and pelvis	20%	29%	16%	20%	11%	11%
Thorax	1%	1%	2%	1%	10%	6%
Thoracic Spine	2%	3%	3%	4%	2%	1%
Abdomen	0%	0%	1%	0%	2%	1%
Lumbar Spine	1%	1%	1%	1%	0%	0%
External (Skin)	2%	2%	0%	0%	39%	35%
Total injuries single bicycle	100%	100%	100%	100%	100%	100%
n injuries single bicycle	2535	4339	264	532	1264	3547

TABLE C

INJURY DISTRIBUTIONS BY BODY REGIONS, WITH AND WITHOUT BICYCLE HELMET, IN BICYCLE-MOTOR VEHICLE CRASHES

	PMI 1+		PMI 10+		ISS 9+	
	helmet	no helmet	helmet	no helmet	helmet	no helmet
Head	4%	11%	16%	45%	9%	22%
Cervical Spine	12%	7%	19%	6%	5%	3%
Face	3%	2%	7%	3%	5%	8%
Upper extremity	25%	21%	14%	10%	9%	6%
Lower extremity and pelvis	28%	33%	19%	18%	11%	8%
Thorax	3%	3%	2%	4%	16%	11%
Thoracic Spine	15%	9%	17%	8%	6%	3%
Abdomen	0%	1%	1%	1%	2%	2%
Lumbar Spine	6%	9%	4%	5%	3%	3%
External (Skin)	3%	4%	0%	0%	34%	34%
Total injuries bicycle-mv	100%	100%	100%	100%	100%	100%
n injuries bicycle-mv	820	1332	123	238	613	1374