Head Injuries in Bicyclists and Associated Crash Characteristics

Axel Malczyk, Klaus Bauer, Christian Juhra, Sylvia Schick

Abstract Two hospitals in two major German cities documented 543 injured bicyclists arriving at the emergency departments. Head injuries and crash circumstances were of particular interest. The latter information, like type of crash, type of bicycle and estimated cycling speed was mostly self-reported. Injuries to the head and face were present in 239 bicyclists. 77 % received only AIS 1 injuries consisting of soft tissue injury, cerebral concussion and minor facial fractures. Nearly 10 % sustained AIS 3+ head injuries. Cyclists with head and face injuries tended to be older than the control group without head injuries, were involved more often in collisions with motor-vehicles and were cycling faster. Single-vehicle crashes represented more than half of all bicycle crashes that resulted in head trauma. Age and type of crash were associated with head injury severity. Helmet rate was 17 % among cyclists without and 18 % among those with head injury. No AIS 3+ head injuries were seen in helmet-users. Analysis of the location of head soft tissue injury and helmet damage indicated that most contacts occur in the frontal and fronto-temporal region of the head.

Keywords bicyclist, head injury, traumatic brain injury, bicycle helmet, single-vehicle crash

I. INTRODUCTION

Bicycle-related crashes are becoming increasingly the focus of road safety activities in many countries. While the number of all killed road users in Germany dropped by 33 % between 2005 (5,361 fatalities) and 2012 (3,600 fatalities), the decrease for killed bicyclists was 29 % (575 in 2005, 406 in 2012) [1, 2]. The number of seriously injured cyclists declined by 5.4 % compared to a drop by 16.9 % among passenger car occupants [3]. In German national accident statistics, seriously injured are defined as in-patients (hospital stay of at least 24 hours) and slightly injured as out-patients, accordingly [2].

Single-vehicle crashes of bicyclists represent a considerable portion of incidents leading to injury or death. Of the 406 cyclist fatalities in 2012, 86 (21 %) were attributed to crashes without third-party involvement. A 2009 study in the city of Muenster, Germany, documented 2,250 injured cyclists in total and 1,766 of them received medical care as in-patients and out-patients in the city's hospitals [4]. With nearly 27 %, injuries due to cyclist falls were approximately as frequent as due to collisions with motor-vehicles.

The study also demonstrated that injured cyclists tend to be under-reported in official accident statistics. Particularly, bicycle single-vehicle crashes and those with minor injury severities rarely come to the attention of the police. Merely 239 (14 %) cases documented by the Muenster hospitals were registered by the police whereas an additional 484 bicyclists with minor injuries were police-reported, but not treated in hospitals.

Knowles et al., in a report for the British Department for Transport (DfT) [5], stated a 16 % proportion of killed and seriously injured cyclists resulting from non-collision events based on 2005 – 2007 accident statistics. They also pointed out that this type of crash is poorly reported in official statistics.

The head region is frequently affected when bicyclists are injured and is of particular importance with regard to serious trauma. The 2012 German statistics of causes of death stated head injuries in 223 cases as the primary cause of death of the 412 killed cyclists in the register [6]. According to Knowles et al., a British database of post mortem examinations of 116 killed cyclists showed AIS 3+ injuries to the head in approximately three out of four cases [5]. The authors also quote results from the British Hospital Episode Statistics (HES) between 1999 and 2005 that the head was involved in nearly 42 % of all treated bicyclists and in 37 % after non-collision crashes. In the Muenster study, 26 % of all 2,250 injured cyclist showed head injuries, either as the sole affected body region or in combination with injuries in other regions [4]. Nearly 5 % sustained traumatic brain

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injuries (TBI), the large majority of these being confined to concussions. TBI's were particularly frequent in collisions involving motor-vehicles (13 %) and among cyclists aged 70 and over.

Depreitere et al. published a study on serious head injuries of 86 bicyclists who underwent neurosurgical intervention at a Belgian Hospital between 1990 and 2000 [7]. In about half of the cases, a motor-vehicle was involved. The remaining half was due to cyclist single-vehicle crashes. The large majority of the 86 cyclists presented skull fractures (86 %), brain swelling (83 %) and contusions (73 %). The authors concluded from their material that cerebral contusions, subdural haematomas, subarachnoid haemorrhage and brain swelling would often appear in combination. The location of head impact was derived from CT-scans, scalp injuries and depressed skull fractures in 64 patients. Of 26 cases of cyclist falls with a single impact to the head, almost half showed impact locations in the parietal region, followed by the frontal region (30 %).

Utsch analyzed 149 bicyclist fatalities in Berlin between 1993 and 2004 from autopsy documentation and police reports [8]. Head injuries, in general, were found in 78 % of all killed cyclists. A large proportion of cyclists died after being run over by a truck (42 %). Traumatic brain injury (TBI) was found to be the cause of fatal outcome in half of all cases, followed by multiple severe injuries ("polytrauma") in 40 %. Of the 75 cyclists who died of TBI, 43 % collided with a passenger car and 33 % with a truck or a bus. Cyclist falls without third-party involvement accounted for 13 %. Half of the 64 TBI's that did not result from being run over and head crush were combinations of contusions and extra-cerebral haemorrhages. Among the 62 cases of head contact trauma (i.e., diffuse trauma and run-over of head excluded) the most frequent impact locations were in the temporal-parietal region (42 %), followed by the occipital (27 %) and frontal region (16 %).

Despite the relevance of head injuries in fatally and seriously injured bicyclists, cycle helmets are still rarely being used in Germany. Regular monitoring of helmet wearing rates by the German Highway Research Institute (BASt) determined a 13 % helmet-wearing rate among bicyclists in urban areas in 2012 [9].

In 2014, Otte et al. published a study of cyclist crashes [10] to determine the frequency of head injuries and the protective potential of cycle helmets designed according to European standard EN 1078 [11]. They analysed 4,245 bicyclists from the GIDAS database (German In-Depth Accident Study) between 2000 and 2012, approximately 74 % of which sustained only MAIS 1 trauma. Most of the bicyclists in the GIDAS material had been involved in crashes with passenger cars, around 11 % were crashes without third party involvement. Helmets had been worn by 433 cyclists and around 70 % of them remained uninjured in the head and face region, compared to 62 % of those not wearing a helmet.

When addressing head injuries in bicyclists, most studies either rely only on hospital data which rarely provide detail information about the crash circumstances or they focus on police-reported crashes that tend to be biased towards collisions with motor-vehicles and more serious injuries. Data from the Muenster study [4] and from the British hospital statistics [5] is based on ICD (International Classification of Diseases) coding, not AIS, but suggest that head injury in bicyclists is also common in less severe outcomes and that single-vehicle crashes represent an important crash type which is not adequately reflected in official accident statistics.

Our study is intended to investigate into the incidence of head injuries of all severities sustained by bicyclists and shed more light on the crash circumstances that possibly affect the occurrence of head injury, including bicyclist single-vehicle crashes. For future efforts in head injury prevention, it will be beneficial not only to describe the severity and type of head trauma, but also where head contact with objects or the ground occurs in real-world crashes. Data from our study will add to the limited knowledge from related studies [7, 8, 10].

II. METHODS

Study region

Two hospitals in two major German cities participated in the study by collecting injury data on cyclist casualties and the related circumstances of the crash. Those are the University Hospital in Muenster in the north-western part of the country and the Hospital at Munich University in the south-east. Both clinics are level I trauma centers that do not only provide basic medical care for patients in their immediate area, but also advanced treatment within larger regional trauma networks. Some victims of road traffic crashes, particularly in critical condition, may be transported from more remote areas or transferred from other hospitals. Therefore, it is not possible to define strict boundaries of the study regions.

Study duration

Case collection took place for approximately twelve months from May 2012 until April 2013.

Study material

Cases were recruited from patients of the two hospitals either admitting themselves to the emergency department or being transported by ambulance from crash sites or other hospitals. In principle, all cyclists with injuries of any severity were included. Bicyclists without any injury diagnosed were excluded as well as those who had walked their cycle at the time of the crash.

Despite the broad array of injuries and crash circumstances leading to them, representativeness of the complete study material cannot necessarily be assumed. On the one hand, registration or documentation of some bicyclists, particularly when presenting minor injuries and not affecting the head, may have been omitted by clinic staff in busy periods where general patient treatment had priority. On the other hand, bicyclists who had to be transported by helicopter or transferred from other hospitals tended to be more seriously injured.

Contrary to the German national accident statistics, bicycle crashes which occurred off public roads were not excluded. Incidents on playgrounds, in public parks or skate parks, for instance, were few, though.

Case documentation

Injured bicyclists, whether arriving on their own or by ambulance, were registered by emergency department staff upon admission. Regular documentation included verbal injury description and coding according to ICD-10. Study assistants coded the injuries according to the Abbreviated Injury Scale 2005, Update 2008, and determined MAIS (Maximum AIS) and ISS (Injury Severity Score) values.

Particular attention was paid to head injuries, also of lesser severity. For the purpose of this study, the head includes the face (and excludes the neck), unless otherwise noted. Available data from pre-clinical treatment, e.g., Glasgow Coma Scale, were included to substantiate patient unconsciousness at the crash site. Where soft tissue injuries to the skull and face could be established, the type of injury (lacerations, abrasions, etc.) and the location on the head were documented for the study on an extra form. Contrary to the assignment of skeletal or organ injuries, external injuries located on the frontal (i.e., forehead) or the temporal head area were attributed to the face region, as prescribed by the AIS coding manual [12]. If the patient arrived with a bicycle helmet, the type of damage (dent, fracture, etc.) and its location on the helmet was also documented on a separate form by clinic staff or study assistants.

Clinic staff asked patients for their consent to participate in the study. Together with the patient, they filled out a specially designed questionnaire about details of the crash as well as the background and motivation for cycling. The questionnaire was based on multiple choice answers in order to increase acceptance by the patient and clinic staff. Among other items, the form inquired about:

- Type of crash: bicyclist single-vehicle crash / crash involving pedestrian or other bicyclist / crash involving motor-vehicle / other type of crash.

  Single-vehicle crashes include falls without previous collision as well as after hitting objects like railings, trees or sign posts during the ride. Crashes involving motor-vehicles include moving motorcycles, passenger cars, trucks or buses and opening vehicle doors. Involvement of other road users does not necessarily entail physical contact with the opponent, but may also include cyclist falls due a conflict, e.g., after hard braking to avoid a collision. The category of “other type of crash” includes bicyclist falls after sudden health problems, but also due to collisions with dogs or straying skateboards, footballs etc.
- Type of bicycle: comfortable bicycle / sport bicycle / other type of bicycle.

  Comfortable bicycles include so-called city and Holland bikes. Sport bicycles comprise sport, racing, mountain and trekking bikes. Other types of bicycles include folding bikes, children’s bikes, and electric-assisted bikes.
- Cycling speed: Cyclist standing or starting to cycle / cycling slowly / cycling quickly

  Slow cycling was defined as less than 20 km/h, quick cycling as more than 20 km/h. Cycling speed was estimated by the patient and referred to the speed before the collision or fall occurred without taking braking into account.
- Helmet use: no helmet worn / helmet worn.

  Helmet wearing includes also cases where the helmet came off the head in the course of the crash.

Only information about the course of the crash was entered as free text. The patients' answers to the questionnaire were voluntary and anonymous. Some questionnaires were not answered completely or in part, because the patient opted against it or because the injury prevented him or her from recalling details of the crash. The questionnaires were linked by a patient number to the clinical documentation of patient demographic and injury data as gathered regularly in the course of medical treatment. Where additional information from police reports or media reports could be obtained, this was added to the dataset. Study assistants regularly collected the documentations and questionnaires and entered the relevant information into a database (Filemaker, Inc.) for further evaluation.

Due to the previously mentioned reasons, some datasets of crash circumstances were incomplete. Only cases providing the required information were used for the respective analysis. Depending on the investigated variable, the number of valid cases differed. There was no indication that this biased the results unduly.

The study was approved by the ethics committee of Ludwig-Maximilians University, Munich.

Analysis

In a first step, the case group of bicyclists presenting head injury, regardless of severity or presence of injury in other body regions, was compared to the control group of injured bicyclists without head injury. For comparison of variable distributions between groups, Chi-square tests were performed.

For the next evaluation, the bicyclists with head injuries were differentiated by overall head injury severity levels of AIS 1, AIS 2 and AIS 3+. Due to small sample sizes, particularly at AIS 3+ level, no testing was performed. The crash characteristics of cyclists with different head injury severity levels were compared descriptively. Moreover, the effect of a bicycle helmet on head trauma was investigated. For this purpose, unhelmeted and helmeted bicyclists with head injuries were compared regarding the types of head trauma sustained and Chi-square tests performed.

In the third step, head and helmet contact locations were analyzed to determine which areas of the head are frequently exposed to impacts in crashes. For this purpose, the locations of soft tissue injuries were documented by assigning them to defined regions on the surface of the head (including the face). Where individuals presented more than one external injury on the head, all locations were considered. For cyclists who had worn a helmet, the locations of damage were evaluated in a similar fashion.

Statistical testing of differences between distributions assumed significance at p-values < 0.05, otherwise the difference was considered non-significant (n. s.). Sample sizes and p-values for each variable are provided in the Appendix.

III. RESULTS

During the study period, 571 patients were documented in the two hospitals. Twenty-five cyclists, who did not demonstrate any injuries after clinical diagnostics, and three persons, who had not been actually on their bicycle during the crash, were excluded. 543 injured bicyclists were suitable for analysis. All of them survived.

Head-injured bicyclists and crash circumstances

Injuries in the head region were found in 239 patients, mostly coexisting with injuries in other body regions. 304 cyclists had injuries exclusively in other body regions.

Demography and overall injury severity: Females accounted for slightly more than half (52.0 %) of the bicyclists who presented no head injuries whereas females constituted 42.8 % among those with head injuries. This difference was statistically significant (Chi^2, $p < 0.05$).

The distributions of bicyclists' age differed significantly (Mann-Whitney U-test, $p < 0.05$). The age category of 15 to 24 years represented the largest portion among both groups, but cyclists with head injuries were more frequently seen in the older age groups (Fig. 1). Differences between cyclists without head injuries and cyclists with head injuries were significant only for those aged 35 to 44 years (8.8 % and 20.1 %, respectively) (Chi^2, $p < 0.01$). Children represented a minority both in the control and the case group.

The maximum injury severities ranged between MAIS 1 and MAIS 4. While the proportions of MAIS 1 trauma were similar for bicyclists without (62.8 %) and those with head injuries (64.0 %), the two groups differed significantly at higher severity levels (Chi^2, $p < 0.05$) (see Appendix). Among those without head injury, 3.3 % displayed overall injury severities of MAIS 3+, as opposed to 11.8 % among bicyclists with head injury.

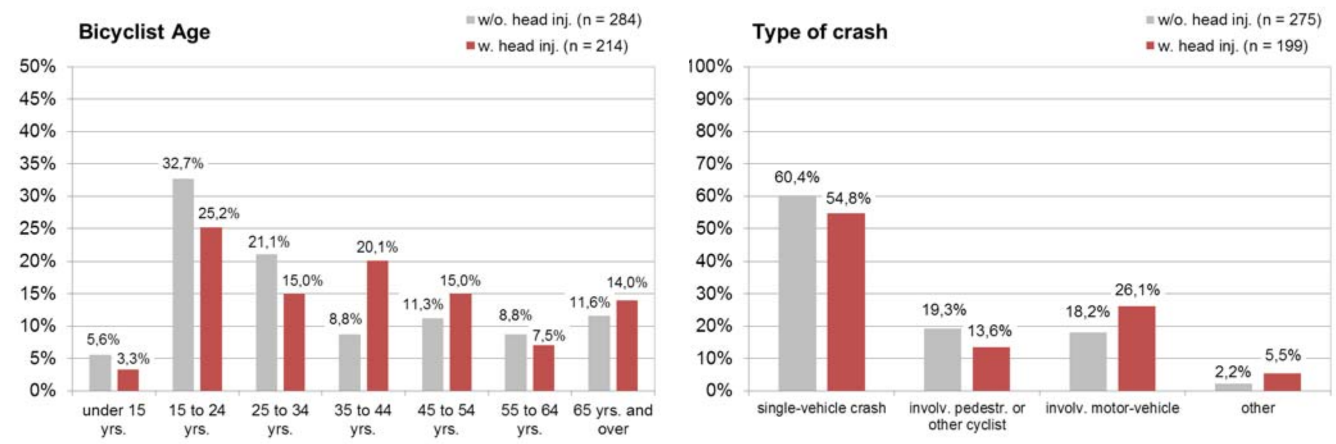


Fig. 1. Comparison of bicyclists without head injury and with head injury: Age distribution (left) and distribution of types of crashes (right)

Crash type: Single-vehicle crashes were by far most frequent both among cyclists without head injury (60.4 %) and those with head injury (54.8 %) (Chi^2, n. s.) as Fig. 1 demonstrates. Causes for direct falls to the ground comprised slipping, tripping over sticks or stones on the pavement, hard braking or items getting into the cycle wheels. Bicyclist single-vehicle crashes against fixed objects occurred rarely.

Crashes that involved pedestrians or other cyclists were more frequent among bicyclists without head injury (19.3 %) than among bicyclists with head injury (13.6 %) (Chi^2, n. s.). Collisions between two bicyclists prevailed in number and injuries were rather due to losing balance and the subsequent fall to the ground than to the physical contact with the opponent.

Crashes involving motor-vehicles represented the second most frequent type among bicyclists with head injury (26.1 %), significantly more than among those without head injury (18.2 %) (Chi^2, $p < 0.05$). These were mostly collisions with passenger cars.

Bicycle type and cycling speed: Bicycles used were clearly dominated by comfortable bicycle types and sport bicycle types (Fig. 2). Cyclists without head injury rode more comfortable bikes (55.1 %) than sport bikes (39.6 %). Other bicycle types, most of them being electric-assisted cycles, played a minor role. The distribution of bicycle types among non-head-injured cyclists was not statistically different from that among head-injured cyclists (Chi^2, n. s.).

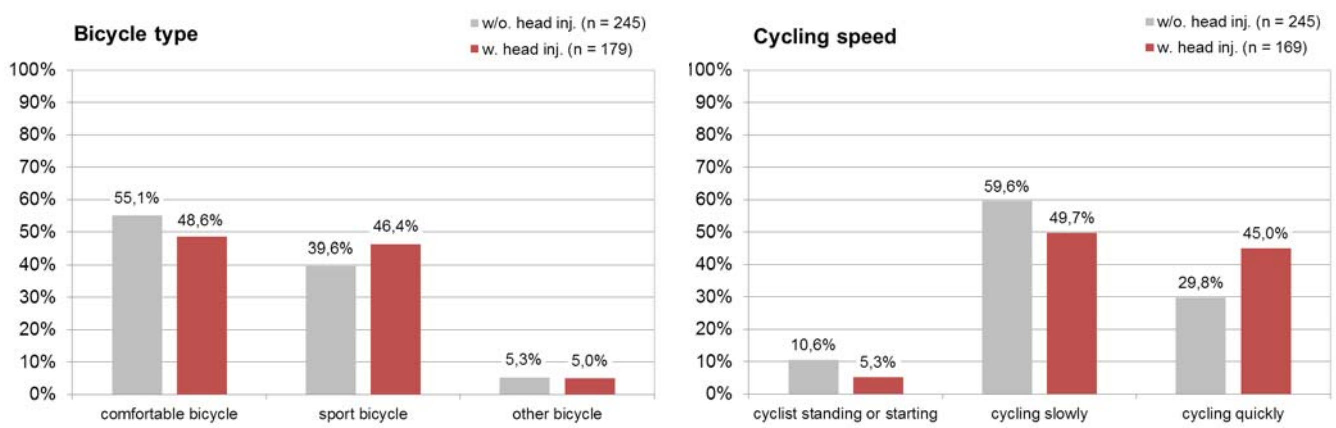


Fig. 2. Comparison of bicyclists without head injury and with head injury: Distribution of bicycle types used (left) and distribution of cycling speeds (right)

In contrast, the distributions of reported cycling speeds before the crash occurred differed highly significantly between cyclists without head injury and cyclists with head injury (Chi^2, $p < 0.01$) (Fig. 2). Cyclists without head injury reported slow cycling (59.6 %) almost twice as often as quick cycling (29.8 %). Among cyclists with head injury, the proportion of reports of slow cycling (49.7 %) was comparable to the proportion of quick cycling (45.0 %).

Bicycle helmet use: Only a small number of injured bicyclists was wearing a helmet at the time of the crash. The proportion of helmet use was 16.7 % among bicyclists without head injuries and 18.0 % among bicyclists with head injury, the differences not being significant (Chi^2, n. s.). One cyclist each in the control group and in the case group reported that the helmet came off their head during the crash. On the basis of all 543 injured bicyclists, helmet wearing rate was 26.0 % among cyclists who reported quick cycling and 12.4 % among those who stated slow cycling.

Head injury severity and crash circumstances

For the 239 bicyclists with trauma to the head (including the skull, brain and face), the type and severity of injuries were investigated in detail. Table I lists the number of cyclists presenting different injury types per overall head injury level (head AIS 1, head AIS 2, head AIS 3+). The Appendix provides the distribution of overall head injury levels, also differentiated by skull/brain injury and facial injury.

TABLE I
TYPE AND SEVERITY OF HEAD INJURIES

Overall injury level of head (incl. face) (n = 239 cyclists)	Skull and brain injury					Facial injury	
	Soft tissue injury	Intra-cerebral injury	Extra-cerebral injury	Con-cussive injury	Skull fracture	Soft tissue injury	Skeletal injury
Head injury max. AIS 1 (n = 184 cyclists)	94 (AIS 1)	-	-	59 (AIS 1)	-	86 (AIS 1)	39 (AIS 1)
Head injury max. AIS 2 (n = 32 cyclists)		-	-	3 (AIS 1)	-	6 (AIS 1)	5 (AIS 1)
		1 (AIS 2)	1 (AIS 2)	18 (AIS 2)	3 (AIS 2)		13 (AIS 2)
Head injury max. AIS 3+ (n = 23 cyclists)		-	-		-	2 (AIS 1)	2 (AIS 1)
		1 (AIS 2)	5 (AIS 2)	3 (AIS 2)	2 (AIS 2)		5 (AIS 2)
		7 (AIS 3)	10 (AIS 3)		9 (AIS 3)		3 (AIS 3)
		1 (AIS 4)	1 (AIS 4)		2 (AIS 4)		

In 184 (77 %) of all head-injured bicyclists, the overall head injury level did not exceed AIS 1. Of these, 94 patients displayed soft tissue injuries in the form of contusions, haematomas and abrasions and 86 had soft tissue injuries in the face region (including the frontal and temporal surface area of the head). Concussion without loss of consciousness (commotio cerebri) was found in 59 patients and 39 patients had skeletal injuries AIS 1 in the face region which included nose, mandibula and zygoma fractures, but also broken or lost teeth.

Overall head trauma at AIS 2 level was present in 32 (13.4 %) of all bicyclist with head injuries. Of these, 18 sustained a concussion with brief loss of consciousness, coded as AIS 2. While there were only three skull fractures, AIS 2 facial fractures were seen in 13 cases.

Overall head injury of AIS 3+ was found in 23 bicyclists (9.6 %), including two with AIS 4 head trauma (0.8 %). Altogether, 16 bicyclists had extra-cerebral injuries, nine had intra-cerebral injuries and 13 showed skull fractures. Moreover, eight cases of AIS 2+ facial fractures were documented. Three cyclists showed serious facial fractures (AIS 3), two of them in absence of any TBI. Concussion with loss of consciousness (AIS 2) was mentioned only in three cases. Diffuse axonal injury was reported in none of the cases.

Table I does not provide the number of soft tissue injuries to the skull at head injury levels AIS 2 and AIS 3+ as these tend to be neglected in clinical documentation when much more severe head injuries are present.

Also for the following evaluation, the 239 bicyclists with head injuries are differentiated by overall head injury severity levels of AIS 1, AIS 2 and AIS 3+.

Demography and overall injury severity: The proportion of females decreased with increasing head injury severity. While females represented 47 % at head AIS 1 level, their share declined to 34 % at AIS 2 level and to 22 % at AIS 3+ level.

When looking at age, the category of 15 to 24 years was most prominent among bicyclists with AIS 1 head injury (28 %) (Fig. 3). Among those with AIS 2 severity level, the category of 35 to 44 years was most frequent whereas at AIS 3+ level the age category of 65 years and over was clearly dominant (52 %). Of all 93 cyclists in the age categories up to 34 years, only one person, aged 15 and riding without a helmet, sustained AIS 3+ head injury.

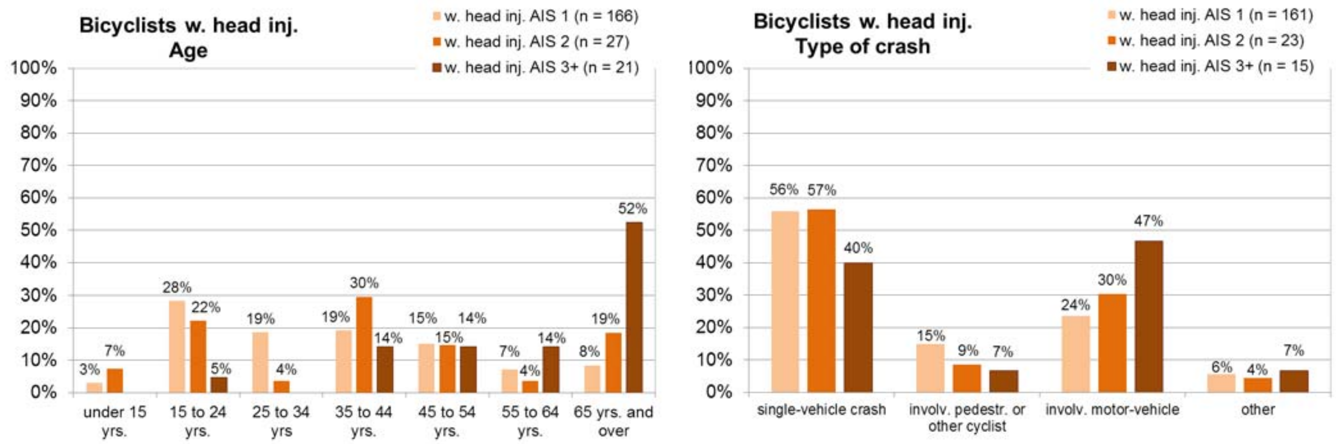
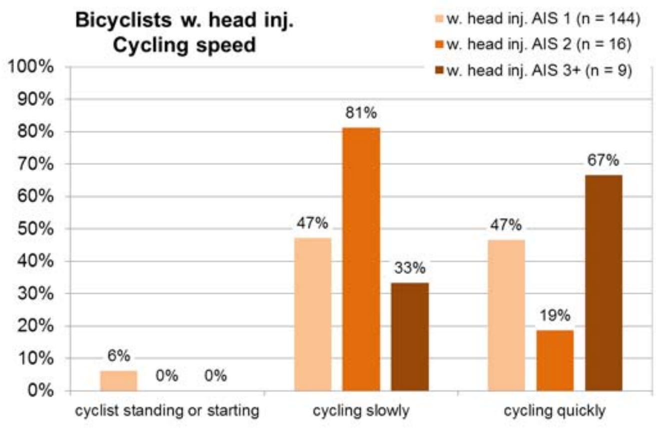


Fig. 3. Comparison of bicyclists with head injury by injury severity: Age distribution (left) and distribution of types of crashes (right)

Crash type: The type of crash was associated with head injury severity as well (Fig. 3). While bicyclist single-vehicle crashes had a proportion of approximately 56 % among cyclists with AIS 1 and AIS 2 head injury, their share declined to 40 % among cyclists with AIS 3+. Instead, the proportion of motor-vehicle involvement grew with increasing head injury levels. Among bicyclist crashes leading to AIS 3+ head injury, conflicts with motor-vehicles accounted for 47 %. Of the 15 cases with AIS 3+ head injuries and known crash type, five bicyclists experienced falls without external influence and six collided with passenger cars and a truck. The remainder consisted of one collision each with an open car door and with a roadside object and one fall each after sudden dizziness and when trying to avoid another cyclist.

Bicycle type and cycling speed: The distribution of bicycle types used did not demonstrate large differences between cyclists with head injury severities of AIS 1 (comfortable bikes: 50 %, sport bikes: 47 %, other bikes: 4 %) and AIS 2 (comfortable bikes: 48 %, sport bikes: 38 %, other bikes: 14 %). At AIS 3+ level, a trend towards sport bicycles may be suspected (comfortable bikes: 33 %, sport bikes: 58 %, other bikes: 8 %), though based on 12 cases with known bicycle type. Similarly, information on cycling speed was available only for a limited number of patients with moderate and serious head injury (Fig. 4). No clear correlation between cycling speed and head injury severity could be deduced from these data.



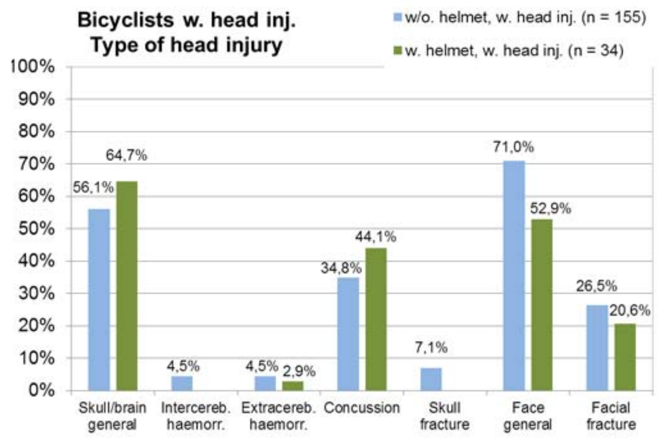


Fig. 4. Comparison of bicyclists with head injury by injury severity: Distribution of cycling speeds (left). Comparison of bicyclists with head injury by helmet use: Distribution of head injury types (right)

Bicycle helmet use: Cycle helmet wearing rate was nearly the same among bicyclists with AIS 1 (19.3 %) and those with AIS 2 head trauma (20.0 %). None of the 14 patients with AIS 3+ head injury and documentation of helmet use was actually wearing a helmet.

It was also investigated how helmet use and the type of head trauma are interrelated. For this purpose, the 155 unhelmeted bicyclists with head injuries were compared to the 34 helmeted cyclists with head injuries (Fig. 4). The frequency of facial injury in general was significantly lower for helmet-users ($p < 0.05$). Also, the proportion of facial fractures was smaller, however not significantly. In contrast, the frequency of injury to the skull or brain (i.e., excluding the face) in general was higher for those who wore a helmet (n. s.). This difference was solely due to the larger proportion of concussion among helmeted bicyclists (n. s.). Among unhelmeted cyclists, AIS 1 concussive injury accounted for 25.8 % and AIS 2 concussion for 9.0 %. Of the helmet-users, 35.3 % displayed AIS 1 concussion and 8.8 % sustained AIS 2 concussion. The higher frequency in concussive injury among cyclist with a helmet was therefore caused only by the increase in AIS 1 concussion. Except for one extra-cerebral haemorrhage, none of the 34 head-injured helmet-users sustained cerebral injuries or skull fractures. In contrast, 15 of the 155 head-injured non-helmeted cyclists with head injury presented cerebral injuries or skull fractures.

Head and helmet contact locations

The suspected points of contact of the head during the crash were derived from the location of soft tissue injuries. This was possible for 151 cyclists with head injuries, 126 of which were unhelmeted and 25 of which used a helmet. Some individuals presented more than one external injury on the head. The overall injury severity (MAIS) distributions as well as head AIS distributions were similar both for cyclists with documented soft tissue injury locations and those lacking this kind of documentation, indicating that the sub-sample of 151 patients is fairly representative of all head-injured bicyclists in the material.

Fig. 5 depicts how frequent superficial injuries were in the different head regions among the 126 bicyclists who did not wear a helmet. The region around the left eyebrow (20 % and more) and the left portion of the face were affected most frequently. Only 5 % to 10 % of these cyclists presented superficial injuries in the frontal and fronto-temporal regions and the rear portion of the parietal region.

The frequencies of soft tissue injury locations of the 25 helmeted cyclists are shown in Fig. 6. Generally, fewer areas on the head presented such injuries, particularly in the temporal and parietal region. With 15 % to 20 %, the left eyebrow and the forehead were affected most frequently.

The distribution of external injuries on the skull and in the face suggests that in the majority of cases the impact to the head came from the front, either straight or oblique. Soft tissue injuries in the immediate top portion of the skull were not registered in any of these bicyclists.

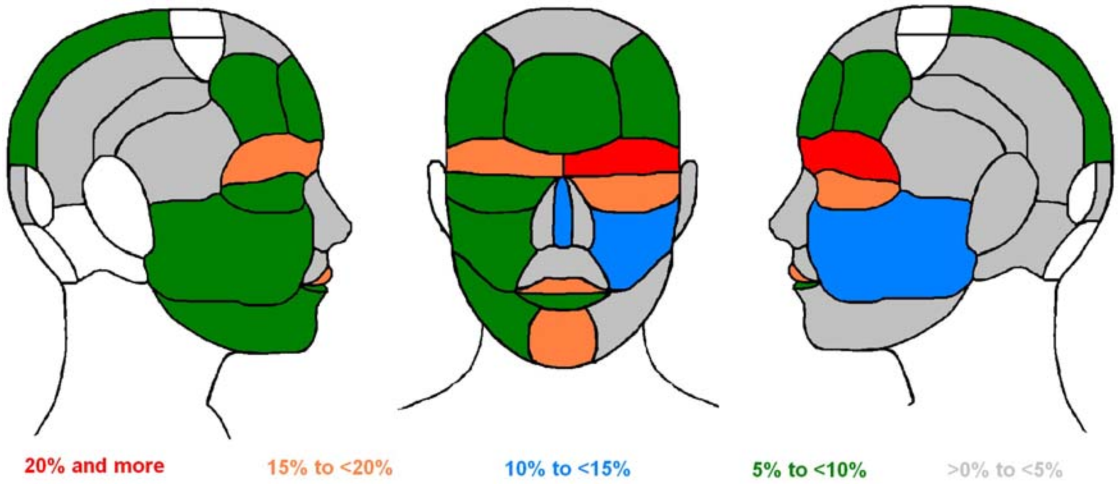


Fig. 5. Frequency of soft tissue injury locations in 126 bicyclists not wearing a helmet

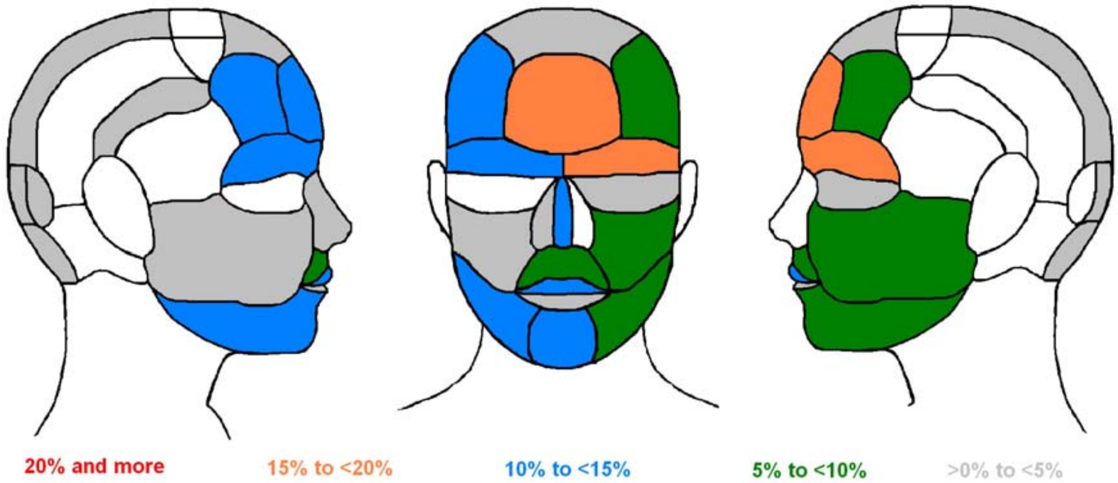


Fig. 6. Frequency of soft tissue injury locations in 25 bicyclists wearing a helmet

For 26 helmeted cyclists, helmet contact to the ground or an object could be established from scratches, dents or fractures. This particular sample included also four cyclists from the original dataset (571 patients) who were not injured, neither to the head nor elsewhere, but for whom a contact to their helmet could be confirmed. Fig. 7 shows the distribution of the locations of damage in absolute numbers. The frontal portion of the lower rim of the helmet was the most frequently affected area, followed by the rear of the helmet. Only two contacts pertained to the top of the helmet.

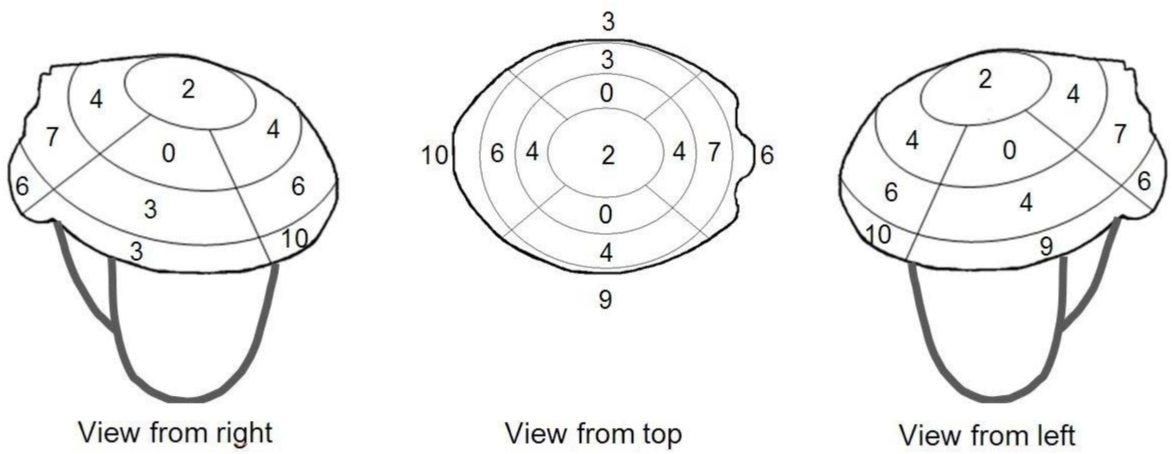


Fig. 7. Absolute frequency of locations of helmet damage in 26 bicyclists wearing a helmet

IV. DISCUSSION

In order to learn more about the crash circumstances that affect head injury in bicyclists it is necessary to combine detailed data on injury with information on the characteristics of the crash. While injury data can usually be obtained from hospital documentation, police data is often not suitable or even available to describe the circumstances of a cyclist crash. Particularly, bicyclist falls without third party involvement are frequent, but tend to be under-reported by the police [4, 5].

Our study was aimed at providing a comprehensive view of cyclist crashes that lead to head injury and contribute to the understanding which factors are relevant for the occurrence of cyclist head trauma. Our method combined injury documentation based on hospital data with crash information obtained from several sources. Description of the course of the crash was based in a large part on self-reporting by the patients themselves. This was necessary to capture information on many cyclist crashes that would otherwise not have been documented at all.

At the same time, self-reporting represents the strongest limitation of our study. There is little reason to believe that the study participants intentionally provided incorrect answers or that the responses were otherwise biased. However, partially filled questionnaires resulted in missing values in some cyclist documentations, thus reducing the statistical power when analyzing the data. Our study material represents the average population of injured bicyclists not entirely. Bicyclists in the Muenster and the Munich region may differ regarding their cycling habits, thus possibly influencing the circumstances of crashes. Yet, it can be assumed that through the merging of datasets from both regions typical cyclist crashes are better reflected than if based on samples from only one region or solely on police data. The consolidation of data and comparison of one group of bicyclists without and one group of bicyclists with head injuries allowed to determine variables that are likely associated with the occurrence of head trauma.

Cyclists in the age group of 35 to 44 years sustained head injuries more frequently, particularly at AIS 2 level. Knowles et al. [5] reported an increasing proportion of those aged 30 to 49 years among killed and seriously injured cyclists in the United Kingdom between 1994 and 2007. Elderly (65 years and over) were particularly prominent in our material among bicyclists with AIS 3+ head injury. Furthermore, gender showed stronger correlation with outcome as head injury severity increased. Depreitere et al. [7] also noted peaks among middle-aged and elderly cyclists and a prevalence of men in their material.

Single-vehicle crashes accounted for approximately half of all crashes in our study, both among bicyclists without and with head injury. This underscores the importance of this type of bicycle crash, in general as well as for the occurrence of head injuries. Otte et al. [10] reported a share of approximately 10 % of these crashes compared to 75 % of collisions with motor-vehicles from their on-the-spot accident research. The relatively low proportion of single-vehicle crashes was probably due to the fact that the GIDAS team is only alerted to crashes if the police is called [13]. Depreitere et al. [7] found nearly as many bicyclists due to falls than due to collisions with motor-vehicles in their clinic data. SWOV [14] published results from hospitals in the Netherlands according to which approximately three times as many cyclists had to be hospitalized with head injuries after crashes without motor-vehicle involvement than after collisions with motor-vehicles.

Nevertheless, our study confirms that collisions with motor-vehicles play a crucial role when serious head injuries are concerned. The proportion of motor-vehicle involvement rose to nearly 47 % among bicyclists with AIS 3+ head injury. This is similar to the proportion of collisions with a motor-vehicle (51 %) among cyclists requiring neurosurgery in Depreitere et al.'s material [7]. Motor-vehicle involvement is even more predominant in cases with fatal outcome. According to Utsch [8], collisions with passenger cars or trucks were responsible for three quarters of cases with traumatic brain injury being the cause of death.

Our data suggests that cycling speed is significantly associated with the incidence of head injury in general. Though this may appear to be self-evident, it has not been adequately considered in crash-related cyclist studies so far. Cycling speed before the crash had to be estimated by the participants of our study and data was scarce for bicyclists with serious head trauma. Yet, the simple classification into cycling speed categories under and over 20 km/h appears to be practicable. This threshold value is similar to the approximately 18 km/h determined as the average cycling speed in cities by a recent German field study [15].

The vast majority of head trauma in our material consisted of AIS 1 injuries to the face, the skull or concussions of minor severity. These injuries are possibly under-reported even in hospital statistics since they usually do not require in-patient treatment. Nevertheless, approximately 13 % of the head-injured bicyclists showed AIS 2 severity, with a predominance of concussive injury with short-duration unconsciousness and facial fractures. AIS 3+ head trauma was present in 10 % of the head-injured, often characterized by the coexistence of several TBI's and skull fractures. The latter was also noted by Depreitere et al. [7], though more pronounced in their material.

The locations of soft tissue injuries and of helmet damage suggest that the face and the frontal and fronto-temporal skull area are the areas where head contact with the ground or an opponent occurs most frequently. Depreitere et al. [7] and Utsch [8] found larger proportions of contacts in the parietal and occipital region of unhelmeted cyclists. These differences may be due to the fact that they analyzed more serious head trauma that involved a large percentage of collisions with motor-vehicles which may have been associated with different impact directions.

Some helmeted bicyclists in our material showed soft tissue injuries in skull areas that could be expected to be covered by the helmet. From the locations, it is assumed that these were caused when impact forces on the helmet were transferred to the skull by the inner plastic head band.

Otte et al. [10] reported similar locations of helmet damage than those found in our study. Both indicate that the top of the head (or helmet) is very rarely subjected to an impact.

With 17.2 % altogether, the cycle helmet use rate among all injured bicyclists in our study was higher than 13 % reported by BASt for bicyclists in general [9], but the same as the rate reported by Otte et al. for cyclist casualties in 2010 [10]. With regard to the protective effect, our results appear contradictory at first glance: 18.0 % of the bicyclists presenting head injuries wore helmets, slightly more than the 16.7 % helmet-users among cyclists without head injuries. However, all AIS 3+ head (including face) injuries were sustained by unhelmeted cyclists, and of those who wore a helmet, none showed skull fractures. Regardless of head injury, helmet wearing rate among cyclists who had reported quick cycling was twice as high as the rate among cyclists who had cycled slowly. From these results, we hypothesize that bicyclists who – on average – ride faster will more often choose to wear a helmet. However, faster bicyclists are probably at a higher risk to have a crash that affects the head. Therefore, the positive effect of a bicycle helmet may be outweighed by the effect of riskier cycling.

Helmets may not be able to prevent serious injuries entirely, but reduce the risk considerably [16]. This may, at least in part, explain why the helmet-users presented a higher proportion of minor concussive injury (AIS 1) than unhelmeted cyclists. Nevertheless, the frequency of other cerebral injuries and skull and facial fractures was dramatically lower when helmets were worn. Otte et al. [10] reported very similar results for helmet wearers, with a slightly higher proportion of AIS 2 brain injury in comparison with non-users.

V. Conclusions

A large proportion of cyclist head traumata are caused by single-vehicle crashes. Analyses that are based entirely on police-reported data tend to focus on collisions with motor-vehicles and may overlook this fact. Hospital documentation, complemented by information about crash circumstances, is probably more suited to provide a realistic image of the extent of cycling crashes and injuries.

Our study suggests that cycling speed is an important risk factor for bicyclist head injury. New cycle concepts, particularly those which support pedaling by electric power, are popular particularly among middle-aged and elderly cyclists, thus combining higher speed with higher vulnerability. These age groups need to be better addressed by safety campaigns and encouraged to wear cycle helmets.

Research and discussion about bicyclist head protection may provide wrong conclusions if analysis of real-world data is based solely on the incidence of head injuries. Ideally, head injury severity, but also cycling behavior which largely determines exposure and crash risk, should be considered as well.

VI. REFERENCES

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VII. Appendix

Bicyclists Without and With Head Injury; Crash Circumstances

		Bicyclists without head / face injury (n = 304)		Bicyclists with head / face injury (n = 239)		statist. signif. (p-value)
gender	male	146	48.0 %	135	57.2 %	0.034
	female	158	52.0 %	101	42.8 %	
	unknown	-		3		
age [yrs.]	mean	36.0		39.9		
	(+/- STD.)	(+/- 18.9)		(+/- 18.8)		
	median	29		38		
	under 15	16	5.6 %	7	3.3 %	n. s.
	15 to 24	93	32.7 %	54	25.2 %	n. s.
	25 to 34	60	21.1 %	32	15.0 %	n. s.
	35 to 44	25	8.8 %	43	20.1 %	< 0.001
	45 to 54	32	11.3 %	32	15.0 %	n. s.
	55 to 64	25	8.8 %	16	7.5 %	n. s.
	65 and over	33	11.6 %	30	14.0 %	n. s.
	unknown	20		25		
type of crash	single-vehicle	166	60.4 %	109	54.8 %	n. s.
	involv. pedestr. or other cyclist	53	19.3 %	27	13.6 %	n. s.
	involv. motor-vehic.	50	18.2 %	52	26.1 %	0.038
	other	6	2.2 %	11	5.5 %	n. s.
	unknown	29		40		
type of bicycle	comfortable bicycle	135	55.1 %	87	48.6 %	n. s.
	sport bicycle	97	39.6 %	83	46.4 %	n. s.
	other bicycle types	13	5.3 %	9	5.0 %	n. s.
	unknown	59		60		
cycling speed	standing or starting	26	10.6 %	9	5.3 %	n. s.
	cycling slowly	146	59.6 %	84	49.7 %	0.047
	cycling quickly	73	29.8 %	76	45.0 %	0.002
	unknown	59		70		
helmet use	no helmet	205	83.3 %	155	82.0 %	n. s.
	helmet	41	16.7 %	34	18.0 %	
	unknown	58		49		

BICYCLISTS WITHOUT AND WITH HEAD INJURY; INJURY SEVERITY

		Bicyclists without head / face injury (n = 304)		Bicyclists with head / face injury (n = 239)		statist. signif. (p-value)
Maximum AIS	MAIS 1	191	62.8 %	153	64.0 %	n. s.
	MAIS 2	103	33.9 %	58	24.3 %	0.015
	MAIS 3	9	3.0 %	25	10.5 %	< 0.001
	MAIS 4	1	0.3 %	3	1.3 %	-
Injury Severity Score	ISS 1-3	192	63.2%	154	64.4%	n. s.
	ISS 4-8	102	33.6%	50	20.9%	0.001
	ISS 9-15	8	2.6%	26	10.9%	< 0.001
	ISS ≥ 16	2	0.7%	9	3.8%	-
Head (incl. face) AIS	Head AIS 0	304	100.0%	-	0.0%	
	Head AIS 1			184	77.0 %	
	Head AIS 2			32	13.4 %	
	Head AIS 3			21	8.8 %	
	Head AIS 4			2	0.8 %	
Head (skull/brain) AIS	Skull/Brain AIS 0	304	100.0%	99	41.4 %	
	Skull/Brain AIS 1			97	40.6 %	
	Skull/Brain AIS 2			22	9.2 %	
	Skull/Brain AIS 3			19	7.9 %	
	Skull/Brain AIS 4			2	0.8 %	
Face AIS	Face AIS 0	304	100.0%	78	32.6 %	
	Face AIS 1			140	58.6 %	
	Face AIS 2			18	7.5 %	
	Face AIS 3			3	1.3 %	