

Enduro World Series (EWS) Mountain Biking Injuries: A 2-year Prospective Study of 2010 Riders



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ABSTRACT

The sport of Enduro is the newest International Cycling Union sanctioned discipline in mountain biking. There are a number of studies reporting mountain biking injury to date however there are none detailing injuries in Enduro. The aim of the present study was to determine the rate, severity and nature of rider injury during the Enduro World Series. Rider injury, and race and practice exposure data were recorded prospectively during 10 events across the 2017 and 2018 seasons. Incorporating 2010 riders (males 90%; females 10%) from 46 countries. 8.9% of riders were injured with mean 12.3 days time-loss per injury. Racing injury incidence was 38.3/1000 hours and practice injury incidence 3.6/1000 hours ($p = 0.01$). The shoulder/clavicle (12.8% of all injuries), hand (9.0%) and head (9.0%) were the most injured locations. Concussion injury was the most frequent diagnosis (7.4%), and shoulder/clavicle fractures caused the greatest burden (442 total days lost). Of those with concussion 28.6% continued racing, and 42.9% reported no time-loss (i. e. time off) post-race. In conclusion, the rate of injury during EWS race events was comparable to Downhill racing. Targeted injury prevention strategies around rider concussion education and rider qualification criteria may help to reduce the risk of injury in Enduro.

Introduction

Mountain biking is a hugely popular sport and it has continued to grow, from its birth in California in 1973 [1], to the first International Cycling Union (UCI) World Championship event in Colorado in 1990 and to an Olympic Sport in Atlanta in 1996. Disciplines have traditionally consisted of cross-country, downhill and freeride. However, recent years have seen the emergence of a new mountain bike discipline called enduro. The essence of ‘enduro’ or ‘all

mountain’ riding has been undertaken by recreational riders for many years, and the rise of unofficial locally built trails over the last few years has seen the growth of enduro as a sport. In 2013 the first competitive, international race series was started by the Enduro World Series (EWS), and in 2019, enduro mountain biking also became the newest International Cycling Union recognized event.

Enduro racing consists of a series of stages, with time limited uphill riding (transitions) followed by race timed steep and techni-

cal downhill riding (stages). The fastest cumulative stage times determining the winner. Successful athletes need to have the ability to negotiate technical terrain following large anaerobic bursts of effort, which can occur both within the stages, and during the transition phases between stages (e. g. to avoid late stage start-time penalties) [2]. This cumulative demand places high loads, on both physical and cognitive systems and can lead to errors when piloting the bike over technical terrain. As a new sport the risk of injury in enduro is currently unknown. There is an increasing recognition of the importance of injury recording from international governing bodies [3–7]. Understanding the magnitude and nature of injury in sport is an important first step in developing and implementing prevention initiatives and reducing the risk associated with sport participation.

Studies reporting injury patterns in mountain biking have covered different disciplines (or sometimes combined) and employed varied methodologies. For example, studies have included off-road bicycling [8–11], Mountain Bike park riding [12], mountain stage racing [13] and downhill and cross-country mountain biking [7, 8, 10, 14, 15]. Studies range from recreational riding [9, 16], training and race practice [7, 15, 17] and racing [7, 8, 14, 15, 17] in youth [18] and amateur and elite riders [7, 8, 13–17]. Clinical studies have reported severe mountain bike injuries presenting to hospital [9, 19], and retrospective and prospective questionnaire studies have presented self-reported rider injuries during competitive and recreational riding [10, 11, 13, 16, 17].

To date there have been no prospective longitudinal studies on elite level competitive mountain biking and none in enduro. The aim of the present study was to describe the incidence, severity and nature of injury among mountain bike riders participating in the Enduro World Series.

Materials and Methods

This was a two-season prospective epidemiological study collecting rider injury data between March 2017 and September 2018 from ten Enduro World Series (EWS) tier 1 race events. Data were collected from events in 2017 in Ireland, Madeira, New Zealand, Australia, and in 2018 in Canada, Chile, Italy (La Thuile and Finale Ligure), France, and Slovenia/Austria. Rider registration and results data were provided by the EWS organizers and rider medical data recorded by medical staff at each EWS event.

Participants

All riders participating in the EWS during the 10 EWS events, including male and female riders, across all race categories, e. g. under 21 (17–20 years), senior professional, and masters (35 + /40 + years female; 40 + years male), were included in the study.

Detailed study information including information on data handling and confidentiality was provided on the EWS website and in rider emails as part of their EWS race registration. It was outlined that rider consent was implicit through their registration and participation in each EWS event. The study was approved by the School of Applied Sciences research ethics committee at Edinburgh Napier University (SAS/0035). The study meets the ethical standards cited for the International Journal of Sports Medicine [20].

Implementation

Event chief medical officers and on-course medical staff were provided with an injury reporting questionnaire, in both paper and electronic formats. Data were recorded for any injury that occurred from the start of first practice to the end of the final race stage. Rider race exposure (hours) were provided from EWS race result time sheets. Rider practice times were estimated by EWS organizers based on the venue and number of stages.

Each rider was assigned a unique study identifying number (rider ID), which was utilized only for the purposes of identifying duplicate injury entries, and for tracking rider data across multiple races/seasons (e. g. multiple injuries per rider). The database was fully de-identified immediately after end of the 2018 season. Confidentiality and anonymity of rider information was ensured at all times.

Injury recording

Questionnaires were developed in line with previous sports injury surveillance methodologies and categories [15, 21]. Rider ID, race category and event, date of injury and estimated time loss from competition or training were recorded. The anatomical location, injury type (e. g. structure), cause and onset of injury, i. e. during practice or racing, transition or stage, were recorded. In addition, the trail surface (rocky, dirt, etc.), profile (steep, flat, etc.) and speed (0–20 km, 21–40 km, etc.), and protective equipment worn were also reported. Injury was defined as any rider injury incurred in practice or racing during the event and receiving medical attention, regardless of the consequence with respect to absence from competition or training [21]. If a rider sustained an injury during one stage/transition, and another during a different stage/transition, they were reported as two injuries. If a rider sustained multiple injuries during the same injury event, only the most severe was recorded. Injury severity was reported in days of estimated absence.

Data analysis

Descriptive data are presented as frequencies (number or proportions) for categorical variables and mean for numerical variables. Severity data were not normally distributed and so median and mean are presented together, the latter to allow comparison to other studies. Injury prevalence is presented as the number of injured riders relative to the total number of riders (%). Injury incidence is presented as the number of injuries per 100 riders [7, 15], and per 1000 hours exposure with 95% confidence intervals (CI). Differences in severity were analyzed by Mann-Whitney U, and incidence rates between groups using Two-tailed Z tests [22]. Significance was accepted at $p < 0.05$ (equal variances assumed).

Results

Overall, 2010 riders (females 198; males 1,812) representing 46 countries participated across the 10 EWS races during the 2017 and 2018 seasons. A total of 249 riders competed in both seasons, and 1411 riders only ever competed in one EWS race. In total, there were 3082 rider race hours and 18 379 rider practice hours.

Injuries by category and sex

A total of 188 injuries (females $n = 24$; males $n = 164$) were reported in 179 riders, with seven riders experiencing two injuries and

► **Table 1** Injuries by race category and sex.

Race Category	No. of riders	No. of injuries (r/p)	Severity mean days (& median)	No. riders injured (%)	Inj/1000 race hrs (95% CI)	Inj/1000 practice hrs (95% CI)
Male Pro	1224	106 (61/44)	14.9 (7)	102 (8.3)	33.1 (24.8 to 41.4)	3.8 (2.7 to 4.9)
Male u21	277	33 (28/4)	11.2 (0)	31 (11.2)	72.5 (45.7 to 99.4)*	1.7 (0.1 to 3.4)
Male Masters	330	25 (15/9)	8.7 (2)	25 (7.6)	35.0 (17.3 to 52.7)	3.8 (1.3 to 6.3)
Male total	1831	164 (104/57) ^b	13.2 (7)	157 (8.6) ^c	39.1 (31.6 to 46.6)	3.5 (2.6 to 4.4)
Female Pro	150	24 (14/10)	5.8 (0)*	22 (14.7)	41.5 (19.8 to 63.2)	5.8 (2.2 to 9.3)
Female u21	19	–	–	–	–	–
Female Masters	29	–	–	–	–	–
Female total	198	24 (14/10)	5.8 (0)	22 (11.1)	33.1 (15.8 to 50.5)	4.7 (1.8 to 7.6)
Grand Total	2029 ^a	188 (118/67) ^b	12.3 (5.0)	179 (8.9) ^c	38.3 (31.4 to 45.2)	3.6 (2.8 to 4.5)*

r = race, p = practice; ^a19 riders raced in more than one category, i. e. as U21 then senior, senior then masters; ^bonset unknown for 3 injuries; ^cone rider had injuries competing in Male u21 and Male Pro; * significant difference.

one rider three injuries (► **Table 1**). 8.9% of riders competing across the 10 EWS events sustained at least one injury, equivalent to 9.3 injuries per 100 riders. 57% of injuries were reported to result in time-loss (n = 108). On average 12.3 days (median 5 days) were lost per injury. The severity of injury was significantly lower for female professional versus male professional riders (p = 0.01). The majority of injuries (63%) occurred during race stages and the remainder (36%) during practice (for 3 injuries the onset was unknown). The incidence of injury was higher in racing (38.3 injuries per 1000 race hours; 95% CI 31.4 to 45.2), compared with practice (3.6 practice injuries per 1000 practice hours; 95% CI 2.8 to 4.5; p = <0.01) and higher for u21 men versus professional men (p = <0.01).

Injuries by location and type

The shoulder (12.8% of all injuries) followed by the head (9.0%), hand (9.0%) and lower leg (8.0%) were the most commonly injured body locations (► **Table 2**). The thoracic spine (45 days), thumb (34 days), shoulder (26 days) and ankle (23 days) were the most severely injured. The most common types of injuries were lacerations/abrasion/skin lesion (26% of all injuries) followed by contusion/hematoma/bruise (19.2%) and fracture (traumatic) (17.7%), with the latter the most severe type of injury (34 days). Concussion was the most commonly reported injury diagnosis (7.4% of all injuries), followed by lower leg (5.9%) and forearm (5.3%) lacerations, shoulder/clavicle fractures (4.7%) and hand fractures (4.7%). Shoulder/clavicle fractures were also among the most severe injuries (49 days), alongside one thoracic spine fracture (90 days) and two ankle fractures (50 days). Overall, shoulder/clavicle fractures caused the greatest burden, with a total of 442 days lost.

Cause of injuries

Just over half of all injuries (55%) occurred during rocky stages, 39% on steep gradients and 41% at slow speeds (► **Fig. 1**). Injuries occurred most frequently on a combination of slow, steep, rocky/dirt stages (22.3%, n = 42) (► **Fig. 2** shows an example of an incident during practice in Madeira, on a steep, dirt stage). 71% were caused by a fall (contact with the ground). 55.7% of injuries resulted in a rider who either *did-not-start* (DNS) or *did-not-finish* (DNF). Of those who were injured during the event, 39.4% continued racing. A third

(31.2%) of the injuries occurred to riders who only competed in one EWS event.

Around two-thirds of hand fractures (66%), shoulder dislocations (60%) and half of all shoulder/clavicle fractures (56%) and concussions (50%) occurred on steep, rocky stages. Of those experiencing concussion during racing (n = 12; 11 males, 1 female), four riders completed the race (33.3%), and six had no time loss reported post-race (50.0%). Half of all concussions occurred in riders who only ever participated in one EWS race.

Discussion

This is the first prospective longitudinal study on medical practitioner reported injuries in enduro mountain bike riders. The aims were to describe the incidence, severity and nature of injuries among riders participating in the Enduro World Series across two-seasons (2017 & 2018). The main findings were 1) 8.9% of riders sustained at least one injury; 2) the incidence of injury was higher in racing (38.3 race injuries per 1000 race hours), compared with practice (3.6 practice injuries per 1000 practice hours); 3) concussion injuries were most frequent and shoulder/clavicle fractures caused the greatest burden, and 4) significant injuries were most common on slow, steep and rocky/dirt stages.

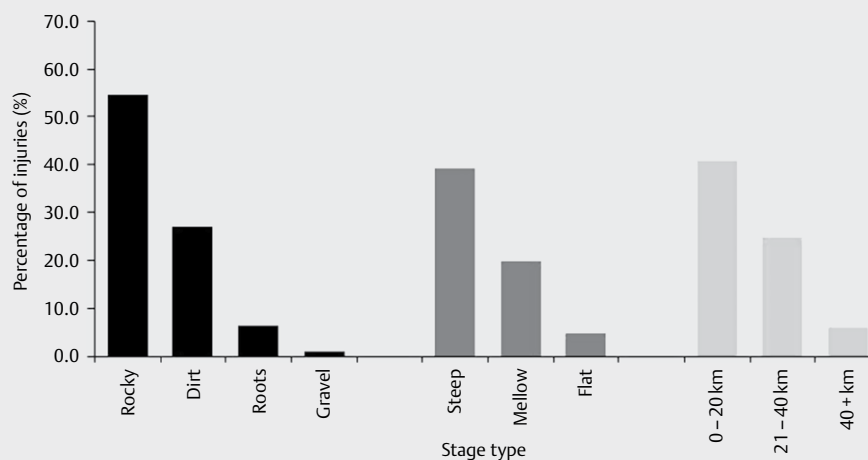
Rate of injury

To date there have been few prospective studies on mountain biking injuries and no other injury studies on enduro mountain biking for comparison. Overall, the prevalence of injury was low with 8.9% of riders injured (race and practice combined) across the two seasons, and this was lower than that reported in a retrospective study on downhill riders, where approximately 80% of World-Cup and 50% of recreational riders reported at least one significant injury during the previous two years [16]. The prevalence of injury was also lower compared with the Swiss Epic multi-stage cross-country event (71%) [13] and cross-country mountain biking at the Olympic Games, where during the 3-week event 16% of mountain bike athletes at London 2012 and 24% at Rio 2016 were reported to be injured [7, 15]. However, when taking into account the amount of time (hours) spent exposed to enduro racing, the risk of injury was similar or higher compared to previous studies. For example,

► **Table 2** Number of injuries by body location and injury type, with severity mean days (in brackets).

	Concussion	Contusion/ hematoma/ bruise	Dislocation/ subluxation	Fracture (traumatic)	Laceration/ abrasion/skin lesion	Ligament rupture	Sprain (joint and/or ligaments)	Strain (muscle rupture/tear)	Other	Unknown	Grand Total
ankle	1 (-)			2 (50)		1 (-)	1 (-)			3 (16.7)	8 (23.1)
elbow	4 (5.5)		1 (-)	1 (-)	7 (0)	1 (-)					14 (5.1)
face (incl. eye, ear, nose)					5 (1.4)						6 (1.2)
finger	1 (-)		1 (-)	3 (26.6)	1 (-)		4 (26.3)	1 (-)			11 (18.1)
forearm					10 (6.3)					1 (-)	11 (5.7)
hand	4 (8)			9 (17.9)	4 (3.8)						17 (12.2)
head	14 (5.1)								1 (-)	3 (4.0)	17 (5.4)
hip	2 (0.5)				1 (-)			1 (-)		2 (7.5)	6 (4.0)
knee	3 (5.7)				6 (11.2)	1 (-)				3 (6.7)	13 (8.0)
lower leg	2 (3.5)			2 (50.0)	11 (6.4)						15 (11.8)
lumbar spine	2 (8.5)							1 (-)			6 (4.5)
neck/ cervical spine	2 (0)							1 (-)		1 (-)	4 (0)
pelvis/scrum/buttock/SIJ				1 (-)	1 (-)						2 (0)
shoulder/ clavicle	3 (2.3)		5 (16)	9 (49.1)	1 (-)	1 (-)	1 (-)	1 (-)		3 (5.0)	24 (26.0)
sternum/ ribs	2 (15)			2 (25.5)					1 (-)		6 (13.5)
thigh	3 (3.3)				1 (-)			1 (-)			5 (8.0)
thoracic spine	1 (-)			1 (-)							2 (45.0)
thumb			2 (30)	2 (45.0)		1 (-)					5 (34.0)
upper arm					1 (-)					2 (5.0)	3 (5.7)
wrist	2 (0)			3 (35.0)			1 (-)				6 (17.5)
unknown	1 (-)			1 (-)	1 (-)					1 (-)	4 (2.5)
Grand Total	14 (5.1)	35 (4.7)	9 (17.8)	36 (35.0)	51 (4.8)	5 (16.0)	7 (19.0)	6 (10.8)	5 (1.4)	20 (6.1)	188 ^a (12.3)

^a1 injury each for abdomen, foot/toe and groin not presented; severity data < 2 injuries not presented.



► **Fig. 1** Percentage of injuries occurring by type of stage.



► **Fig. 2** Injuries occurred most frequently on steep, dirt/rocky stages.

race injury incidence in the present study was similar to the 43/1000 hours reported in downhill racing in the US [14] and higher than the 20/1000 hours reported in downhill riders from Germany, Luxembourg, Switzerland and Austria [17]. The rate of injury was also higher compared to that reported previously in cross-country mountain bike racing (4.0/1000 hours racing) [8].

The rate of injury is understood to be influenced by several factors. A combination of high speeds and steep, technical terrain may increase the risk of injury, for example, in downhill and enduro riding compared with that of cross-country mountain biking [16]. The level of riding will also influence results, e. g. recreational riding versus competitive racing, and regional versus International level riders, where the technicality of events and intensity of competition in the latter may be greater. In addition, methodological differences may influence results [23]. For example, prospective

studies [9, 17] versus retrospective studies [16], which may be subject to recall bias [24]. The length of study recording, such as single event, single season [9, 17] or multiple season studies [11, 16], and the definition of injury, e. g. hospital attendance [9] versus time-loss [8] versus medical-attention [13, 17]. Finally, how injuries are recorded, whether by medical professional or rider self-reported surveys [10, 11, 17], may also influence the number and rate of injuries presented. The data recording methods in the present study were adapted from the IOC surveillance methodology to ensure consistency of results and allow comparison to other sports injury studies [7, 15, 21]. To date few studies that have employed consensus methodologies for injury recording [17, 18], and it is recommended that future mountain bike injury research include standardized definitions and data recording methods [25].

Type of injury

In the present study the shoulder, followed by the head, hand and lower leg were the most commonly injured body locations, and the most frequent injury types were lacerations/abrasions/skin lesions followed by contusion/hematoma/bruise, and (traumatic) fractures. These findings are consistent with previous studies in downhill and cross-country mountain biking [8, 10, 11, 14, 17]. Also in line with results reported previously, the most frequent injury diagnoses in the current study were concussions (7.3% of all injuries), lower leg (5.7%) and forearm (5.2%) lacerations, and shoulder/clavicle fractures (4.7%). Overall, shoulder/clavicle (total of 442 days lost), hand (161 days lost) and wrist fractures (105 days lost) caused the greatest burden [8, 10–12, 14, 17]. Shoulder/clavicle fractures were also predominant in a UK trauma department study, where they accounted for 25% of all mountain biking-related injuries in riders presenting to hospital [9], confirming both their prevalence and severity. For concussion, the proportion of injuries in the current study (10.2% of all racing injuries) was similar to that reported previously in downhill racers in the US (9.0% of all racing injuries) [8]. Compared with other professional sports, the incidence of concussion injury in enduro (3.9 injuries per 1000 hours racing) was slightly higher than football (2.4 per 1000 match hours) [26], but lower than rugby (15.8 to 18.4 per 1000 match hours) [27, 28].

Awareness of athlete concussion and its short and long-term consequences is increasing in a number of sports, including mountain biking, where there have been a series of high-profile injuries [29]. A lack of concussion recognition, including delayed symptom presentation (sometimes up to 48 h post injury), may result in both under reporting of concussion injury and a subsequent lack of appropriate care. If standard concussion return-to-play (RTP) protocols are followed 7 days should be the minimum time prior to return to normal mountain bike activity [30]. However, in the present study the estimated mean days lost was 5.1 days per concussion injury. This suggests riders may not have been taking adequate time off for recovery, and the results seem to confirm this whereby almost a third of riders were reported to complete their race, and a third to take no time off at all post injury. With a previous concussion known to increase the risk of future concussion [31, 32], awareness and treatment of concussion injury, including following structured RTP guidelines, in line with the recent concussion injury consensus are crucial [30].

Limitations

Unlike racing, it was not possible to directly measure rider practice exposure (hours), and so a composite indirect measure was calculated based on the number of stages and terrain at each event. Hence, despite the lower prevalence presented in practice compared with racing, which the authors believe to be true, race practice injury rates should be interpreted with caution. It is clear enduro is dominated by acute/traumatic injuries. However, the methodology employed in this study may miss the recording of some chronic/overuse issues, i.e. those injuries causing pain and limitations in performance, around the knee and lumbar spine, as previously reported [33–36]. Results presented in some categories were affected by sparse data bias [37]. Hence for severity data (days lost) median values were presented alongside mean (as the traditional measure of severity). Finally, the present descriptive study does not provide direct causal association.

Practical application – injury prevention initiatives

In response to the study findings mountain bike rider concussion education and recognition resources, including detailed *return-to-riding* (RTR) guidelines, were developed and made freely available on the EWS website targeting professional and recreational riders, and race event organizers [38, 39]. Recommendations were made for a rider head injury assessment protocol to be implemented, and this has been used by medical staff in all EWS events [40]. In addition, a new rider concussion withdrawal protocol was included in the EWS race rules. Other recommendations suggest additional medical provision should be targeted by race organizers around steep dirt/rocky race stages, where the more severe injuries tend to occur, and for the course designers to re-assess design of some of these technical sections. Riders should wear equipment to protect against lower leg and forearm lacerations and abrasions, and the mountain bike industry may consider future development of enduro specific shoulder protection products [41]. Finally, new qualification criteria (qualifier and challenger events) were introduced to decrease the number of first-time, only-time riders competing in EWS tier 1 events (i.e. those who may be more frequently injured), to ensure riders possessed sufficient skill and experience to compete at that level [42].

Conclusions

This study provides unique insight into the risk of injury in elite level enduro mountain biking, reporting injuries from over 2000 riders from 46 countries, across two seasons. Objective data from the study should be used to help target injury prevention initiatives in enduro mountain biking. Ongoing monitoring of injuries, as the patterns of mountain biking injuries continue to emerge in this relatively new discipline, and the inclusion of robust risk factor studies, may help inform future injury prevention strategies. While it is important to understand the risk of injury at elite level enduro, previous mountain bike studies have reported that most injuries occur in recreational rather than competitive riding [9]. Hence future research investigating the incidence and nature of enduro mountain biking injuries in amateur and recreational riders is also advocated.

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Conflict of Interest

CB is the Enduro World Series Managing Director.

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