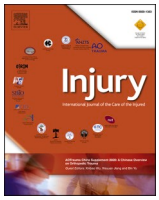
Injury 55 (2024) 111960

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury



Fracture patterns in bicycle accidents: A descriptive national cohort study of fractures sustained in bicycle accidents in the Swedish Fracture Register 2015–2022

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ARTICLE INFO

Keywords:
Fracture
Bicycle accident
Fracture distribution
Bicycle injury
Bicycle
Road traffic accident
Fracture pattern
Swedish fracture register

ABSTRACT

Introduction: Bicycle accidents account for the majority of traffic-related accidents in Sweden. Despite the widespread everyday use of bicycles, little is known about the fracture panorama resulting from bicycle accidents. This study analysed the fracture patterns of bicycle accidents in Sweden in regard to fracture type, sex, age, and type of bicycle.

Material and methods: We retrieved data from the Swedish Fracture Register on all fractures caused by bicycle accidents between 2015 and 2022. The study population was comprised of both children and adults who had sustained one or more fractures in a bicycle accident as registered in the Swedish Fracture Register.

Results: We included 33,384 fractures (25,960 in adults and 7424 in children) in 30,815 patients, with a dominance of fractures in men. The mean age at fracture was 41.6 years (SD 23). The majority of fractures (62.7 %, $n = 20,932$) were sustained via a low energy mechanism. Overall, the most commonly fractured body parts were the forearm (35.2 %, $n = 11,747$), the hand (15.6 %, $n = 5,196$) and the clavicle (13.7 %, $n = 4,558$). In children, fractures of the forearm (56.8 %, $n = 4,215$) clearly dominated, followed by the hand (11.7 %, $n = 868$), and the humerus (11.0 %, $n = 816$). In adults, the top 3 fracture locations were the forearm (29.0 %, $n = 7,532$), the hand (16.7 %, $n = 4,328$), and the clavicle (15.7 %, $n = 4,086$). Mountain bikes and road bikes showed a fracture panorama that was very similar with a predominance of fractures to the clavicle. Fractures were more common during the warm season.

Conclusion: The main finding is that bicyclists predominantly sustained fractures of the upper limb via low energy mechanisms. The fracture panorama differed by age, sex, and type of bicycle.

Introduction

Cycling is a popular form of transportation, especially in densely populated urban areas [1]. In addition, it is a popular form of recreation and exercise. Regardless of its many well-known beneficial effects on health, an increasing number of bicycles on the road has led to an increasing number of bicycle-related accidents [2,3].

Despite the widespread everyday use of bicycles, little is known about the panorama of fractures sustained in bicycle accidents. Above all, there is a lack of observational data from a nation-wide perspective providing information on the fracture panorama on a detailed level allowing stakeholders to implement potential protective measures from a European perspective. The fractures sustained during bicycling are reported in injuries to the upper extremity and shoulder [4,5]. This was also confirmed by mapping the injuries of elite cyclists participating in the Tour de France, where clavicle and wrist fractures were the most common types of fractures [6]. Apart from extremity fractures, other common injuries related to bicycling are overuse injuries and head and skull trauma [4,5].

Bicycle accidents account for most transportation-related accidents in Sweden today. We have estimated incidence rates for bicycle-related accidents with the data from the SFR and data on population statistics

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https://doi.org/10.1016/j.injury.2024.111960
Accepted 14 October 2024
Available online 18 October 2024
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published by Swedish Tax Agency's population register to be as high as 1,090 and 1,049 / 100,000 / year for 2021 and 2022 respectively. Accordingly, the Swedish National Board of Health and Welfare reported an increase in admissions for inpatient hospital care over the last years [7], and the Swedish Traffic Administration reported an increase in casualties related to bicycle accidents in Sweden in 2021 [8].

Recent developments in the bicycle industry have led to a broad variety of bicycles on the market. Particularly, e-bikes, with integrated electrical motors to assist propulsion, have gained popularity. This new technical addition of bicycle types with increased speed may have altered the fracture panorama.

This study aimed to analyse and describe the fracture patterns sustained from bicycle accidents from a nation-wide perspective in Sweden based on data from the Swedish Fracture Register (SFR). Descriptive statistics is provided with special regards to the distribution of fracture types, sex, age, type of bicycle and seasonal variations.

This study provides unique data on bicycle accident-related data from a nation-wide perspective in Europe including detailed data on cyclists, bicycle types and environmental factors allowing a broad overview on the related fracture panorama. This information can hopefully guide to an improved understanding of possible protective measures and preventative interventions in the future.

Material and methods

Study design and setting

This observational register-based national cohort study was based on data from the SFR. The SFR is a web-based national quality register established in 2011. With >900,000 registered fractures, it is the largest dedicated fracture register worldwide, and the only including both operative and non-operative treatment [9–11]. It has provided full coverage since 2021, with data from all Swedish hospitals providing trauma care. The fracture registrations in SFR are regularly linked to data from the Swedish National Patient Register and figures on completeness are published yearly in its annual report [12,13]. Several studies proved the validity of the SFR fracture classification [14–18].

Registrations are physician-based by filling out three panels containing variables on: (1) mechanism of injury; (2) fracture specifics and classification (AO/OTA); and (3) treatment options, including options for both operative and non-operative management. The AO/OTA 2007 classification is the most common classification used in the SFR. Registration of paediatric fractures in the SFR started in May 2015 and specific classification of paediatric long bone fractures is available. Therefore, registration is recommended for paediatric long bone fractures, and fractures in other locations can be registered according to adult classifications.

Study population

The study population includes all fractures caused by bicycle accidents in children and adults registered in the SFR between January 1st, 2015, and December 31st, 2022. Both patients with one isolated fracture or multiple fractures were included. Multiple fractures were defined as two or more fractures sustained in either one or more bicycle accidents. Fractures lacking a fracture classification ($n = 238$) were excluded. The

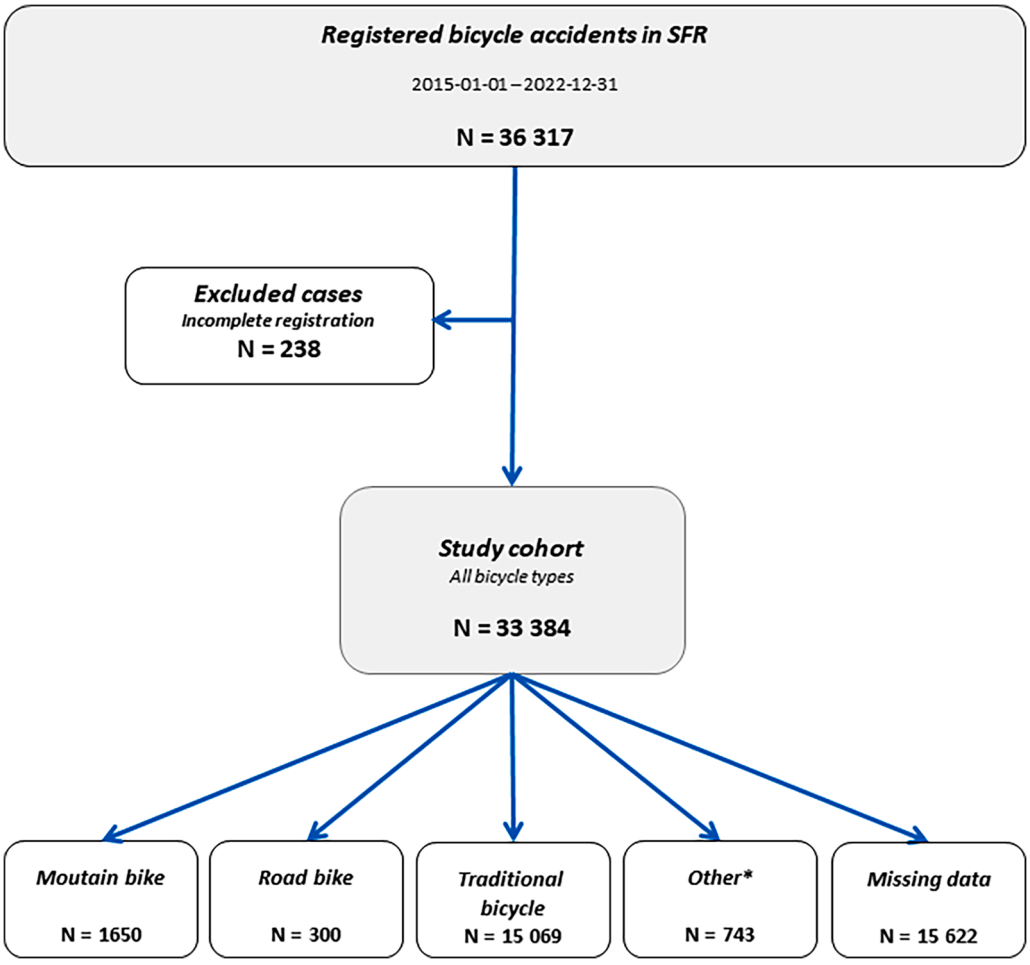

Fig. 1. Flowchart showing included and excluded fractures.

remaining 33,384 fractures in 30,815 patients were included and analysed in the study (Fig. 1).

Data extraction

All fractures registered as having been sustained by a transportation accident related to bicycling (and specified as bike, e-bike, cargo bike, mountain bike, road bike, or unspecified bike) between January 1st, 2015, and December 31st, 2022 were extracted from the SFR (n = 33,622).

Variables of interest

Variables of interest included age, sex, number of fractures per patient, location of fracture and segment, injury date, open or closed fracture, bicycle type, and high or low energy mechanism of injury.

Statistical analysis

Descriptive statistics such as mean (standard deviation (SD)) and median (interquartile range (IQR)) were used for continuous variables. Frequency and proportions (%) were used for categorical variables. Patients <18 years were defined as children, patients ≥18 years as adults.

Significance was calculated using Pearson's chi-squared test. Statistical significance was defined as a two-sided alpha of <0.05.

Missing data is presented but was not accounted for by calculation of statistical estimates (e.g. imputation).

The statistical analyses were performed using the R Software package version 4.2.3 [19] and Jamovi (version 2.3.26.0; jamovi.org).

Ethics

The study was approved by the Swedish Ethical Review Authority (approval number 2022-04355-01, date of issue: September 20, 2022) and was performed in accordance with the Declaration of Helsinki.

Results

We included 33,384 fractures in 30,815 patients in this study. The majority (n = 29,020) sustained a single fracture, and 1795 patients had sustained two fractures or more, either on the same or on different occasions.

Adults accounted for 25,960 fractures (78 %) and children for 7,424 fractures (22 %). A total of 60 % (19,993) of all fractures were sustained by men.

For men, the age distribution showed a typical bimodal pattern, with the major peak at 13 years and another minor peak at 47 years (Fig. 2). Women showed a similar bimodal pattern, with peaks at 11 and 57 years.

Injury mechanism

The majority of fractures (62.7 %, n = 20,932) were sustained via a low-energy mechanism. An additional 15.8 % (n = 5,263) of fractures were sustained via high-energy mechanisms, of which 72.2 % (n = 3,800) were diagnosed in males. The remaining 21.5 % (n = 7,189) were registered either as unknown mechanism of energy or information about energy impact was missing completely.

There was a higher proportion of high-energy injuries in road bike (43.3 %) and mountain bike (32.1 %) accidents compared to accidents with traditional bicycles (11.4 %).

The age distribution for high- and low-energy injuries was similar with a mean of 42.5 years (SD 19) for high-energy injuries and 41.8 years (SD 23) for low-energy injuries.

Bicycle types that are more frequently used for recreational purposes (MTB and road bikes) differed from traditional bicycles by significantly higher proportions of high-energy–related fractures (n = 659 of 1,666

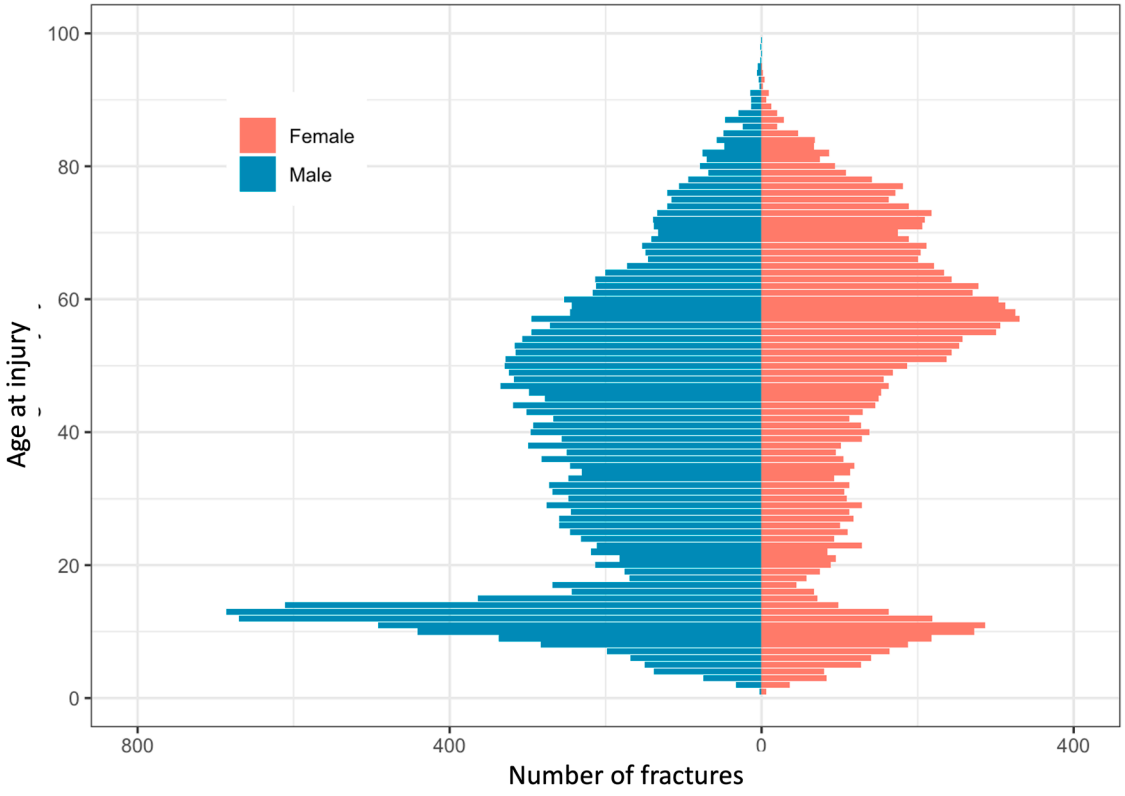

Fig. 2. Age and sex distribution of fractures sustained in bicycle accidents.

(40 %) versus $n = 1,725$ of 12,921 (13 %), $p < 0.01$). This was also reflected by a significantly higher portion of clavicular fractures ($n = 575$ of 1,950 (29 %) versus $n = 1,706$ of 15,069 (11 %), $p < 0.01$).

Bicycle types

Since July 2019 type of bike can be specified. Of those listed, the second most commonly used bike when sustaining a fracture was a traditional bicycle (45.1 %, $n = 15,069$). Mountain bikes accounted for 4.9 % ($n = 1,650$) and road bikes for 0.9 % ($n = 300$). E-bikes, bicycles with a cargo box, and/or a trailer accounted for the remaining bicycle types (2.2 %, $n = 743$).

There was no difference in fracture panorama when comparing E-bikes to traditional bicycles.

Fracture distribution

Overall, the most commonly fractured body parts were the forearm (35.2 %), the hand (15.6 %), and the clavicle (13.7 %) (Table 1, Fig. 3).

Fracture distribution differed between the sexes. In males, the forearm (31.9 %), the clavicle (18.9 %), and the hand (17.7 %) accounted for the three most commonly fractured body parts; whereas in women, these were the forearm (40.2 %), the hand (12.4 %), and the humerus (11.2 %) (Fig. 4).

In children, fractures of the forearm (56.8 %) clearly dominated, followed by the hand (11.7 %), and the humerus (11.0 %). When dividing children into girls and boys, the three most commonly fractured body parts in girls were the forearm (59 %), the humerus (12.7 %), and the tibia (12.1 %), whereas the most commonly fractured body parts in boys were the forearm (55.8 %), the hand (12.9 %), and the humerus (10.3 %).

The top three fractured body parts in mountain bikers and road bikers were the clavicle (27.7% vs. 39.3 %), the forearm (25.6% vs. 17.0 %), and the hand (18.1% vs. 15.0 %) (Fig. 5). Traditional bicyclists sustained more fractures of the forearm (37.2 %), followed by fractures of the hand (15.5 %), and clavicular fractures (11.3 %) (Table 2).

Open fractures were rare and accounted for only 1.5 % of all fractures ($n = 490$).

Seasonal variation

Most fractures were registered from April to September; i.e., 72.8 % ($n = 24,313$) with males dominating in absolute numbers for every single month (Fig. 6).

Table 1
Fracture distribution in males and females by body part.

	Female ($n = 13,391$)	Male ($n = 19,993$)	Total ($n = 33,384$)
Injury age			
Mean (SD)	47.1 (22.8)	38.0 (21.5)	41.6 (22.5)
Median [Min, Max]	53.0 [1.00, 95.0]	38.0 [1.00, 99.0]	44.0 [1.00, 99.0]
Fractured body part			
Acetabulum	38 (0.3 %)	141 (0.7 %)	179 (0.5 %)
Ankle	1,023 (7.6 %)	710 (3.6 %)	1,733 (5.2 %)
Clavicle	770 (5.8 %)	3,788 (18.9 %)	4,558 (13.7 %)
Femur	733 (5.5 %)	1,150 (5.8 %)	1,883 (5.6 %)
Foot	513 (3.8 %)	505 (2.5 %)	1,018 (3.0 %)
Forearm	5,377 (40.2 %)	6,370 (31.9 %)	11,747 (35.2 %)
Hand	1,657 (12.4 %)	3,539 (17.7 %)	5,196 (15.6 %)
Humerus	1,495 (11.2 %)	1,367 (6.8 %)	2,862 (8.6 %)
Patella	142 (1.1 %)	188 (0.9 %)	330 (1.0 %)
Pelvis	276 (2.1 %)	227 (1.1 %)	503 (1.5 %)
Scapula	101 (0.8 %)	527 (2.6 %)	628 (1.9 %)
Spine	182 (1.4 %)	584 (2.9 %)	766 (2.3 %)
Tibia	1,084 (8.1 %)	897 (4.5 %)	1,981 (5.9 %)

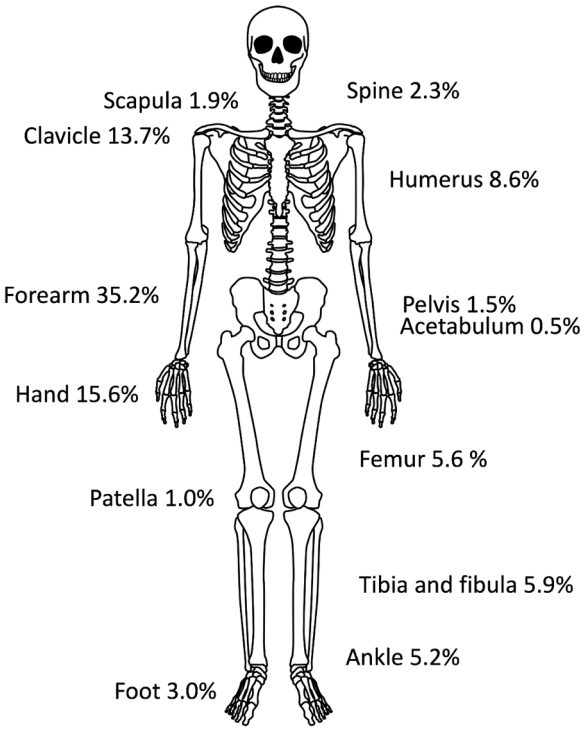

Fig. 3. Distribution of fractures caused by bicycle accidents in the entire study population.

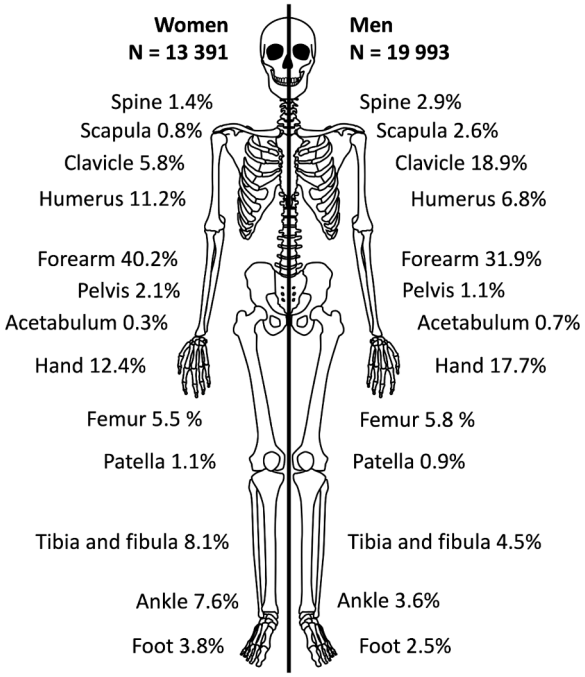

Fig. 4. Distribution of fractures caused by bicycle accidents in women and men.

Discussion

Fractures sustained during bicycle accidents in Sweden demonstrate bimodal age distributions in both men and women. A majority of fractures are located in the upper extremity, with variations between adults and children, between sexes, and between bicycle types.

Our results show similarities to previous publications that have

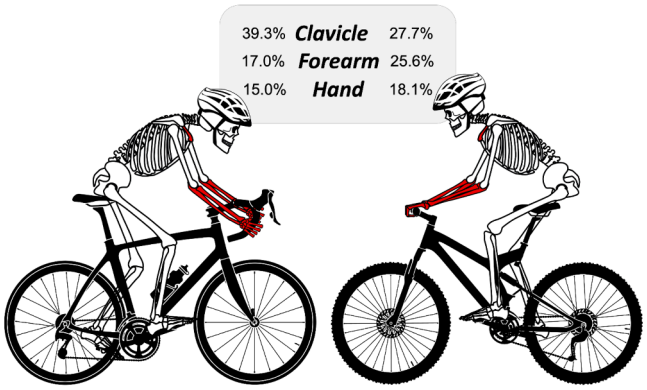

Fig. 5. The three most common fractures caused by bicycle accidents in mountain and road cyclists.

studied sport-related fractures. Wood et al. showed that sports-related fractures in adolescents were more common in males, and they tend to result from low-energy injuries affecting the upper limb [20,21]. Johnson et al. also showed that a significantly higher number of injuries occurred in men (72.2 %), which puts men at a higher risk of bicycle-related injuries [1].

In children, fractures of the forearm clearly dominated, followed by the hand and the humerus. However, data on paediatric fractures localised outside long bones may have a lower level of completeness in the SFR, affecting distribution, which could be a potential bias.

Fractures to the upper limb are often seen in sports accidents, with falls being a common injury mechanism. Court Brown et al. showed that the highest rate of sport-related fractures occurred in the clavicle and that clavicular fractures were very common in mountain biking in a single-center retrospective study [22]. Similarly, clavicular and wrist fractures are the most common types of fractures sustained by bicycle accidents in elite cyclists who participate in the Tour de France [21]. Our results showed that mountain bikers and road bikers showed a fracture panorama that was much alike, with a predominance of fractures to the clavicle, the forearm, and the hand. Expectedly, mountain bike and road bike accidents resulted in a higher proportion of high-energy injuries when compared to traditional bicycles. This may explain the marked predominance of clavicular fractures, which were about 3–4 times more frequent in mountain and road cyclists. Furthermore, mountain bikes and racer bikes are generally ridden in a more forward-positioned body posture, which is more likely to result in an impact on the upper thorax including the clavicle or axial loading of the arm in case of falls.

Our results confirm the predominance of fractures in the upper extremities, as suggested by previous studies [4–6,23,24]. We found that the forearm, the hand, and the clavicle were the most commonly injured body parts, which also corresponds well with previous studies [3,21,25]. Particularly the forearm and the wrist are easily accessible and therefore anatomic regions that should benefit from protective gear such as braces and straps. Despite this, there is insufficient evidence to support such recommendations that could possibly governed by regulatory bodies.

As expected, we noted a seasonal variation, with an increased frequency of fractures during the warmer season. This is in line with data from Australia, where bicycle-related accidents varied with school holidays and decreased during the winter months [3]. Similarly, Johnson et al. showed in a study from the US looking at data from 2012 to 2021 that bicycle-related injuries were more frequent in the summer months (36 % of all injuries) [1]. For obvious reasons, this increase of injuries during the warmer season was even more pronounced in the subgroup of mountain bikers and racer cyclists. In Sweden, some enthusiastic bikers even use studded winter tires in order to avoid accidents on icy roads. To reduce the risk of bicycle accidents, pre-seasonal prevention and public awareness interventions should take place repetitively during the year.

Our study provides unique information on the fracture panorama sustained in cycling accidents due to its nation-wide coverage and the large number of fractures included. To our knowledge, this is the only study reporting on European data from a helicopter perspective including all types of fractures including those of recreational, sports and commuting reasons. Johnson et al. have published interesting similar data from the U.S. [1], their findings may though not necessarily apply to the European conditions. Other studies have mainly focused on reporting on subgroups like elite sportsmen or particular bicycle types [20–22]. Apart from the above, the multitude of variables in the SFR allowed for the analysis of multiple variables such as age, sex, seasonal variation, degree of energy involved, etc., allowing for a good overview of fractures sustained in different cycling accidents. SFR coverage has gradually increased over the years as new departments join the register. Since 2021, the SFR has had 100 % coverage and multiple studies have demonstrated good validity regarding its fracture classifications [14,17,18]. Given the nature of the SFR, we were unable to analyse head trauma-related injuries, as these are not registered in the SFR. A further drawback is the amount of data missing on high- versus low-energy injuries. The inclusion of this variable is not mandatory in the SFR. About 10 % of data was missing and another 10 % of data listed the amount of energy as unknown. This may have introduced bias affecting the precision of our estimates. We judged this effect to be limited as missing data appeared evenly distributed throughout all participating sites. Overall completeness for all fracture types is now >65 % when compared to the National Patient Register, which may, however, overestimate the true number of fractures [15]. Another drawback that is

Table 2
Distribution of fractures and bicycle types.

	Bike (n = 15,069)	**Cargo bike (n = 36)**	**E-bike (n = 707)**	**Mountain bike (n = 1650)**	**Road bike (n = 300)**	**Unspecified bike (n = 15,622)**	**Total (n = 33 384)**
Sex							
Female	6,570 (43.6 %)	26 (72.2 %)	364 (51.5 %)	263 (15.9 %)	46 (15.3 %)	6,122 (39.2 %)	13,391 (40.1 %)
Male	8,499 (56.4 %)	10 (27.8 %)	343 (48.5 %)	1,387 (84.1 %)	254 (84.7 %)	9,500 (60.8 %)	19,993 (59.9 %)
Fractured body part							
Acetabulum	76 (0.5 %)	0 (0 %)	5 (0.7 %)	6 (0.4 %)	6 (2.0 %)	86 (0.6 %)	179 (0.5 %)
Ancle	790 (5.2 %)	4 (11.1 %)	50 (7.1 %)	45 (2.7 %)	2 (0.7 %)	842 (5.4 %)	1,733 (5.2 %)
Clavicle	1,706 (11.3 %)	3 (8.3 %)	73 (10.3 %)	457 (27.7 %)	118 (39.3 %)	2,201 (14.1 %)	4,558 (13.7 %)
Femur	888 (5.9 %)	1 (2.8 %)	31 (4.4 %)	21 (1.3 %)	28 (9.3 %)	914 (5.9 %)	1,883 (5.6 %)
Foot	462 (3.1 %)	2 (5.6 %)	25 (3.5 %)	38 (2.3 %)	0 (0 %)	491 (3.1 %)	1,018 (3.0 %)
Forearm	5,603 (37.2 %)	6 (16.7 %)	229 (32.4 %)	423 (25.6 %)	51 (17.0 %)	5,435 (34.8 %)	11,747 (35.2 %)
Hand	2,330 (15.5 %)	3 (8.3 %)	114 (16.1 %)	298 (18.1 %)	45 (15.0 %)	2,406 (15.4 %)	5,196 (15.6 %)
Humerus	1,380 (9.2 %)	3 (8.3 %)	68 (9.6 %)	103 (6.2 %)	3 (1.0 %)	1,305 (8.4 %)	2,862 (8.6 %)
Patella	175 (1.2 %)	0 (0 %)	14 (2.0 %)	7 (0.4 %)	1 (0.3 %)	133 (0.9 %)	330 (1.0 %)
Pelvis	245 (1.6 %)	0 (0 %)	9 (1.3 %)	15 (0.9 %)	5 (1.7 %)	229 (1.5 %)	503 (1.5 %)
Scapula	221 (1.5 %)	1 (2.8 %)	7 (1.0 %)	73 (4.4 %)	18 (6.0 %)	308 (2.0 %)	628 (1.9 %)
Spine	265 (1.8 %)	0 (0 %)	11 (1.6 %)	109 (6.6 %)	18 (6.0 %)	363 (2.3 %)	766 (2.3 %)
Tibia	928 (6.2 %)	13 (36.1 %)	71 (10.0 %)	55 (3.3 %)	5 (1.7 %)	909 (5.8 %)	1,981 (5.9 %)

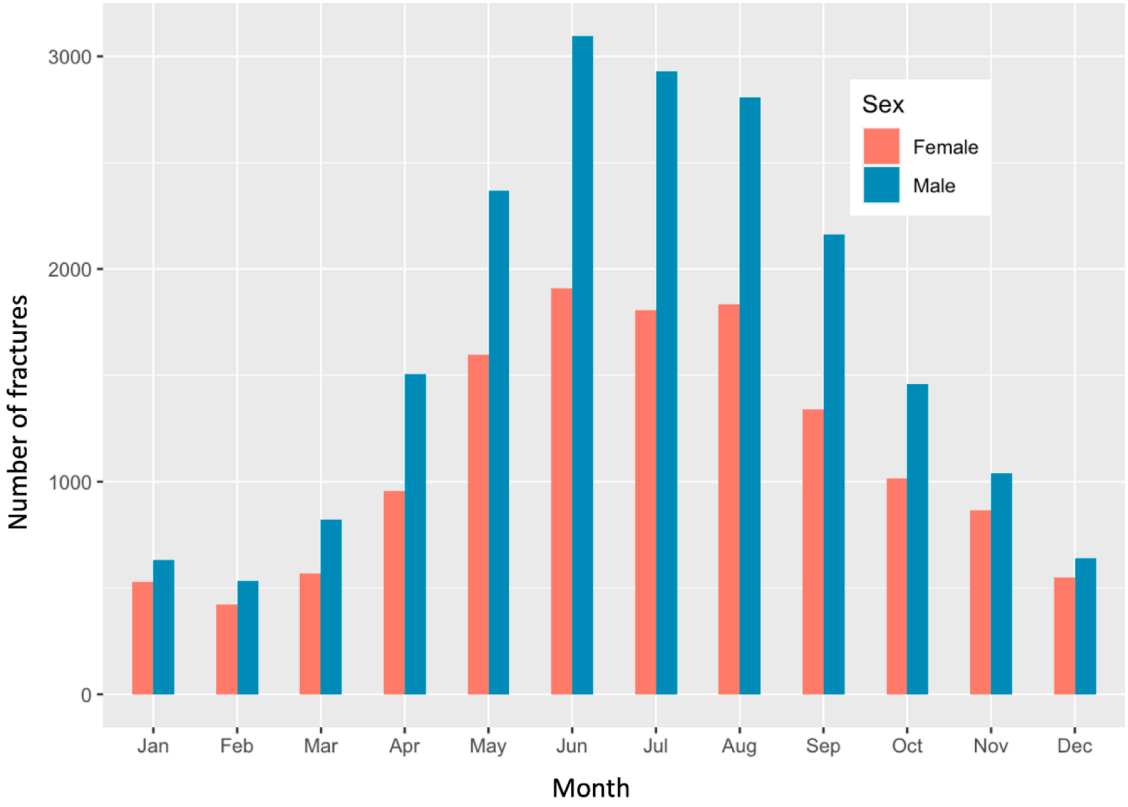

Fig. 6. Seasonal variation of fractures caused by bicycle accidents.

inherent to observational studies is incomplete data. The SFR contains both compulsory variables but also optional variables. For obvious reasons there is missing data in the set of optional variables. Amongst those is the information on the type of impact (high versus low energy and unknown energy) and bicycle types. We chose not to account for this lack of data by handling missing data with e.g. multiple imputation as missing data appeared evenly distributed among the participating sites. There is little reason to believe that this missing data should introduce systemic bias. Despite that, it may still represent a source of possible bias in our data.

E-bikes with assisted electric propulsion have become more popular during the recent years. We do see an increase of fractures related to e-bike accidents parallel to the e-bikes popularisation in society. Having aided propulsion by an electric motor may suggest that the fracture panorama would shift towards more serious injuries and more high energy mechanisms. This could not be confirmed in the analysis of our data when comparing e-bikes with e.g. traditional bicycles. E-bike accidents lead to a fracture panorama much alike that of traditional bikes. This stands in contrast to the publication of Tenenbaum et al. [26] that studied data on e-bikes injuries and showed that fractures to the lower limb, especially the tibia, were the most common in accidents associated with E-bikes.

Since cycling accidents are common and account for the majority of transportation related accidents in Sweden, they pose a significant burden and cost for healthcare providers. For obvious reasons this raises the question of preventive measures to minimise this burden. Protective measures could be many, all from protective gear, educational measures or even regulatory measures.

The recognition of fracture patterns sustained from bicycle accidents is a prerequisite to implement adequate protective measures, The most commonly used protection is the cycling helmet. Wearing a helmet and choosing the bicycle in appropriate size has been shown to minimize the risks of sustaining injuries while riding a bicycle [27]. Helmet use may have some protective effect against head injuries, although there is no evidence of benefits regarding other preventative equipment, such as facemasks, elbow pads and shoulder protective gear [28–30]. Particularly in the field of brain injury mitigation newer technologies such as helmets fitted with a friction-reducing layer (MIPS), a shearing pad (SPIN), a wavy cellular liner (WaveCel), an airbag helmet (Hövding) have shown early promising results [31]. Unfortunately, there is insufficient research activity with respect to protective gear to prevent extremity fractures.

The lack of data on skull trauma and resulting traumatic brain injuries is a noted limitation of our study that is rooted in its data origin from a national fracture register. Future research could overcome these shortcomings by combing data from several registers such e.g. the Swedish National Patient Register (NPR) and/or the Swedish Trauma Register (SweTrau) and the SFR.

Conclusion

We found that bicyclists predominantly sustained fractures of the upper limb via low-energy mechanisms during the summer, and that the fracture pattern differed by age, sex, and mechanism. Despite the numerous benefits of cycling, fracture patterns should be considered, and protective measures implemented to reduce the injury burden sustained in bicycle accidents.

CRediT authorship contribution statement

Sofie Josefsson: Writing – review & editing, Writing – original draft, Visualization, Validation. **Anders Brüggemann:** Writing – review & editing, Supervision, Formal analysis, Data curation. **Olof Wolf:** Writing – review & editing, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hans Peter Bögl:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

None.

Acknowledgements

We would like to express our gratitude to Pontus Andersson at Pontus Art production AB for helping us with the illustrations used in our figures.

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