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‘Downhill race for a rainbow jersey’: the epidemiology of injuries in downhill mountain biking at the 2023 UCI cycling world championships—a prospective cohort study of 230 elite cyclists

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ABSTRACT

Objectives This study aims to understand the prevalence, incidence rate, anatomical sites, injury severity and main medical actions carried out during official training and racing by elite downhill mountain biking (DHMTB) riders during the 2023 Union Cycliste Internationale (UCI) Cycling World Championships.

Methods The participants of this prospective, observational study were elite male and female cyclists competing at the UCI DHMTB World Championships located in the Nevis range in Fort William, Scotland, in 2023. This study followed the injury reporting guidelines established by the International Olympic Committee, which include the Strengthening the Reporting of Observational Studies in Epidemiology—Sports Injury and Illness Surveillance (SIIS) and the cycling-specific extension. Injuries were defined as ‘tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy requiring medical attention’. All epidemiological data were collected by the local organising committee medical professionals working at the event through an online survey. All data inputted were screened daily by the lead event physician and UCI medical delegate.

Results Throughout 5 days of the championships, 10.4% of the 230 cyclists sustained at least one injury. The overall injury incidence rate was 3.3 (95% CI 3.1 to 3.5) per 100 rides. The incidence rates were higher in the training 4.3 (95% CI 4.0 to 4.6)/100 rides than in the racing 2.2 (95% CI 2.1 to 2.3)/100 rides. There was a greater incidence of injury in female cyclists in the training 5.8 (95% CI 5.0 to 6.6)/100 rides and racing 4.5 (95% CI 3.9 to 4.9)/100 rides compared with male cyclists. Female cyclists experienced more severe injuries, with an average of 12.6 (±14, 95% CI 5.66 to 19.54) days lost to injury compared with 5.5 (±1.6 95% CI 1.89 to 9.11) seen in male cyclists. The main event medical actions were lifting, immobilisation and helmet removal.

Conclusion This study provides insights into the risk of injury to athletes within DHMTB. Our findings suggest more focus should be placed on the female DHMTB athlete. Additionally, this study provides unique information about common medical actions required of medical professionals working at DHMTB events and the importance of pre-event scenario training.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Downhill mountain biking (DHMTB) is one of the more extreme subdisciplines of mountain bike cycling and has been shown to have an injury prevalence as high as 20/1000 hours competition.

⇒ There is a lack of methodological homogeneity among the prospective injury surveillance studies conducted within DHMTB and across competitive cycling.

⇒ The risk of injury and injury profile in DHMTB is poorly understood. Therefore, more studies are needed to better understand the injury profile in DHMTB and to direct medical professionals working within DHMTB events.

INTRODUCTION

The sport of cycling consists of several individual sporting disciplines. The world governing body for cycling, Union Cycliste Internationale (UCI), oversees the cycling disciplines of road cycling, cyclocross, mountain bike (MTB), trail, gravel, BMX freestyle, BMX racing, track, e-sport, para-cycling and indoor.[1] MTB as a discipline has grown exponentially since its founding in 1973 in California to the first world championship in Colorado in 1990 and the Olympics in Atlanta in 1996.[2] Downhill Mountain Biking (DHMTB), one of the more extreme subdisciplines of MTB cycling, is where riders navigate high-speed, steep, technical descents on rugged trails, aiming for the fastest time to complete the course. The performance determinants of DHMTB include rider skill, handgrip endurance, self-confidence and aerobic capacity.[3] The 2023 UCI Cycling World Championships witnessed elite downhill mountain bikers converging to test their skills and mettle on a technically demanding course. Among all categories of elite competition, the spectre of injuries looms as riders

WHAT THIS STUDY ADDS

⇒ Within DHMTB, injury incident rates were higher in training (6.4/100 rides) compared with racing (2.3/100 rides).
⇒ The risk of injury for a female cyclist overall was 1.26 (95% CI 0.72 to 2.22), with male cyclist injury risk being 0.78 (95% CI 0.44 to 1.38).
⇒ Female athletes have a 2.21 (95% CI 1.5 to 5.4) higher risk of injury than male DHMTB cyclists.
⇒ Female athletes have a significantly higher risk of head/neck (relative risk, RR 9.5) injuries and concussion (RR 6.34) compared with their male counterparts.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Female cyclists may benefit from an extra official training ride based on the high risk of injury during racing (RR 1.14, 95% CI 0.55 to 2.35) compared with injury risk seen in males of 0.4 (95% CI 0.13 to 0.54).
⇒ With the high risk of head injuries seen in female cyclists, there may be benefits in the addition of neck strengthening and resistance training to reduce the number of head/neck injuries.
⇒ Lifting, immobilisation and helmet removal were among the most common medical actions performed by event personnel. Pre-event scenario training, including helmet removal, neck stabilisation and lifting of injured athletes, should be considered by event medical teams.

push physical and mental extremes for world champion status, recognised by the awarding of the 'rainbow jersey' by the UCI.[3–5]

Across the subdisciplines of MTB cycling, injury incidence rates vary by discipline, rider level and study methodology. Numerous studies have examined injury incidences within MTB and have focused on the subdisciplines of MTB. Studies have examined DHMTB,[4–7] cross-country,[4 7–11] enduro,[12] MTB stage racing[13] and MTB park riding.[14] Epidemiological research in DHMTB has shown a unique injury profile characterised by diverse injury types, mechanisms and anatomical locations.[4–7] Historically, studies reporting injuries within competitive cycling disciplines lacked methodological guidance and standardised reporting until the publication of the International Olympic Committee (IOC) consensus statement extension for competitive cycling in 2021.[15 16] To date, the methodology of studies examining injuries within DHMTB has differed in terms of study design and participant levels.[4–7] A key limitation of the studies to date is reporting injuries per 100 hours or 1000 hours, which differs from the preferred exposure in the IOC consensus per 100 rides/runs, which has not been completed in any DHMTB studies.[4–7] Expressing per 100 rides compared with per 1000 hours is more representative of how the rules are written and how riders would compete as often each ride will only last 4–6 min. Presenting an injury rate of 1000 hours may under-represent the injury rate relative to the discipline demands. Studies within DHMTB have used prospective monthly email surveys to examine injuries in DHMTB, which found 16.8 injuries per 1000 hours with a higher injury rate in experts, 17.9 injuries per 1000 hours of exposure compared with professional riders 13.1/1000 hours.[4] This contrasted with a prospective study of injuries reported by medical teams showing rates of 4.3/100 hours[7] and a retrospective study of 1.08/1000 hours injury rates.[5] Seminal injury prevention models place injury surveillance as the first step in developing preventative measures to improve rider health and reduce injury risk.[17 18] Therefore, due to the differences in study designs and reporting standards of studies within DHMTB to date, further prospective injury surveillance research that aligns with IOC cycling extension is needed within the discipline of DHMTB.

Therefore, our study's primary aim was to prospectively document the spectrum of injuries incurred by elite DHMTB riders during the 2023 UCI Cycling World Championships in Glasgow, Scotland. This study will extend our knowledge through the comprehensive analysis of injury-related aspects, encompassing characteristics, prevalence, incidence rate, severity, mechanisms, anatomical sites, main medical actions and the diverse array of factors influencing injury occurrence.

METHODS

Study design and participants

The participants of this prospective, observational study were male and female cyclists in junior and elite categories competing at the UCI DHMTB World Championships, located in the Nevis range in Fort William, Scotland, between 1 August 2023 and 5 August 2023. This study followed the injury reporting guidelines established by the IOC, which include the Strengthening the Reporting of Observational Studies in Epidemiology-SIIS and the cycling-specific extension.[15] The injury surveillance protocol through which this study data were generated has been published; thus, the details included within this manuscript will focus on the DHMTB discipline.[19]

We divided cyclists into two different levels, modified by Heron *et al*.[20] (1) An elite cyclist is a cyclist who competes at the national or international level but does not receive a regular salary or income for their involvement in the sport. (2) A professional cyclist is a cyclist who competes at the national or international level and receives a regular salary or income for their involvement in the sport. To do this, cyclists were asked, 'Do you make a living from competing in this sport?' Those answering 'yes' were categorised as 'professional', while those answering 'no' were categorised as 'elite'.

Injury definitions

Injuries were defined as 'tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy requiring medical attention'. In the event of an injury, the cyclists were notified of the study by the local organising committee (LOC) medical staff caring for them and advised that if they objected to their anonymised medical information being shared, they were free

to do this, and their medical information would not be shared with the researchers.

Data collection

The event LOC medical team received information about the study's objectives, methodology and inclusion criteria during the medical briefing 1 month before the event and a briefing each morning by the lead onsite physician. Medical teams of all competing nations were informed of the study objectives during the event medical briefing delivered 1 month before the event. The event LOC medical teams were required to complete all injury forms through an online Qualtrics survey-based application daily and return them to the chief medical officer for the event on the same day (online supplemental file 1). The lead physician screened the data daily, and any incomplete or unclear data were queried with the named person completing the form to allow full data capture. The questionnaire was developed from the consensus on reporting and recording injuries in cycling[15] with injury diagnosis classified by the Orchard Sports Injury Classification System version 10.[21 22]

Descriptive and statistical analysis

Injury incidence was calculated per 100 rides in training and racing (formula 1) and 1000 hours in competition (formula 2). As per the UCI rules 4.3.022, '*Riders must complete at least two training runs, or they will be disqualified from the race.*[23] *The start commissaire must ensure that this rule is applied.*' Therefore, it was assumed that each rider completed four rides for calculating injury incidence rates. These include two official training sessions, a qualification round and a final round. Total racing exposure time (hours) was calculated based on the finishing time of each cyclist in both the qualification and final rounds across all levels, as obtained from official results.[20 24]

All data were processed on a Macintosh computer using Microsoft Office and R statistics (V.4.1.1; R Core Team 2014). The methods applied included frequencies (%), crosstabs and descriptive statistics. The relative risk (RR) was calculated using formula 3 and is presented with 95% CIs using R statistics (V.4.1.1; R Core Team 2014). Bootstrapping (1000 iterations) for injury burden CI was used to provide a robust CI around injury burden estimate as discussed by Williams *et al*.[25] Per the IOC consensus, the burden was expressed per 100 rounds and 365 days for each injury type and location.[16] All the cyclists were analysed together, and the different cycling demographics (gender, level, injury severity and training vs racing) were analysed separately to compare injury data between the level of cyclists, injury event (training/racing) and time lost. All the statistical tests were two sided, and results with $p<0.05$ were statistically significant.

$$\text{Injuries per 100 rides} = \left(\frac{(\textit{Injury Event})}{(\textit{Total Number of Rides})}\right) \times 100 \quad (1)$$

$$\text{Injuries per 1000 hours Competition} = \left(\frac{(\textit{Number of Injuries})}{(\textit{Total Hours Exposure})}\right) \times 1000 \quad (2)$$

$$\text{Risk Ratio} = \left(\frac{\frac{(\textit{Injuries in the Exposed group }(A))}{\textit{Total injuries Sex A}}}{\frac{(\textit{Injuries in Unexposed OR compator Group }(B))}{\textit{Total injuries Sex B}}}\right) \quad (3)$$

Table 1 Cyclists demographics and total number of rides per category

Category	Number of riders	Number of rides
Men elite	91	364
Men junior	61	244
Women elite	43	172
Women junior	35	140
Continents		
Europe	22	
Oceania	2	
Asia	1	
America	8	
Africa	1	

RESULTS

Participants and injury occurrence

230 cyclists (152 male; 78 female) competed in the 2023 elite DHMTB world championships over 5 days of competition. A total of 920 rides were completed across the four race categories (table 1).

Overall, 10.4% (n=34) of all cyclists sustained at least one injury during the 2023 UCI DHMTB World Championships. During the world championships, 59% (n=20) of the injuries occurred in female cyclists, and 65% (n=22) of all injuries occurred in non-professional cyclists. There was no significant difference between the number of years of competing and injury locations (p=0.128).

Injury incident rates and injury burden

The overall event injury incidence rate was 3.3 (95% CI 3.1 to 3.5) injuries per 100 rides. During training, there were 4.3 (95% CI 4.0 to 4.6) injuries per 100 rides, and in racing, there were 2.2 (95% CI 2.1 to 2.3) injuries per 100 rides (table 2). Compared with the number of competition hours, the injury incidence rate was 7.6 (95% CI 7.3 to 7.9)/1000 hours (table 2). The average time lost due to injury was 5.5 (95% CI 2.5 to 9.0) days for male riders. Female cyclists lost more than double the estimated time due to injury, with an average of 12.6 (95% CI 6.25 to 19.25) days and a maximum of 42 days with an injury burden of 73.95 (95% CI 33.15 to 119.85) per 100 rides. There was no significant difference between the level of cyclists (p=0.239) or sex (p=0.445) and the time lost to injury (tables 3 and 4).

Types of injuries reported

Female cyclists were at significantly greater risk of overall injury (RR 2.21, 95% CI 1.5 to 5.4). Female cyclists were

found to have a significantly greater risk of head injuries (RR 9.5, 95% CI 2.15 to 41.9 p=0.002) and of concussion (RR 6.34, 95% CI 1.34 to 29.84, p=0.01) when compared with males. Also, those diagnosed with concussion had a greater prevalence of headache/neck pain (figure 1). All bone fractures were confirmed in elite female cyclists. Female cyclists presented a greater number and prevalence of observable concussive signs (figure 1).

Among male cyclists, 50% (n=7) of injuries led to no time off. Among female cyclists, 40% (n=8) of the injuries that required medical attention led to no time off. All injuries were sudden-onset acute injuries. Medical actions taken by medical professionals during injury are presented in table 5. Overall, the medical team carried out 65 medical actions. The main actions performed by medical professionals treating injured riders were helmet removal, lifting and immobilisation (table 5).

DISCUSSION

This was the first study within DHMTB to apply the IOC consensus statement extension for reporting injury and illness in competitive cycling.[15] The main findings were as follows:

1. Throughout the championship, 10.4% of riders sustained at least one injury, with 4.3% injuring more than one body location per incident.
2. The overall injury incidence rate was 3.3 injuries/100 rides.
3. Injury incidence rates were greater during training (4.3/100 rides) than during racing (2.2/100 rides).
4. The injury incidence rate was significantly greater in females.
5. Females had a 6.3-fold greater risk of concussion injury and a 9.5-fold greater risk of head injuries than males did.
6. The head was the injury location with the highest injury burden, with bone fractures and concussion being the injury types with the highest burden.

Injury incidence

To date, few prospective studies have examined injuries within DHMTB.[4–7] Our findings show a relatively low proportion of injuries (10.4%) across the World Championship DHMTB compared with those reported in the DHMTB World Cup series (80%),[5] cross-country MTB events[13] (71%) and MTB at the London (16%) and Rio (24%) Olympic games.[9 10] However, the 10.4% overall prevalence of injury observed was higher than the 8.4% observed in enduro cycling and 7% in MTB at the 2021 Tokyo Olympics.[8 12] However, our study shows that 25.6% of female riders sustained an injury, much larger than the 9.2% of male riders. When comparing injury proportions, consideration must be given to the similarities and differences in risks and demands between MTB disciplines. DHMTB is more extreme than Olympic Mountain bike disciplines, such as short course or cross country, which are more bunch-based than solo event rounds based on time. Therefore, DHMTB athletes may be more willing to take further risks at the cost of injury to achieve qualification criteria or results.

One of the unique strengths of this study is the expression of injury incidence rates. The IOC consensus cycling extension recommends that injury incidence rates be expressed per 100 rides in DHMTB, in addition to reporting incidences per 1000 hours of exposure within the competition.[2 4 5 7] Studies have represented injury incident rates per 100 hours and 1000 hours, arguably in a discipline where the average ride time per round is below 5 min, which is not an accurate exposure measure. In training, injury incidence rates of 1.08/1000 hours within DHMTB world cups[5] and 3.6/1000 hours in enduro cycling[12] have been observed. Cyclists included in these studies would have encountered sections similar to timed downhill as athletes in this study. Our findings of injury incidents in racing are lower than those noted in previous DHMTB studies of 16.8/1000 hours[4] and 4.3/100 hours[7] and within enduro of 38.3/1000 hours.[12] Limited comparisons between injury incidence in training or racing and previous DHMTB studies can be made because they were not individually specified[4] or included[7] within previous surveillance captures. However, the overall injury incidence trend differs from that in field-based sports, such as amateurs,[26] premiership,[27] rugby and football,[28] where injury incidences are greater in competitions than in training.

Many factors can influence injury incidence rates in DHMTB. DHMTB requires technical skill, speed, concentration, reaction, aerobic capacity and strength.[3] Thus, athletes are pushed to the limit physically and mentally to win at the elite level. The level of performance (recreational vs elite, regional vs national, national vs international), duration of the course and technical nature of the course influence the challenge of different skill profiles and injury incidence.[4 5 7] Furthermore, the methodology of the study will influence incident rates, that is, retrospective versus prospective reporting[4 5 12 29] or self-reported versus physician diagnosed,[2 4 12 14] which could increase the risk of bias.[30 31] Few studies have followed the IOC consensus[15 16] when reporting injuries and illness in MTB,[4 9 10 12 32] with this being the first study to do so within elite DHMTB. Our study supports the need for further surveillance research that follows the IOC consensus recommendations within cycling.[15]

Influence of sex on injuries

This is the first study to present differences in injuries between sexes among elite DHMTB cyclists. Female cyclists exhibited a significantly greater injury incidence rate than males, with an RR of 2.89 (95% CI 1.5 to 5.4). Despite the higher incidence of injury observed in competition, female cyclists' injury incidence rates (4.5/100 rides (14.2/1000 hours) and injury RR (2.0, 95% CI 0.64 to 6.23) did not significantly differ from males (0.94/100rides (1.3/1000 hours)). These findings are similar to previous MTB studies[12] and injury incidence rates in team-based sports.[33] Female cyclist participation

Table 2 Injury incidence rates per 100 rides and 1000 hours in racing, injury severity (days) and injury burden (95% CI in parentheses)

	Inj/100 rides (95% CI)	Inj/1000 hours (95% CI)	Injury severity (95% CI)	Injury burden (95% CI)
Training overall	4.3 (4.0 to 4.6)	–	6.3 (3.50 to 9.45)	27.09 (14.3 to 51.71)
Racing overall	2.2 (2.1 to 2.3)	7.6 (7.3 to 7.9)	14.51 (6.5 to 23.5)	31.90 (15.05 to 39.13)
Male training	3.6 (3.3 to 3.9)	–	–	–
Male racing	0.94 (0.12 to 1.2)	1.13 (1.1 to 1.2)	–	–
Female training	5.8 (5.0 to 6.6)	–	–	–
Female racing	4.5 (3.9 to 4.9)	14.2 (13.2 to 15.2)	–	–
Female overall	5.1 (4.6 to 5.6)	–	12.69 (6.25 to 19.25)	73.95 (33.15 119.85)
Male overall	2.3 (2.2 to 2.4)	–	5.50 (2.5 to 9.0)	14.49 (8.05 20.93)
Overall	3.3 (3.1 to 3.5)	–	9.72 (6.17 to 15.20)	–

has grown in the past decade, and studies within DHMTB date back to 1996[7]; more recent studies in DHMTB did not include sex-specific analysis,[4 5] potentially limited by the competitive sample of female athletes. A limitation when presenting DHMTB injury incidence per 100/rides is that both male and female cyclists compete on the same course. Male cyclists complete the course quicker than their female counterparts; therefore, the duration of risk exposure for females is greater than that for males, which is not represented per 100 rides. When comparing the injuries in racing per 1000 hours, our overall injury incidence rates (7.6/1000 hours) are lower than those seen in previous studies in the DHMTB[7] and enduro[12]; however, they are similar to those seen within elite competition road cycling studies.[34 35] The greater injury trends among female cyclists observed in this study are similar to those observed in prospective cycling studies of pro-enduro cyclists.[12] However, these sports differ from team-based sports because there is no difference between male and female injury incidence.[33] Our findings raise the question of whether additional work needs to be done to protect female DHMTB cyclists. Examples of injury prevention could include rule changes, such as adding an extra official practice ride in training or introducing injury prevention programmes, such as similar programmes to the FIFA 11+or Gaelic Athletic Association 15, particularly regarding neck strengthening and concussion prevention.[36–38]

Table 3 Percentage of injuries (with the number (n) in parentheses) reported within training and competition, rider level and sex

Injuries	Male (%)	Female (%)
In racing	21 (3)	55 (11)
In official training	79 (11)	45 (9)
Level of cyclist		
Non-professional	57 (8)	70 (14)
Professional	43 (6)	30 (6)

Injury regions, types and burden

Our findings highlight the spectrum and prevalence of injuries among elite male and female DHMTB cyclists. Among male DHMTB cyclists, joint sprains and ligament tears were the most common, with 21% of injured males reporting such injuries. These injury regions are similar to previous cycling studies in the DHMTB, enduro MTB and cross-country MTB, showing that joint and ligament injuries are highly prevalent among males.[4 7–10 12 39] The high prevalence of forearm (29%) and shoulder (21%) injuries observed in male DHMTB may be explained by protective fall behaviour displayed by male athletes. Sport-specific steps simulating injury prevention behaviour in training may aid coaches and medical professionals in educating athletes on fall techniques to reduce the severity of injuries caused by falls in the DHMTB.[40]

This is the first study within DHMTB to present injury burden. The injury burden for female riders was 5.1 times greater than that of males per 100 rides. The injury burden per 365 days for bone fracture is 44.4/365 days.[41] Fractures have been found within professional road cycling to carry the highest injury burden out of all injuries seen.[35] The injury burden seen in DHMTB athletes is higher than in short-course triathletes at 31.38/365 days, likely explained by the higher prevalence of acute complex injuries within DHMTB compared with stress fractures seen in triathletes. Bone health in cyclists has been a key topic of discussion throughout the past decade.[42–44] Early-career female cyclists had lower bone mineral density than their male counterparts, which may influence fracture risk with acute injury.[45] This may partly support our findings, showing that all fractures observed in this study occurred in elite-level female cyclists due to shorter training/competition histories. Other factors, such as physical and technical capabilities, may explain the greater fracture injury risk noted among amateur DHMTB cyclists than their professional counterparts. Additionally, the small sample size contained within this study will impact the strength of the associations observed.

Table 4 Percentage of injuries by location, injury type, injury incident rate and injury burden (with the number (n) in parentheses and 95% CI)

Injured location	Male (n)	Female (n)	Injuries per 100 racing rides (n)	Injuries per 100 training rides (n)	Injury burden/100 rides (95% CI)	Injury burden/365 days (95% CI)
Abdomen (including Abdominal organs)	7 (1)	10 (2)	0.2 (1)	0.4 (2)	6.09 (5.29, 6.89)	22.2 (19.3, 25.1)
Ankle	7 (1)	5 (1)	0.4 (2)	0	4.57 (4.02, 5.11)	16.7 (14.7, 18.6)
Chest (including chest organs)	7 (1)	5 (1)	0.2 (1)	0.2 (1)	1.52 (1.42, 1.62)	5.55 (5.19, 5.92)
Hand	7 (1)	0	0.2 (1)	0	3.04 (2.76, 3.32)	11.1 (10.1, 12.2)
Wrist	7 (1)	0	0	0.2 (1)	0	0
Forearm	29 (4)	0	0.2 (1)	0.6 (3)	0.761 (0.725, 0.796)	2.78 (2.65, 2.90)
Shoulder	21 (3)	5 (1)	0.4 (2)	0.4 (2)	3.80 (3.41, 4.20)	13.9 (12.4, 15.3)
Head	14 (2)	55(11)	0.4 (2)	2.4 (11)	10.7 (8.70, 12.6)	38.9 (32.1, 45.7)
Elbow	0	20 (2)	0.4 (2)	0	4.57 (4.04, 5.09)	16.7 (14.8, 18.5)
Groin	0	10 (2)	0.2 (1)	0.2 (1)	0.761 (0.72, 0.79)	2.78 (2.65, 2.90)
Injury type						
Joint sprain/ligament tear	21 (3)	5 (1)	0.4 (2)	0.4 (2)	1.52 (1.42, 1.62)	5.55 (5.18, 5.92)
Concussion	14 (2)	35 (7)	0.7 (3)	1.3 (6)	9.13 (7.66, 10.6)	33.3 (27.8, 38.8)
Muscle contusion	14 (2)	5 (1)	0.2 (1)	0.4 (2)	1.52 (1.42, 1.62)	5.55 (5.19, 5.92)
Abrasion	14 (2)		0.2 (1)	0.2 (1)	0	0
Muscle strain/rupture/tear	14 (2)	5 (1)	0.2 (1)	0.4 (2)	2.28 (2.09, 2.47)	8.33 (7.64, 9.02)
Contusion/bruise (superficial)	7 (1)	15 (3)	0.4 (2)	0.4 (2)	1.52 (1.42, 1.62)	5.55 (5.19, 5.92)
Internal organ trauma	7 (1)	5 (1)	0.2 (1)	0.2 (1)	6.09 (5.27, 6.91)	22.2 (19.1, 25.3)
Laceration	7 (1)	5 (1)	0.2 (1)	0.2 (1)	1.52 (1.42, 1.62)	5.55 (5.19, 5.92)
Bone fracture	0	15 (3)	0.6 (3)	0	12.2 (9.94, 14.4)	44.4 (36.1, 52.8)
Unknown or not specified	0	10 (2)	0.2 (1)	0.2 (1)	0	0

Concussion accounted for 24.5% of all injuries, with a 35% prevalence among female DHMTB cyclists. The overall incidence of concussion observed in the DHMTB cohort was like that observed in previous DHMTB studies (25%[39] and 23.6%, respectively).[32] However, the reported incidences of concussion vary significantly within MTB cycling, with an incidence as low as 5% being reported; this incidence is arguably linked to diagnostic challenges and variability in course styles and competition demands across MTB disciplines.[39 42 43] Some authors have reported that female athletes are more susceptible to concussion and have more prolonged symptoms after concussion.[44] We found that the concussion injury burden was 33.3/365 days, identical to that seen in women's rugby sevens competition.[46] Among female cyclists, the concussion incidence rate was 3.7/1000 hours within the race, similar to the overall 3.9/1000 hours in enduro racing.[12] Our injury incidence rates among female cyclists are similar to those seen in female footballers (3.5/1000 hours)[47] and slightly greater than those seen in female

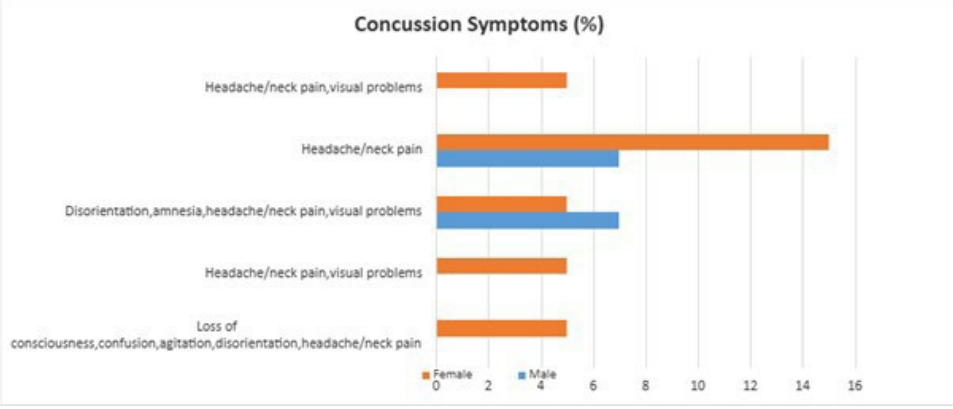

Figure 1 Concussion symptom prevalence between female and male athletes.

Table 5 Injury mechanism and medical action percentages (with the number (n) in parentheses)

	Male (n)	Female (n)
Cycle-specific injury mechanism		
Collided with an inanimate object related to competition	7.1 (1)	5 (1)
Collided with the ground only	92.8 (13)	95 (19)
Injury mechanism		
Direct contact with an object (eg, ball, wall, ground)	100 (14)	100 (20)
Unable to finish and needed to be removed from the field of play		
No	64 (9)	45 (9)
Yes, removed from play	35 (5)	55 (11)
Main medical actions		
Lifting	4.4 (1)	17.4 (3)
Immobilisation	13 (2)	17.4 (3)
Helmet removal	8.7 (1)	13 (3)
Vacuum mattress	8.7 (1)	13 (3)
Icing	4.4 (1)	8.7 (2)
Cervical collar	8.7 (1)	8.7 (2)
On back	13 (2)	8.7 (2)
Arm sling	4.4 (1)	4.4 (1)
Splint	17.4 (2)	4.4 (1)
Bandage	13 (2)	4.4 (1)
Disinfection	4.4 (1)	0 (0)
Spinal board	0 (0)	3 (1)

rugby 15 players (2.8/1000 hours).[46] However, our findings are much lower than those observed for the rugby 7 s (8.9/1000 hours) and rugby league (10.3/1000 hours) players.[46]

The most reported concussion symptoms were headache and neck pain, with visual problems/amnesia and disorientation commonly reported among both male and female cyclists. These symptoms are included in the recently published SCAT-6 symptom checklist[48] and the UCI concussion recognition pocket tools.[49] There have been recent calls for action around the diagnosis of concussion within DHMTB.[42] Our findings highlight a lower incidence of concussion injury (n=3) in racing compared with training (n=6), arguably linked with the diagnostic challenges of making this diagnosis.[42] This study also raises the question of whether there is a link between neck strength and concussion in individual sports.[50] Compared with male DHMTB cyclists, female DHMTB cyclists were found to have a significantly greater RR of neck injury. There is a weak relationship between neck strength and concussions in team-based sports, and research has shown that female athletes have 47% less neck strength than males.[44 50 51] Like male DHMTB cyclists, female DHMTB cyclists use similar-weight helmets, and their reported risk of crashing is almost double the amount of neck pain/headache. During crashes, the differences in neck strength between female athletes and helmet weight may contribute to peak linear acceleration and rotational shear, resulting in whiplash injuries (neck pain) and potentially a coup-contrecoup mechanism leading to concussive symptoms.[52] Although no studies have been completed to date in cycling, sports such as ice hockey have linked helmet geometry and injury mechanisms to play a role in concussion.[53] This requires further exploration within DHMTB.

Implications for injury management and prevention within cycling and DHMTB

The epidemiological insights presented within this study will provide a foundation for the discussion and subsequent development of evidence-based injury prevention and management strategies within the DHMTB. The insights provided within this study can also help medical services and medical organisations preparing for such events understand the type of injuries they may need to deal with.

We highlight that the most common medical actions undertaken are immobilisation, lifting and helmet removal. Cycling, unlike other sports such as rugby and football, does not have specific trauma courses that provide theoretical and practical knowledge on injury management. Our study provides specific insights into medical actions by event medical teams covering DHMTB. Some practical considerations from our findings are that medical teams should familiarise themselves with the various helmet clasps, protective gear and extraction process of such equipment, acknowledging the high incidence of head injuries within the discipline and the importance of protecting the cervical spine in early assessment. Additionally, essential mountain extraction processes are discussed and drilled before the event. The UCI should provide cycling-specific medical training focusing on helmet removal, neck stabilisation and field extraction to LOC medical teams at such events in future.

As this was the first study to apply the IOC cycling extension to injury, it has raised points of improvement around the consensus application in cycling. When reporting injuries per 100 rides or 100/rounds, the round in which the injury occurred should be included to improve the accuracy of the data. This point should also apply to some events in BMX and track cycling sprint events. Additionally, within the DHMTB, our study showed that the incidence of injury during practice was greater than that during racing in both males and females. As per UCI rule 4.3.022, a prerequisite is required to officially ride 2 practice rounds.[23] For male riders, this is satisfactory, given the low incidence of injury observed within racing. However, for female athletes, should there be a protected time window for an additional practice round or mandatory review of the course video analysis, which may reduce the number of crashes/injuries seen in racing? With the high prevalence of neck/head injuries, including concussions,

noted in female DHMTB athletes, the inclusion of neck strengthening exercises may have a positive impact on reducing soft tissue injury risk as well as reducing concussion risk. Last, the high incidence (15%) and RR (13.5) of bone fractures noted among female athletes raise the importance of encouraging resistance-based exercise and screening for risk factors for low BMD in cyclists. These risk factors include low body mass index, fracture incidence, smoking, lack of bone-specific physical activity and low energy availability.[45]

Limitations and future considerations

Given that this study was descriptive and included a small sample size, the associations noted cannot be assumed to be causative factors for injury. Second, as this was a 'within competition surveillance study', the methodology of this study was biased towards sudden-onset acute injuries; thus, the representation of illnesses and overuse injuries was not reported. In contrast to racing, determining rider training exposure (hours) directly was not feasible. Therefore, a composite indirect measure using the number of rides in line with the UCI rules was used.

To understand all 'health problems' in DHMTB cyclists, future research should prospectively monitor cyclists throughout a season using a validated survey such as the Oslo sports trauma research questionnaire.[54] Lastly, with the high incidence of concussions noted within DHMTB, the UCI, in conjunction with the DHMTB Worlds series, should consider developing discipline-specific concussion screening for cyclists.

CONCLUSION

To our knowledge, this is the first study to prospectively examine injuries within the UCI DHMTB World Championships and report these injuries in line with the cycling extension of the IOC consensus statement. This study provides insights into the injury trends that cyclists are exposed to at world championships and can be used to inform injury prevention programmes and basis to recommend rule changes in the future. Compared with male DHMTB cyclists, female DHMTB cyclists are significantly more at risk of injury than their male counterparts are at risk of injury, and they show a greater incidence of injury within official training and competition, particularly in terms of greater risk of head injury and concussions. This study further highlights that injury surveillance can be performed with little burden on event organisers and medical staff and calls for the UCI to endorse similar projects at major competitions. This approach will facilitate the development of our knowledge of the prevalence of injuries within various cycling disciplines.

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