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Characteristics of Lower Limb Running-Related Injuries in Trail Runners: A Systematic Review

REVIEW

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XINYAN JIANG
JÓZSEF SÁROSI
ISTVÁN BÍRÓ

*Author affiliations can be found in the back matter of this article

ABSTRACT

Trail running is becoming a more popular sport, offering many health advantages, though it also has a significant risk of injury. Due to a lack of data on trial runners' injury characteristics, there is a need for focused research to inform prevention strategies. The objective of this review was to outline the injury characteristics observed in trail runners. We performed an extensive search of the literature across PubMed, Web of Science, Scopus, and Google Scholar. We thoroughly examined titles, abstracts, and full texts to select studies that detailed injury characteristics specific to trail runners. The review included 24 articles, encompassing a total of 17,664 runners. The findings reveal significant variability in the prevalence of lower limb injuries among trail runners, ranging from 12.3% to 100%. The incidence of injuries varied from 2.2 to 65 per 1000 hours of running. We identified the knee as the most frequently injured region, followed by the ankle and Achilles tendon. Running-related injuries have a multifaceted etiology and are influenced by multiple factors. The insights gained from this review provide a foundation for developing targeted injury prevention strategies that should also integrate clinical expertise and practical experience to enhance both safety and enjoyment for participants.

CORRESPONDING AUTHOR:
Xinyan Jiang
Doctoral School on Safety and Security Sciences, Óbuda University, Budapest, Hungary; Faculty of Engineering, University of Szeged, Szeged, Hungary
jiangxinyan168@gmail.com

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INTRODUCTION

The popularity of running continues to rise. Meanwhile, trail running has emerged as a distinct branch of road or track running. Trail running involves outdoor running across diverse natural settings such as forests, deserts, mountains, coastal zones, and jungles (Malliaropoulos, Mertyri and Tsaklis, 2015). This form of off-road running is not defined by specific distances or changes in elevation, and it encompasses a variety of terrains, including forest paths, single tracks, dirt roads, and beach sands. Notably, less than 20% of the competition distance occurs on paved or asphalt surfaces (Scheer et al., 2020; Viljoen et al., 2021d). The sport has witnessed a surge in popularity, as evidenced by the global increase in organized trail races. Approximately 20 million participants engage in trail running, marking a 15% rise in the past ten years (Viljoen et al., 2022). The International Trail Running Association (ITRA) reported that 195 countries organized 25,700 trail competitions from 2013 to 2019.

There is evidence to suggest that participating in sporting activities in outdoor settings have a more positive result on mental health than in indoor activities (Thompson Coon et al., 2011). Trail running has been associated with improvements in mental health and resilience, as reported by its participants (Lincoln, 2021). Despite its various health benefits, trail running poses a higher injury risk due to the challenging terrain and varied conditions it involves (Jooste et al., 2023; Malliaropoulos, Mertyri and Tsaklis, 2015; Krabak, Waite and Schiff, 2011). Previous studies have primarily concentrated on the epidemiology of injuries related to road running (Dempster, Dutheil and Ugbolue, 2021; Jiang et al., 2021; Van Gent et al., 2007). However, applying these findings to trail running can be challenging owing to the unique characteristics of the sport. Trail running requires a distinct type of endurance effort that is affected by factors like significant elevation changes, varying environmental conditions, the distance covered, and uneven terrain (Viljoen et al., 2021b). The need to continually adjust to varying running conditions requires increased effort, which exposes the body to heightened physiological and biomechanical stress. These distinct aspects make it challenging to generalize the results from road running studies to trail running.

Several studies have examined acute metabolic responses to trail running races (Waśkiewicz et al., 2012; Jouffroy et al., 2019; Atkins et al., 2022), but there has been limited research on injuries associated with trail running, particularly those affecting the lower limbs. Ultra-endurance running, involving long hours, can significantly strain the musculoskeletal system, potentially leading to injuries (Almekinders and Engle, 2019). Both racing and training can cause overuse injuries if the physical demands exceed the body's ability to adapt. These injuries primarily affect the lower limbs and include conditions like patellofemoral pain syndrome, medial tibial stress syndrome, and Achilles tendon injuries, as well as joint sprains and fractures (Krabak, Waite and Schiff, 2011; Scheer and Krabak, 2021). Additionally, trail runners often train or compete in remote areas, which complicates the task for medical providers who may need to reach or evacuate injured participants (Hoffman et al., 2014). This underscores the significance of discovering runners who are at risk of injury prior to training or racing, aiming not only to prevent severe injuries but also to maintain the health benefits of running (Viljoen et al., 2021b; Viljoen et al., 2022).

The growing awareness of demand and potential risks associated with outdoor sports has underscored the importance of understanding how injuries occur among trail runners. Researchers have investigated several risk factors linked to running injuries among trail runners, which can be categorized into three main groups: personal factors (such as age, sex, and BMI) (Owen et al., 2024; Easthope et al., 2010; Krabak, Waite and Schiff, 2011), training or racing-related factors (including distance, intensity, and footwear) (Vercruyssen et al., 2016; Knobloch, Yoon and Vogt, 2008; Matos et al., 2020), and health-related factors (including medication use, previous injuries, and chronic diseases) (Viljoen et al., 2021c; Scheer and Murray, 2011; Viljoen et al., 2021a). Appropriate medication for injuries in trail running is crucial for preventing long-term problems (Krabak, Waite and Lipman, 2014). Thus, it is essential to study and collect data on musculoskeletal injuries in various aspects of trail running, including during competitions and training sessions. Lower extremity injuries are the most common in sports, with a particular focus on their prevalence in running, as extensively discussed in numerous research articles (Emery and Pasanen, 2019). Despite various studies on running injuries among trail runners (Easthope et al., 2010; Gajardo-Burgos et al., 2021; Graham et al., 2012; Hamill et al., 2022), the

specific risk factors and types of running-related injuries remain unclear in the existing literature. The aim of our review is to analyze various studies on this topic to discover the characteristics (incidence, injury region and type of injury) of lower extremity injuries among trail runners. Insights gained from this review will establish baseline data, guide future studies and inform the development of effective prevention and treatment approaches for this particular style of running.

METHODS

DATA SOURCES AND SEARCH STRATEGY

The design of the present review was systematic, adhering to the guidelines specified in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Figure 1 is a flowchart that shows the search procedure. We performed an online literature search utilizing three databases: PubMed, Web of Science, and Scopus, along with Google Scholar. The search employed a combination of keywords including "trail running," "trail race," "trail runner," "injury," "lower limb," "lower extremity," "injury factor," and "prevalence," using Boolean operators "AND" and "OR." To ensure the review's relevance and timeliness, only peer-reviewed papers published in English since 2000 were included.

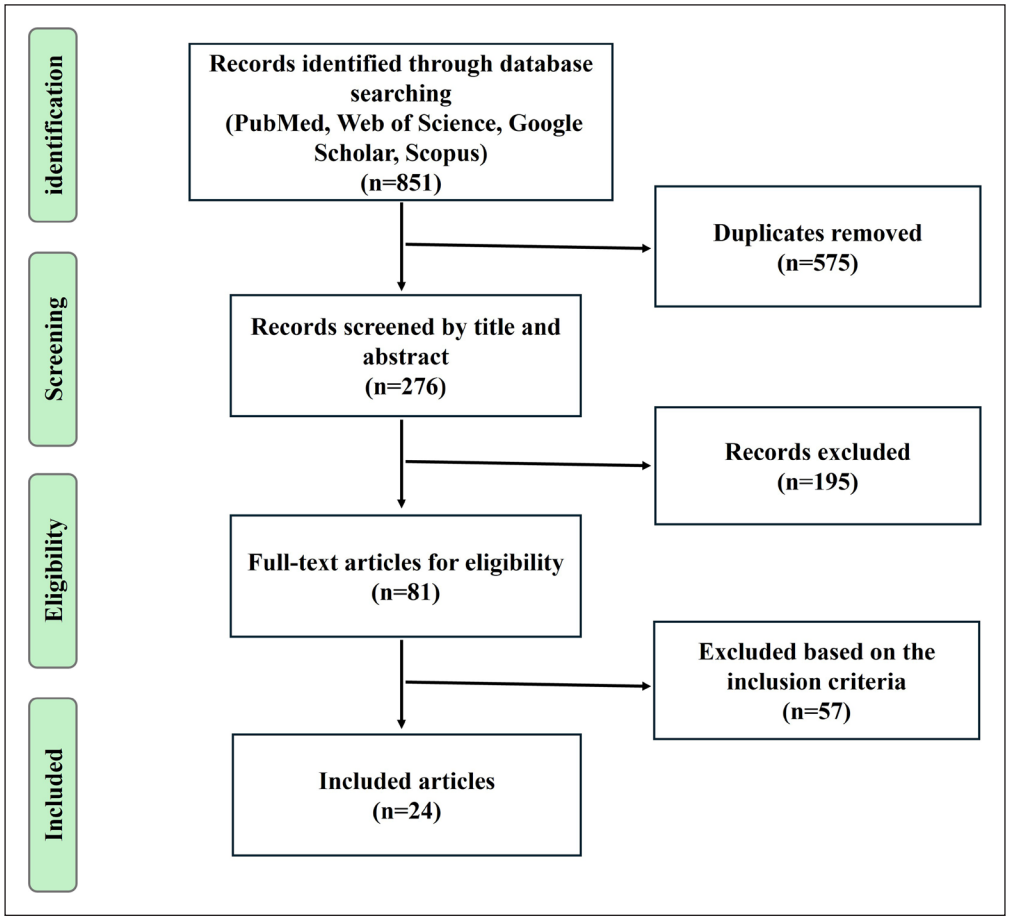

Figure 1 Flowchart of articles selection procedure.

INCLUSION AND EXCLUSION CRITERIA

We retrieved full papers when abstracts did not provide enough information to determine eligibility. The term "trail running" generally denotes running on unsealed, natural surfaces without specific requirements concerning distance, the proportion of off-road surface, terrain, or elevation. However, the definition provided by the International Trail Running Association (ITRA) is the most comprehensive, offering clear details on the surface, terrain, support, and route markings, without imposing limits on elevation or distance (Scheer et al., 2020; Viljoen et al., 2021b). Consequently, for this systematic review, we have adopted the ITRA's definition of trail running to determine the inclusion of studies.

The inclusion criteria included: 1) studies addressing lower body injuries, the injury data in this review includes self-reported data and medical data; 2) studies involving trail runners as participants, they were classified as trail runners if they had taken part in a race or training session that met the ITRA's definition; 3) research discussing the prevalence or incidence of injuries; 4) studies published in peer-reviewed journals as prospective cohorts, retrospective cohorts, cross-sectional, observational, or randomized controlled studies; 5) articles written in English.

Exclusion criteria included: 1) review articles; 2) research involving participants in sports other than running; 3) studies concerning acute physiological changes due to running, such as kidney injury; 4) studies focusing solely on biochemical markers like lactate, creatine kinase, and cortisol; 5) studies that only analyzed injured runners or failed to clarify whether all trail runners were free from injury at baseline; 6) studies focusing on the psychological impacts of sports on mental health; 7) multiple publications from the same cohort study.

DATA EXTRACTION AND QUALITY ASSESSMENT

Initially, one author conducted data extraction from the included studies. A second reader then verified and completed the data extraction when necessary. The extracted information included: 1) author and year of articles; 2) participant demographics, including gender (male/female) and age; 3) study setting, such as country, race distance, and elevation changes; 4) risk factors; 5) injury epidemiology, detailing injury rates, the anatomical regions affected, and the types of injuries.

A modified version of the Downs and Black assessment tool (Downs and Black, 1998) was employed to evaluate the quality of each included study, with two authors conducting the assessment. This modified tool, previously applied in systematic reviews of running-related injuries (Ceyssens et al., 2019; Neal et al., 2016), consists of 15 items across 4 categories: reporting (items 1, 2, 3, 5, 6, 7, 9 and 10), external validity (items 11 and 12), bias (items 16, 18 and 20), and selection bias (items 25 and 26). The maximum attainable score was 15, and studies scoring positively on more than 50% of the items were deemed high quality. The scores for each item given by the two authors were compared. Any discrepancies between the two authors were addressed through a consensus meeting. The third author was brought in to make the final decision once they could not reach an agreement.

RESULTS

We initially searched a total of 851 articles, as shown in Figure 1. After removing 575 duplicates, we left 276 records for screening. After reviewing titles and abstracts, 195 articles were excluded, narrowing the pool to 81 articles. Subsequent application of the exclusion and inclusion criteria further reduced the selection to the 24 articles that were included in this study. These selected articles are all considered to be of high quality.

The review incorporated 24 studies published between 2020 and 2024, with a summary provided in Table 1. These studies sampled populations from Chile, France, Germany, Greece, Italy, the Netherlands, Portugal, Scotland, South Africa, Spain, Sweden, and the USA. Collectively, they involved 17,664 trail runners, with 44.5% being female (Figure 2). All studies focused on lower limb injuries and presented a variety of injuries among trail runners. Risk factors related to trail running were examined in 22 of the studies, 19 reported injury rates, and 16 described the race settings.

DISCUSSION

The objective of this review is to explore the literature from 2020 to 2024 concerning the characteristics (incidence or prevalence, injury region, and type of injury) of lower limb injuries in trail runners. This review included 24 articles that met the inclusion criteria. The diverse study designs and varying definitions of injury among these studies posed challenges in forming definitive conclusions about injury epidemiology in trail runners. Nevertheless, we managed to compile a unified discussion on shared injury characteristics, including injury rates, the anatomical regions involved, injury types, and risk factors.

Table 1 Description of studies included.

STUDY	PARTICIPANTS	AGE	COUNTRY OF ORIGIN	RACE SETTING	RISK FACTORS	INJURY RATE	INJURY REGION	TYPE OF INJURY
Knobloch et al. (2008)	N = 291 (248 males, 41 females and)	42 ± 9 years	Germany	/	Running surface and running experience	The injury rate was 0.08/1000 km (2.93 per runner)	Achilles tendon, knee, tibia, and plantar	Achilles tendon overuse injury (56.6%), anterior knee pain (46.4%), shin splints (35.7%), and plantar fasciitis (12.7%)
Scheer et al. (2011)	N = 69 (48 males and 21 females)	Male: 46 years, female: 40 years	Spain	A 219-km, 5-day competition	Musculoskeletal, dermatological and other illness	39 runners (or 56.5 %) were deemed to have a medical condition	Hip, knee, Achilles, ankle and muscle	Foot blisters (33.3%), chafing (9.1%). Lower body musculoskeletal injuries (22.2%)
Krabak et al. (2011)	N = 407 (323 males and 84 females)	/	USA	7 days, staged, 240-km ultramarathon running race	Age and sex	The injury or illness rates were 3.86 per runner and 65 per 1000 h	Foot (73.7%), lower limb (8.6%), ankle (4.9%), and knee (3.5%)	Skin-related disorders (74.3%), musculoskeletal injuries (18.2%), and medical illnesses (7.5%)
Graham et al. (2012)	N = 11 (11 males)	33 ± 11 years	Scotland	150 miles in 7 days, Gobi Desert, Mongolia	Mood alterations and sleep duration	The injury rate was 100%	Lower limb	Skin and soft tissue injuries
Scheer et al. (2014)	N = 50 (30 males and 20 females)	40.4 ± 7.9 years	Spain	Al Andalus Ultimate Trail (219 km)	Race experience	A blistering incident was reported in 76% of the participants	Toes (65%), ball of the foot (16%), heel (14%), and sole (5%)	Blisters
Hoffman et al. (2015)	N = 376 (320 males and 56 females)	/	USA	A 161-km ultramarathon	Muscle fatigue	The prevalence of cramping was 14.3%, and near cramping was 26.8%	Calf (54%), quadriceps (44%), and hamstring (33%) muscles	Muscle cramping (14.3%) and near cramping (26.8%)
Malliaropoulos et al. (2015)	N = 40 (36 males and 4 females)	38.4 ± 8.73 years	Greece	/	Training and surfaces	At least one injury was reported by 90% of the runner	Lower back, Achilles tendon and hip joint	Overuse bone stress injuries (22%) and iliotibial band syndrome (16%)
Giandolini et al. (2016)	N = 23 (23 males)	39 ± 11 years	France	A downhill route of 6.5 km, consisting primarily of forest trails, that descends 1264 m.	Musculoskeletal damage and fatigue	/	Knee and plantar	Deficit in voluntary activation
Vercruyssen et al. (2016)	N = 13 (13 males)	38.2 ± 4.8 years	France	An 18.4-km trail running exercise	Footwear	/	Calf	Calf pain
Vernillo et al. (2016)	N = 77 (64 males and 13 females)	43.6 ± 10.9 years	Italy	A 65-km race (altitude between 725 and 2100 m)	General fatigue and muscle cramps	The overall injuries/illnesses were 1.9 per runner and 13.1/1000 h	Plantar (28.6%), ankle (28.6%), knee (14.3%), thigh (14.3%), Achilles (7.1%) and neck/cervical spine strain (7.1%)	Medical illnesses (50.3%), musculoskeletal injuries (32.8 %), and skin related disorders (16.9 %)
von Rosen et al. (2016)	N = 64 (31 males and 33 females)	17 ± 1 years	Sweden	/	Training volume, competition time and surfaces	The injury incidence rate was 18/1000h of training	Foot/lower leg (48.6%), knee (22.9%), hip (11.9%) and lower back (6.4%)	Overuse injuries (78.0%,) and acute injuries (22.0%)

(Contd.)

STUDY	PARTICIPANTS	AGE	COUNTRY OF ORIGIN	RACE SETTING	RISK FACTORS	INJURY RATE	INJURY REGION	TYPE OF INJURY
Hespanhol et al. (2017)	N = 228 (171 males and 57 females)	43.4 years	Netherlands	The median of the distance was 28.0 km, ranging from 3 to 230 km	/	The injury rate was 10.7 injuries per 1000 h and the mean prevalence of RRIs (22.4%)	Knee, Achilles tendon, calf and ankle	Achilles tendon injury (12.8%), calf muscle injury (10.7%), knee pain undiagnosed (8.7%) and ankle sprain (7.0%).
Kerhervé et al. (2017)	N = 14 (14 males)	21.7 ± 3.0 years	France	Two 24-km trail runs	Calf compression sleeves	/	Achilles tendon and calf	Achilles tendon pain and delayed onset calf muscles soreness
Matos et al. (2020)	N = 719 (529 males and 190 females)	38.01 ± 7.78 years	Portugal	/	Exposure time	87.8% of the sample reported an injury, the injury rate was 10.0 per 1000 h	Toenail (24.8%), knee (17.5%), and ankle (14.5%)	Blisters (20%), irritation (chafing) (14%), superficial wounds (12%), sprains (11%), and iliotibial band syndrome (7%)
Gajardo-Burgos et al. (2021)	N = 654 (413 males and 241 females)	36.2 years	Chile	Several trail runs from 11 to 63 km	Training following injury	Injury frequency rates (31.3%) and illness frequency rates (22.3%)	Knee	gradual onset injuries
Temesi et al. (2021)	N = 32 (32 males)	Long group: 38 ± 10 years, short group: 35 ± 8 years	France	Long race (>100 km) or short race (<60 km)	Race distance	/	Knee and plantar	Muscle contractile property impairment
Viljoen et al. (2021a)	N = 152 (120 males, 32 females)	37.1 ± 9.1 years	South Africa	/	A history of previous injury and chronic disease	A mean prevalence of 12.3% and an overall injury rate of 19.6 injuries per 1000 hours	Knee (29.8%), shin/lower leg (18.0%) and foot/toes (13.7%)	Tendinopathies (27.8%), muscle injuries (20.5%) and joint sprains (8.8%)
Viljoen et al. (2021c)	N = 2824 (1597 males and 1227 females)	/	South Africa	A 10-km and a 22-km race	Distance, chronic disease and history of allergies	The annual incidence of injuries (13%)	Knee (35%), shin/lower leg/ calf (16%) and thigh (11%)	Iliotibial band syndrome (22%), Achilles tendon injury (10%) and hamstring injury (9%)
Viljoen et al. (2021d)	N = 305 (213 males and 92 females)	38.3 years	South Africa	2019 Sky Run races	Training and demographic variables	The incidence was 49.5 injuries per 1000h	Knee (26.5%), ankle (21.6%), and foot (16.7%)	Tendinopathy (27.5%), joint sprain (19.6%), and muscle injury (15.7%)
Hamill et al. (2022)	N = 1016 (518 males and 498 females)	39.0 ±13.2 years	USA	N/A	Trails, terrains and footwear	Injury was reported by 39.8% of the runner during running on a trail	Ankle, foot, Shin, hip, plantar, knee, Achilles	Ankle sprain, hip stress fractures
Sanchez-Garcia et al. (2022)	N = 51 (35 males and 16 females)	15 to 22 years	Spain	N/A	The characteristics of the mountain terrain	2.2±1.8 injuries per 1000 h	Ankle (49.5%), knee (17.9%), and lower leg (9.5%),	Joint sprain (43.2%), tendinopathy (18.9%) and non-specific injuries (11.6%)
Jooste et al. (2023)	N = 251 (181 males and 70 females)	40 years	South Africa	2021 Mac Ultra race	/	The incidence was 19.92/100 runner	Lower limb (26%), thigh (22%), ankle and foot (13%)	Muscle injury (36%), tendinopathy (24%), and joint sprain (9%)
Owen et al. (2024)	N = 9835 (4725 males and 5110 females)	/	USA	N/A	Sex, age and racial disparities	/	Females: elbow, wrist, knee, lower leg, and ankle; males: shoulder, upper trunk, and hand	Females: strains/sprains and fractures; males: lacerations
Viljoen et al. (2024)	N = 162 (103 males and 59 females)	/	South Africa	2022 Mac Ultra races (46 km, 80 km, 161 km, and 322 km)	Race distance categories	The injury rate was 1.66 injuries per 1000 h	Knee (28%), (19%), and lower leg (17%)	Muscle and tendon tissue injuries (56%), muscle injuries (31%) and tendinopathies (25%)

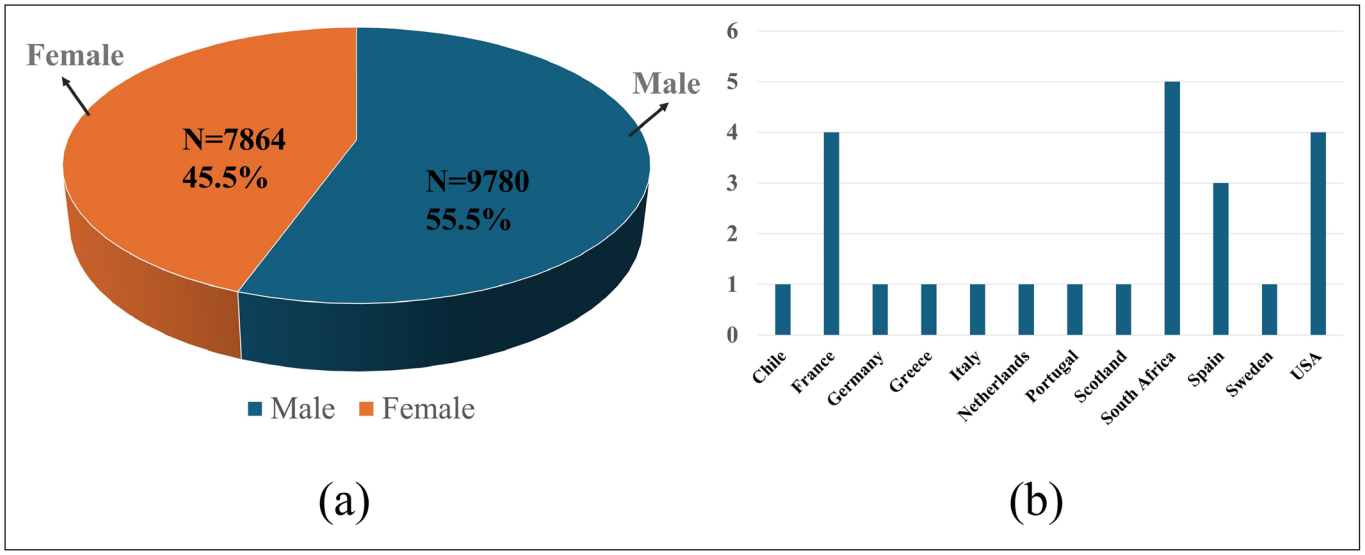

Figure 2 Characteristic information: **(a)** Gender distribution of runners, **(b)** The number of studies according to the nationality.

Running injuries frequently arise from overuse, in which the musculoskeletal system is subjected to excessive strain. Runner typically attributes such injuries to repeated microtrauma instead of a single, identifiable event. The reported overall prevalence of injuries to the lower limb revealed a great range (12.3% to 100%), with injury incidence ranging from 2.2 to 65 injuries per 1000 hours of running. Running injuries frequently arise from overuse, in which the musculoskeletal system undergoes excessive strain (Wen, 2007). Repeated microtrauma, rather than a single identifiable event, typically causes such injuries (Saragiotto et al., 2014). This review revealed that the most frequently injured sites of the lower limb are the knee, ankle, Achilles tendon, foot, plantar area, calf, and hip. The knee joint is particularly vulnerable, often cited in literature as a frequent site for overuse injuries related to running (Van Gent et al., 2007). This review aligns with those findings, with 17 studies identifying the knee as a common site of injury. For instance, Viljoen et al. (2021b) noted that 29.8% of running-related injuries in the lower body during trail running were at the knee. Similarly, Scheer and Murray (2011) found that knee complaints led to the majority of musculoskeletal consultations. Gajardo-Burgos et al. (2021) also observed a high prevalence of knee injuries among both male and female trail runners. The increased knee joint loading over long-term trail running, especially on more technically demanding and uneven surfaces compared to road running, may explain the higher incidence of knee injuries.

The ankle was highlighted as a frequently injured anatomical region in trail running, with 10 studies noting its vulnerability. Sanchez-Garcia et al. (2022) found that 49.5% of trail running injuries occurred at the ankle, with 40.4% happening during competitions and 42.6% during training sessions. Most of these injuries were reported as joint sprains by several sources, emphasizing the importance of ankle stability in trail running (Sanchez-Garcia et al., 2022; Hespanhol, Van Mechelen and Verhagen, 2017; Viljoen et al., 2021a). In terms of overuse injuries, the Achilles tendon also proved significant, with 7 studies citing it as a common region of injury. Specifically, Knobloch et al. (2008) identified Achilles tendinopathy as the primary overuse injury among master running athletes, a finding echoed by Malliaropoulos et al. (2015). Moreover, the relationship between running pace and Achilles tendinopathy is particularly notable in trail running, where maintaining a constant speed is challenging due to the varied inclines and declines of the terrain, further stressing the Achilles tendon. The foot was reported as an injured anatomical site in 6 studies, highlighting its vulnerability among trail runners, particularly due to frequent occurrences of blisters (Scheer and Murray, 2011; Matos et al., 2020; Scheer et al., 2014). Injuries to the plantar area and calf were each noted in 5 studies, indicating these areas are also commonly affected. Specifically, plantar fasciitis frequently affects the plantar area (Knobloch, Yoon and Vogt, 2008), while calf pain and muscle injuries are typical in the calf region (Vercruyssen et al., 2016; Hespanhol, Van and Verhagen, 2017). Additionally, the hip was noted as an injured site in 4 studies, emphasizing its importance in the spectrum of lower extremity injuries faced by trail runners, with conditions such as iliotibial band syndrome often occurring (Viljoen et al., 2021c; Malliaropoulos, Mertyri and Tsaklis, 2015; Matos et al., 2020).

Several risk factors linked to running-related injuries in trail running can be categorized into three primary categories: personal factors, training or racing-related factors, and health-related factors. Personal factors include age, sex, and racial disparities, which can influence susceptibility to injuries (Owen et al., 2024; Krabak, Waite and Schiff, 2011; Viljoen et al., 2021d). Training or racing-related factors encompass a wide range, such as training volume, race experience, competition time, race distance, exposure time, terrains, surface conditions, use of calf compression sleeves, and footwear, all of which can impact injury risk (Knobloch, Yoon and Vogt, 2008; Kerhervé et al., 2017; Temesi et al., 2021; Vercruyssen et al., 2016; von Rosen, Heijne and Frohm, 2016; Malliaropoulos, Mertyri and Tsaklis, 2015; Hamill et al., 2022). Health-related factors involve previous injuries or illnesses, a history of allergies, chronic diseases, mood alterations, and sleep duration. These can significantly affect a runner's risk profile (Scheer and Murray, 2011; Viljoen et al., 2021a; Gajardo-Burgos et al., 2021; Viljoen et al., 2021c; Graham et al., 2012). Studies often do not explore the interaction effects between these potential injury-causing factors. Given the multifactorial nature of running-related injuries and the interdependence of etiological factors, a comprehensive exploration of all potential confounding factors is necessary. The process of lesion production is complex and varied, making it challenging to precisely identify factors that contribute to injuries.

Our study has several limitations. First, trail running encompasses a variety of forms, and different types of trails running (e.g., terrain, distance, climate) may result in different types of injuries. Second, all included studies were assessed using the same quality checklist; however, different types of studies might benefit from more tailored quality assessments. Third, this review did not include a sensitivity analysis. The primary reason for this omission is that most systematic reviews on running injuries do not incorporate sensitivity analysis, leading to a lack of standardized methods for conducting such analyses and making it challenging for researchers to perform systematic sensitivity analysis. Additionally, the diversity in methodologies and outcome measurements among the included studies may hinder cross-study comparisons and the synthesis of results, particularly concerning the definition of injuries.

CONCLUSIONS

Running-related injuries are prevalent among trail runners, predominantly affecting the lower limbs and often resulting from overuse. The reported prevalence of lower limb injuries among trail runners displays a wide range, spanning from 12.3% to 100%. Additionally, the incidence of these injuries ranges from 2.2 to 65 injuries per 1000 hours of running. Notably, the knee emerges as the most frequently injured region, followed closely by the ankle and Achilles tendon. Running injuries have multifactorial origins, indicating that personal or training-related factors cannot be their sole cause. This enhanced knowledge is essential for the development of training plans and protective strategies aimed at reducing injury risk. Ultimately, these efforts will enhance safety for trail runners, ensuring more protected and informed participation in the sport.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Xinyan Jiang orcid.org/0000-0002-8196-7349
Doctoral School on Safety and Security Sciences, Óbuda University, Budapest, Hungary; Faculty of Engineering, University of Szeged, Szeged, Hungary

József Sárosi orcid.org/0000-0002-6303-5011
Faculty of Engineering, University of Szeged, Szeged, Hungary

István Bíró
Doctoral School on Safety and Security Sciences, Óbuda University, Budapest, Hungary; Faculty of Engineering, University of Szeged, Szeged, Hungary

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