A prospective study of downhill mountain biking injuries

Johannes Becker, Armin Runer, Daniel Neunhäuserer, Nora Frick, Herbert Resch, Philipp Moroder

ABSTRACT

Background Downhill mountain biking (DMB) has become an increasingly popular extreme sport in the last few years with high velocities and bold manoeuvres. The goal of this study was to provide information on the pattern and causes of injuries in order to provide starting points for injury prevention measures.

Methods We performed a monthly e-mail-based prospective survey of 249 riders over one summer season ranging from April until September 2011.

Results A total of 494 injuries occurred during the 29 401 h of downhill exposure recorded, of these 65% were mild, 22% moderate and 13% severe, of which 41% led to a total restriction greater than 28 days. The calculated overall injury rate was 16.8 injuries per 1000 h of exposure. For experts it was 17.9 injuries per 1000 h of exposure, which is significantly higher than the 13.4 for professional riders (OR 1.34; 95% CI, 1.02 to 1.75; p=0.03). A significantly higher rate of injury was reported during competition (20 per 1000 h) than during practice (13 per 1000 h) (OR 1.53; 95% CI, 1.16 to 2.01; p=0.0022). The most commonly injured body site was the lower leg (27%) followed by the forearm (25%). Most frequent injury types were abrasions (64%) and contusions (56%). Main causes of injury reported by the riders were riding errors (72%) and bad trail conditions (31%).

Conclusions According to our data DMB can be considered an extreme sport conveying a high risk of serious injury. Strategies of injury prevention should focus on improvements in riders’ technique, checking of local trail conditions and protective equipment design.

INTRODUCTION

In recent years, downhill mountain biking (DMB) has become a popular extreme sport drawing increased numbers of participants at both competitive and non-competitive level. The sport is performed during summer in countries all over the world, especially in mountainous areas where ski resorts are increasingly being used as venues.

DMB typically involves high-velocity runs including jumps, turns and various manoeuvres which in combination with the hard and rocky underground of the downhill trails lead to the risk of serious injury. To defy these demands athletes use bikes, which differ from regular cross-country mountain bikes in terms of weight and frame construction. Moreover, these downhill bikes are generally designed to provide the best possible traction and suspension in order to enable the athletes to perform extreme downhill runs with jumps, turns and obstacles to swerve at high velocities (figure 1).

In particular, this sport has recently been the subject of increasing media attention due to several severe injuries among its athletes; however, little is known about the true risk of injury involved in participation. Retrospective surveys by Jays et al.1 and Apsingi et al.2 reported severe injuries for DMB including fracture dislocations of the cervical spine as well as a case of incomplete tetraplegia. As retrospective studies are subject to sampling and recall bias,1–3 the present study was designed prospectively. The goal of this study was to gather more accurate data about the injury rate, patterns and causes of this increasingly popular extreme sport to provide a starting point for the development of injury prevention measures. According to van Mechelen et al.6 a multistep process is required to prevent injuries in sports. First, information about the injury extent and aetiology in a particular sport are gathered. Next, risk factors and potential remedies are identified followed by the introduction of preventive measures, which then need to be evaluated.6

METHODS

Study population

This study was performed prospectively over one bike season starting in April 2011 and terminating at the end of September 2011. Two hundred and forty-nine downhill bikers from Germany, Luxembourg, Switzerland and Austria were surveyed over this time period. All athletes were recruited voluntarily via official downhill associations, personal contacts or internet-based social networks. In this survey, all downhill bikers were allowed to participate irrespectively of their riding skills or years of experience.

Data collection methods

At the beginning of the survey every athlete was asked to complete an informed consent form and general information about the athletes was gathered including questions regarding athletes name, age, gender, telephone number, weight, height, downhill experience in years, experience in similar sports (eg, cross-country biking, mountain biking, freeride biking and racing cycle), level of performance, safety equipment and previous injuries. The general information also included basic bike data like weight, frame size, pedals, pins, suspension fork, range of spring, tyres and handlebar. Similar to previous sports injury epidemiology studies,7 8 the following classification was developed in order to help the athletes determine their own level of performance: beginners master short and easy downhill runs under perfect trail and weather conditions. Advanced bikers manage long downhill runs with small obstacles and small jumps under good trail and weather conditions, whereas an expert can master large obstacles and long jumps during a downhill run. Professional downhill bikers are able
to swerve large obstacles at high velocities and perform large jumps even under poor trail and weather conditions, and take part in national or international competitions.

During the season every participant had to fill out a monthly e-mail-based questionnaire regarding the amount of hours spent downhill biking either at competitive or non-competitive level. In the case of a reported injury the athlete had to answer further questions concerning the body region affected, type of injury, circumstances and cause of accident, as well as time and location of accident (eg, during a jump, in a curve, terrain with corrugations, sloping terrain, etc). Furthermore information about safety equipment, trail and weather conditions as well as landing zone characteristics (eg, grass, stones, soil and obstacles) was collected for each injury incident. Additionally, the injury-related time of impairment from DMB and the medical treatment received was determined. To secure that none of the athletes lost to follow-up had been sustained a fatal downhill accident DMB-related media was weekly checked. This study did not receive any funding and did not involve any intervention on the study participants. Therefore no approval of the local ethical committee had to be obtained.

**Statistics**
Injury predispositions and risk factors were compared using ORs with 95% CIs. According p values were obtained utilising the Pearson’s χ² test or Fisher’s exact test if cells in the crosstables had a value below 5. The α level was set to 0.05 and all p values were considered as two-tailed.

**RESULTS**
**Response rate**
The follow-up rate decreased throughout the study course to 80% in the final month of survey. Of the 249 athletes 4 were lost after the first month, 7 after the second, 4 after the third, 7 after the fourth, 7 after the fifth and 20 after the sixth month.

**Study population**
Two hundred and forty-nine downhill riders were recruited to submit their general information as well as their specific injury questionnaires. Two hundred and eighteen were from Germany, 19 were from Austria, 11 were from Switzerland and 1 was from Luxembourg. The average age of the participants was 23.5±6.8 years and ranged from 14 to 53. Three beginners, 62 advanced rider, 157 experts and 27 professionals filled out the questionnaire. The participating athletes had an average of 4.0±3.2 years of experience in DMB but only 8% had participated in a professional instructional course. Eleven per cent of the participants performed this sport at a competitive level with an average amount of 13.1 h per month. Ninety per cent of all riders participated in other bike sports as cross-country, mountainbike, freeride and racing cycle as well.

**Protective equipment**
Most common safety equipment used, included fullface helmet (96%), gloves (89%) and knee protectors (88%). Safety glasses (86%), protector jackets (64%) and shin guards (56%) were often used as well. The newly developed neck brace (figure 2) was only employed by 34% of all athletes, followed by back or competition were classified as mild. Injuries resulting in slight restriction but allowing sports participation were defined as moderate, whereas injuries leading to disruption and total restriction of sports participation were classified as severe. Injuries resulting in death or disability were defined as catastrophic.

This study did not receive any funding and did not involve any intervention on the study participants. Therefore no approval of the local ethical committee had to be obtained.
Injury rates, patterns and severity

During the survey period 29,401 h of DMB were recorded, including 3,058 h of competition. In this time, a total number of 494 injuries occurred of which 320 were reported to be mild (65%), 111 moderate (22%) and 63 severe (13%). The average absence from sports of the participants with severe injuries was 31.4 days. For the severe injuries, 26 athletes (41%) reported a time-loss greater than 28 days (0.88 injuries per 1000 h of exposure). Of these cases six were clavicle fractures, four wrists, three hands, two upper arms, two forearms, two fingers, one multiple rib and one rib fracture. Furthermore three concussions, one shoulder dislocation and one ligament rupture were reported. No catastrophic injuries were reported. The calculated injury rate was 16.8 injuries per 1000 h of exposure. In 80% of the cases the athletes sustained multiple injuries over the course of the season. In 47% of all cases of sustained injury multiple body sites were affected.

The most frequently affected body region was the lower leg (27%), followed by the forearm (25%) and the knee (21%; table 1). The most commonly reported types of injury were abrasions (64%), contusions (57%), and torsions (15%; table 2). Lower leg injuries were mainly abrasions (81%) and contusions (55%), similar to forearm injuries in which case abrasions (93%) and contusions (60%) were predominant as well. The 32 reported fractures included 6 clavicular, 5 rib (2 of which multiple), 3 finger, and 2 wrist fractures. One athlete developed a pneumothorax following a multiple rib fracture. In one case a concussion with intracranial haemorrhage, multiple rib fractures and contusions (60%) were considered. All 32 reported fractures were classified as mild (81%), moderate (14%) and severe (5%). One athlete had a compound fracture of the elbow (3%) and a compound fracture of the foot (3%). A total of 320 injuries (65%) were reported to the participants. Of these injuries, 15% were classified as mild, 22% as moderate and 13% as severe. Of all cases of injury athletes did not require any medical treatment. Twenty-eight per cent (n=138) were treated conservatively of which 14% (n=19) needed analgesia, and in 15 of the sustained injuries (3%) surgical treatment was required of which were five clavicles, two fingers, two hands, two upper arms and two wrist fractures, one ligament rupture and one combined abrasion and deep laceration.

Injury circumstances, causes and risk factors

Over half of the injuries (58%) occurred in the middle of a downhill day whereas the rest of the injuries was distributed evenly between the beginning (21%) and the end (20%) of the day. Most accidents happened in a curve (43%), during jumps (32%) and sloping terrain (32%). The main terrain on which the injured athletes lost control of their bike prior to a fall was soil (63%), followed by stones (45%) and roots on the ground (33%). Likewise the landing zone after a fall was mostly constituted by soil (66%), stones (44%) or roots (24%). In 31% of the incidents the trail conditions were rather poor (greater irregularities and holes, excessive roots, slippery underground) and 30% of the injuries occurred despite rather good trail conditions (small irregularities and holes, scattered roots, no slippery underground). Weather conditions at the time of injury were mainly very good (51%), followed by rather good weather (29%). When asked about their injury circumstances, many athletes stated multiple causes, with the most common being riding errors (72%), poor trail conditions (31%) and unforeseen trail obstacles (16%) (table 3). Most common injury mechanisms reported were falling over the handlebar (32%), wrong landing (17%) and sliding (16%) (table 4). Three bikers reported that their injuries resulted from slipping of the pedals with subsequent falling on the handlebar and rolling over the bike.

As compared with professional riders (13.0 injuries per 1000 h of exposure), experts (17.9 injuries per 1000 h of exposure) showed to be at significantly higher risk of getting injured (OR 1.34; 95% CI, 1.02 to 1.75; p=0.03). There was no significant difference in the rate of mild (OR 1.26; 95% CI, 0.90 to 1.75; p=0.17) or severe injuries (OR 1.40; 95% CI, 0.63 to 3.14; p=0.40) between experts and professionals. A significantly higher injury rate (OR 1.53; 95% CI, 1.16 to 2.01; p=0.01) was reported during competition (20.0 per 1000 h) than during practice (13.0h per 1000 h).

DISCUSSION

DMB has become a popular extreme sport in many different countries throughout the world. The goal of the present study was to investigate the rate, patterns and causes of injury in DMB in order to provide starting points for injury prevention measures.

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**Table 1** Affected body region in case of injury (n=494)

<table>
<thead>
<tr>
<th>Anatomic region</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower leg</td>
<td>134</td>
<td>27</td>
</tr>
<tr>
<td>Forearm</td>
<td>121</td>
<td>25</td>
</tr>
<tr>
<td>Knee</td>
<td>103</td>
<td>21</td>
</tr>
<tr>
<td>Elbow</td>
<td>97</td>
<td>20</td>
</tr>
<tr>
<td>Hand</td>
<td>93</td>
<td>19</td>
</tr>
<tr>
<td>Shoulder</td>
<td>86</td>
<td>17</td>
</tr>
<tr>
<td>Thigh</td>
<td>85</td>
<td>17</td>
</tr>
<tr>
<td>Wrist</td>
<td>64</td>
<td>13</td>
</tr>
<tr>
<td>Hip</td>
<td>63</td>
<td>13</td>
</tr>
<tr>
<td>Ankle</td>
<td>43</td>
<td>9</td>
</tr>
<tr>
<td>Head/face</td>
<td>38</td>
<td>8</td>
</tr>
<tr>
<td>Rib</td>
<td>36</td>
<td>7</td>
</tr>
<tr>
<td>Upper arm</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td>Pelvis</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>Neck/cervical spine</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Foot</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Upper back</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Lower back</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Clavicula</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Abdomen</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Others</td>
<td>21</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 2** Sustained injuries in case of incident (n=494)

<table>
<thead>
<tr>
<th>Injury type</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasion</td>
<td>316</td>
<td>64</td>
</tr>
<tr>
<td>Contusion</td>
<td>279</td>
<td>57</td>
</tr>
<tr>
<td>Torsion</td>
<td>72</td>
<td>15</td>
</tr>
<tr>
<td>Laceration</td>
<td>62</td>
<td>13</td>
</tr>
<tr>
<td>Strained muscle</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>Fracture</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Concussion</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>Ligament strain</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>Joint dislocation</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Joint inflammation</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Ligament rupture</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>23</td>
<td>5</td>
</tr>
</tbody>
</table>
Many previous epidemiologic sport injury studies from several different authors were performed using different injury classifications and definitions, thus complicating interstudy comparison. In this study we defined an injury as any injury resulting from practice or competition, irrespective of medical treatment requirement or time loss from sports activities. Based on the extent of impairment from sports participation the injury severity was classified according to Moroder et al. When employing this injury severity classification, in a limited number of cases it might occur that injuries which from a medical viewpoint would be considered as severe are classified as mild or vice versa. However, this definition helps avoid underestimation of the injury extent in sports epidemiology studies as mentioned by Nickel et al and at the same time directly relates the injuries to their effect on training and competition which is the most important aspect for athletes and their teams. In the literature the rate of injury has been reported in different ways including incidence of the injuries adjusted for 100,000 population, injuries per athlete exposure, injuries per 1000 h of exposure, and injuries per 10 000 h of exposure and injuries per 1000 h of exposure. The last named method of reporting was suggested in recent expert consensus statements leading to the decision to express the injury rate in this study in terms of injuries per 1000 h of sports exposure.

The calculated injury rate per 1000 h of downhill exposure was 16.8 injuries. This is distinctly higher than the reported 6.8 injuries for men and 12.0 injuries for women in cross-country mountain biking. Generally, according to our data there is a significantly higher injury rate compared with the related sport mountain biking which mainly can be explained by the more dangerous nature of the sport itself involving high velocities, jumps and trails with obstacles to avoid. However, these studies are hardly comparable due to differences in study design and injury definition. For example Gaurapp et al define an injury as any injury preventing the athlete from at least 1 day of mountain biking. In this study, an injury was defined according to recent consensus statements as any injury of an athlete resulting from training or competition, irrespective of medical treatment required or time loss from sports activities. This definition helps avoid underestimation of the injury extent in sports epidemiology studies and at the same time prevents misconception of common injury causes and consecutive misguided injury prevention strategies. In two cases the athletes sustained a concussion during an accident but continued to participate in downhill runs against medical advice. If in this study an injury would have been defined as causing restriction from sports participation, these two injuries would not have been recorded in this study.

The two most commonly injured anatomic regions were the lower leg and forearms. While forearm injuries primarily resulted from falls over the handlebar, most lower-leg injuries resulted from slipping of the pedals on bumpy parts of the trail or after landing a jump. Another frequent cause of lower-leg injuries reported was the entangling of a leg in trees or bushes close to the trail as well as hitting obstacles. For example, one athlete grazed a tree with his lower leg during a downhill run leading to a fall over the handlebar. As protective equipment is generally vastly employed, the protection of the forearms as the second most frequently affected anatomic regions in case of injury was rather poor with only 1% of the participants using wrist protectors and 23% using elbow protectors. While a greater percentage of riders used protective equipment for the lower leg, there is still room for improvement in this area.

In cross-country mountain biking head and neck injuries were reported to be common with 3–19% of the registered injuries being concussions, 55% of fractures being a maxillofacial trauma and 24% of spine injuries involving the cervical spine. Even some cases of cervical spine trauma resulting in tetraplegia were reported in mountain biking studies. However, few head and neck injuries were recorded during the course of this study and none were catastrophic. The occurrence of such a low percentage of head and neck trauma compared with mountain biking studies could be explained by the high usage of a helmet in this study (96%). Similarly, Chow et al reported a head and neck injury rate in mountain biking of 12% with 88% of the study participants using helmets. A novel protective equipment in downhill biking is the neck brace which was used by 34% of the study participants. The effectiveness of this device in preventing cervical spine injuries is yet to be evaluated.

The injury rate during competition was found to be statistically significantly higher than during practice. Since the trails for competition and practice are mostly the same the increased injury rate during competition is best explained by the altered risk-taking behaviour during competition. This increase of injury rates during competition was similarly observed in other sports. Interestingly, professionals who usually perform downhill runs of greater level of difficulty at a higher velocity had a lower overall risk for injury than their less experienced colleagues. Additionally, regarding the injury severity, professionals did not account for more severe injuries than experts. These findings are possibly explained by the fact that professionals are able to avoid many incidents due to their greater technical skill level.

According to Gaurapp et al one of the main risk factors for injury in cross-country mountain biking is the cyclist’s poor

<table>
<thead>
<tr>
<th>Circumstances</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall over the handlebar</td>
<td>156</td>
<td>32</td>
</tr>
<tr>
<td>Wrong landing</td>
<td>82</td>
<td>17</td>
</tr>
<tr>
<td>Sliding</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>Slipped of the pedal</td>
<td>59</td>
<td>12</td>
</tr>
<tr>
<td>Front wheel sliding</td>
<td>58</td>
<td>12</td>
</tr>
<tr>
<td>Sideslipping</td>
<td>49</td>
<td>10</td>
</tr>
<tr>
<td>Collision with tree</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td>Clinging</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Rolling over</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

*Multiple circumstances possible.

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According to Gaurapp et al one of the main risk factors for injury in cross-country mountain biking is the cyclist’s poor
judgement of the own capabilities. This might be true for DMB as well given that riding errors were identified as the leading cause of injury in this study. In particular, beginners should participate in an instructional course before starting with this high-risk sport in order to avoid riding mistakes leading to incidents. Adverse trail conditions were mentioned in 31% of all cases of injury as main or at least concomitant cause for the incident. This finding resembles the results of a recent report for mountain biking.20 Often trail conditions vary largely depending on the weather conditions, which has to be kept in mind by the athletes in order to avoid injury. The third leading cause for injury was the occurrence of unplanned obstacles such as fallen trees or bikers on the trail. Injury prevention measures should therefore include the strict separation of hiking and downhill trails as well as frequent inspection of the downhill trails for the presence of accidental obstacles.

A fatal injury to a study participant cannot fully be excluded, because 49 athletes were lost to follow-up over the course of the study. A further limitation is the fact that the injury data and exposure data rely on the self-reported information of the participants. Even though the study was conducted prospectively, the monthly collected questionnaires were retrospective in nature giving rise to a potential recall bias. However, prospective repeated monthly questionnaires have been suggested a good way of monitoring all types of injuries among individual athletes.31 Finally, it must be stated that it is unknown to which extent the study population is representative of downhill bikers in general.

CONCLUSION
In conclusion, downhill biking can be considered as an extreme sport with a high risk of injury. More attention should be paid on local trail conditions considering bad weather as well as routine checking of the trails for unwanted obstacles. To improve riders’ technique professional instructional courses are recommended. Additionally, the use of protective equipment should be more encouraged.

What are the new findings?

- The majority of injuries are of minor severity.
- Commonly injured body parts are lower leg and forearm.
- Frequent injury types include abrasion, contusion and torsion.
- Injury prevention measures should focus on protective equipment and downhill trail safety.

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