INCIDENCE AND ANATOMICAL DISTRIBUTION OF LOWER EXTREMITY INJURIES IN PROFESSIONAL AND RECREATIONAL TENNIS PLAYERS ON HARD, CLAY AND GRASS COURT SURFACE: A REVIEW OF EPIDEMIOLOGY

SYSTEMATIC REVIEW

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Preface

Before you lies the bachelor thesis “Incidence and Types of Lower Extremity Injuries in Tennis Players Across Various Surfaces: A Review of Epidemiology”. It has been written to fulfil the graduation assignment for the Bachelor of International Physiotherapy at Hanze Groningen University of Applied Science (Netherlands). I was engaged in researching and writing this thesis from February to April 2023.

Abstract / Summary

Background
Injuries are a huge setback for tennis players. Injury prevention needs a detailed understanding of tennis injury epidemiology. Lower extremity injuries occur about equal to or more often than upper extremity injuries in tennis. Although studies have described the incidence rate of injuries across the whole body per court surface, there is a lack of knowledge on the influence of the court surface on lower limb injury rates and the anatomical location of the injuries.

Objective
The primary goal is to investigate the relationship between tennis court surfaces and lower limb injuries. This will be accomplished by analysing the occurrence and frequency of lower extremity injuries among professional and recreational tennis players across hard, clay and grass court. In addition, a secondary aim is to examine whether the location of lower extremity injuries varies depending on the court surface.

Methods
PubMed, CINAHL, SPORTDiscus and SpringerLink were searched from February to March 2023. A backward citation search was conducted. To formulate the eligibility criteria, the PECOS framework was used. The trial quality of the extracted trials was assessed using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement and the Quality Assessment Tool for Observational Cohort & Cross-Sectional Studies. Absolute numbers, incidence rate and frequency of injuries across the playing surfaces were analysed.

Results
Thirty-seven articles were assessed for eligibility of which 7 were included. Incidence rates were reported using five different types of exposure. On grass court, lower extremity injuries occurred with a mean frequency of 48%, on clay court with a frequency of 43.28% and hard court with a frequency of 40.23%. On hard court, a total of 670 injuries were reported. 25.5% of these injuries occurred in the knee, 21.3% in the foot region and 19.3% in the ankle.

Conclusion
The gathered data suggests that the court surface might influence the occurrence of lower extremity injuries. Based on the analysis, lower extremity injuries seem to occur most often on grass court, followed by clay court and hard court. According to the analysis of injury locations on hard court, the anatomical regions with the highest frequency of injuries seem to be the knee, the foot/toe area, and the ankle. The review suggests that the characteristics of the different court surfaces, such as reaction time, physical exertion and physiological response may contribute to the incidence of lower limb injuries. It highlights the importance of understanding the relationship between court surface and lower limb injuries. Future research should focus on female and recreational tennis players while using standardized injury incidence metrics

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Introduction

Tennis is a popular sport played by professionals and recreational athletes that places significant demands on the body. During a regular hour of playing tennis, the athlete strikes the ball approximately 150 times and covers a distance of 2.5 to 3.5 kilometres while engaging in high-intensity bursts of three meters (Brukner et al., 2017). At the highest level, the Grand Slam competitions, tennis matches are played on three different surfaces: the Australian Open and US Open on hard courts, the French Open (Roland Garros) on clay, and the Championships, Wimbledon on grass (Pluim et al., 2006). Before the introduction of acrylic and clay courts in the 1940s and 1950s, matches were predominately played on grass for many years (Miller, 2006). Many safety concerns have been raised by the evolution of an alternative playing surface for field sports that were previously played on natural grass (Dragoo & Braun, 2010). Carpet courts were once another common surface in professional tennis; however, the Association of Tennis Professionals (ATP) and the Woman's Tennis Association (WTA) stopped using them after 2009 and 2018. It has been suggested that the decision to phase out carpet courts was motivated by a desire to standardize indoor competitions, with a preference for hard courts due to their perceived ability to reduce the risk of injury (Varcelletto, 2021).

Tennis is generally considered to be a safe and low-risk sport as it is a non-contact sport but can still be linked to a specific set of acute and chronic conditions (Fu et al., 2019). Pluim et al. (2006) performed a meta-analysis on injury rates in tennis including 28 descriptive epidemiological studies from all age groups and skill levels dating back to 1976. Injuries ranged from 0.05 to 2.9 per player per year, and 0.04 to 3.0 per 1000 hours of play. Compared to other body parts, lower extremity injuries are reportedly more common (Chard & Lachmann, 1987; Sallis, 2001; Pluim et al, 2006). Pluim et al. (2006) reported that 31-61 % of the injuries in their analysis occurred in the lower extremities, and only 20-49% in the upper extremities. Sports injuries vary in type and location and are affected by several factors. According to research, numerous internal and external factors can contribute to sports-related injuries (Meeuwisse et al., 2007); the court surface has been shown to impact the risk of injury as an external environmental factor in tennis (Miller, 2006; Girard et al. 2007; Dragoon & Braun, 2010). Bastholt (2000) analysed treatment data collected on tournaments of the ATP tour, 9 tournaments played on hard courts, 9 played on clay court and 5 on grass court, all between 1995-1997. He concluded that there was a significantly higher amount of treatments on hard court than on clay or grass court.

While there have been many studies on injuries in the tennis population and their relation to court surfaces, a comprehensive understanding of the incidence of lower extremity injuries across different court surfaces is still lacking. Previous research has mainly focused on the incidence of injuries across the whole body or on specific types of injuries and their associated risk factors, with little attention given to how the type of court surface may be a risk factor for lower limb injuries (Dines et al., 2015; Pluim et al., 2023). Bastholt (2000) has analysed the impact of court surfaces on injury risk and performance. He found that grass courts had the highest frequency of treatments (0.42 per match), followed by hard courts (0.37 per match) and then clay courts (0.20 per match). The relative risk was lowest on clay courts and highest on grass courts. In a recent systematic review conducted by Alexander et al. (2022) for the International Tennis Federation (ITF), the authors aimed to determine whether tennis, clay, hard, grass and concrete surfaces might influence injury rates. Surprisingly, their main finding was that there is no significant difference in the overall injury rate on clay, hard and grass courts. Still, it is often assumed that the court surface influences the total injury rate. Even though the incidence rates in the different court surfaces vary across the available studies, it becomes clear that lower extremity injuries make up a huge amount of the injuries. In a literature review about tennis injuries, Dines et al. (2007) have specifically suggested that the court surface might be a risk factor for lower limb injuries.

Therefore, this systematic review aims to examine the relationship between three types of tennis court, namely hard court, clay court and grass court, and lower limb injuries in professional and recreational tennis players. Additionally, the review aims to investigate whether the location of lower extremity injuries is influenced by the type of court surface.
To prevent injuries in any sport, there are four steps involved: injury surveillance to determine the scope of the issue, identifying the aetiology and mechanisms of injury, implementing preventive measures, and finally assessing the effectiveness of those measures (van Mechelen et al., 1992).
The first step of this process is attempted in this systematic review by determining the frequency and the location of lower limb injuries among tennis players. By synthesizing the existing literature on the topic, a more comprehensive understanding of the impact of court surfaces on injury risk should be slimmed.

Thus, the research question study is: “In professional and recreational tennis players, does playing on different types of court surfaces impact the incidence and types of lower extremity injuries?”

Theoretical framework

Consensus statement

Epidemiological studies on tennis medical conditions are an important tool for understanding the prevalence, risk factors, and outcomes of injury and disease in tennis players. However, conducting such studies requires careful consideration of ethical and methodological issues. One important resource for researchers conducting epidemiological studies in tennis is the Consensus Statement on Epidemiological Studies of Medical Conditions in Tennis, published by Pluim et al. in 2009. The statement by Pluim et al. has been updated by the International Olympic Committee (IOC) regarding acquisition and reporting of epidemiological data on tennis injuries in 2020. The revised statement includes information that is specific to tennis-related injuries, such as the way the injury occurred, how it is classified, how long it lasts, how exposure is recorded and reported, and details about the group of people being studied. (Verhagen et al., 2021). The final product states that due to the missing time limit in tennis, the match length can vary greatly. Therefore, a standardised expression of risk as the number of injuries per 1000 hours and 1000 games played is recommended for tournaments. Only if it is not possible to collect this information, the incidence rate can be expressed as injuries per 1000 sets or matches (athletic exposure). Injuries should be defined and classified in the mode of onset, the region and tissue it occurred in, a diagnosis with the matching Sport Medicine Diagnostic Coding System (SMDCS) code and a code according to the Orchard Sports Injury and Illness Classification System (OSIICS) (Verhagen et al., 2021).

Risk factors in sports

Risk factors in sports can be divided into athlete-related (intrinsic) and environmental (extrinsic) factors (Williams, 1971). Another way to subdivide risk factors is to classify them as modifiable or non-modifiable. Non-modifiable risk factors can be the gender or age of an athlete and modifiable risk factors like strength, balance or flexibility might be influenced by training or behavioural approaches. Important to notice is that only dividing the risk factors into a few categories is not enough, since the mechanism on which risk factors occur is very important and much more complex (Bahr & Holme, 2003).

Willem H. Meeuwisse developed a dynamic model to understand and describe the multifactorial nature of sports injuries in 1994. Based on that model and the work of Gissane et al. (2001) and Bahr & Krosshaug (2005), an improved model was presented in 2007.
Since injuries do not always occur under similar conditions and the fact that exposure is not solely possessing risk factors but also participating with risk factors, a linear approach is not fitting. Due to this dynamic mechanism, a cyclical model was developed. The athlete can therefore join the injury chain at any point. The athlete presents with intrinsic influencing him/her as a predisposed athlete. On that, the exposure to extrinsic risk factors acts, leading to a susceptible athlete. Potentially injurious events are the next step. If an event has no injuries as a consequence, adaptations or maladaptations may occur. If the athlete injures him/herself, recovery or removal from participation are the possible outcomes. Due to the cyclical design, the model assumes that repeated exposure with varying risks takes place (Meeuwisse et al., 2007).

Playing surfaces in tennis

Tennis court construction has reportedly received a §30 billion investment globally. In 2011 only, 210 various court surfaces received approval from the International Tennis Federation (ITF, 2012).
Each surface has a different impact on the style of play, the bounce of the ball and the quality of performance. To make these properties easier to understand, the ITF classifies court surfaces into categories based on the type and Court Pace Rating (see Tables 1 and 2).

Table 1: Tennis court surface types – court construction.

Type	Description
Acrylic/Polyurethane	Textured, pigmented, resin-bound coating.
Artificial clay	Sand-dressed and/or rubber-dressed surface with the appearance of clay.
Artificial grass	Synthetic surface with the appearance of natural grass.
Asphalt	Bitumen-bound aggregate.
Carpet	Textile or polymeric material is supplied in rolls or sheets of the finished product.
Clay	Unbound mineral aggregate.
Concrete	Cement-bound aggregate.
Grass	Natural grass grown from seed.
Hybrid clay	Clay-dressed systems supported by a carpet matrix.
Other	E.g., modular systems (tiles), wood, canvas.

Note. From: ITF (2019). *Abbreviation*. *ITF* International Tennis Federation, *E.g.* Exempli gratia (for example).

The ITF Court Pace Classification Program has been developed in 2000 to classify the courts around the world using a Court Pace Rating (CPR). The ITF has divided the court pace rating into five levels (see Table 2). The rating of one court surface is usually done using a sample piece of the court in a lab setting and has therefore no information about the different locations and tournaments. Many factors next to the primary court type, like the top court or the underlying surface can influence the speed (ITF, 2019).

Table 2: The five Court Rating Categories.

Court Pace Rating		Speed
Category 1	Slow	≤ 29
Category 2	Medium-slow	30-34
Category 3	Medium	35-39
Category 4	Medium-fast	40-44
Category 5	Fast	≥ 45

Note. From: ITF (2012).

The Court Pace Index on the other hand is calculated from the velocity recorded before and after the bounce (coefficient of friction and coefficient of restitution) using a specific system. It uses data tracked during the matches and can therefore determine the speed of one tournament (Merklin, 2021). The Coefficient of restitution (COR) has already been used by Newton and Wren in the sixteen hundreds and describes the “bounciness” of a ball, meaning the ratio of the ball's vertical velocity just after hitting the ground to its vertical velocity just before its impact with the ground. The Association of Tennis Professionals has defined specific requirements for the COR. The Coefficient of friction (COF) characterises a court's surface roughness (ITF, 2012).

Professional and recreational tennis players play most often on hard courts, clay courts or grass courts (Miller, 2006). Since the court can influence the speed of the ball, it has an impact on the speed of the game as well. The match's technical elements will therefore be influenced as well which influences the risk of injury (Martin & Prioux, 2015).

Method

Protocol and registration

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al., 2021) and the Cochrane Handbook for Systematic Reviews developed by the Cochrane Collaboration (Higgins et al., 2022) was followed. The PRISMA checklist is presented in Appendix C. As there are no participants recruited for this review, no ethical testing was necessary (see Appendix D). The review will not be registered.

Eligibility criteria

To define the inclusion and exclusion criteria for this systematic review, the (Population, Exposure, Comparison, Outcome and Study design) framework were used (see Table 4).

Table 3: Inclusion/exclusion criteria for this review.

	Inclusion criteria	Exclusion criteria
Population	Tennis players of all playing levels and age	-
Exposure	Single or double tennis match play according to the ITF, ATP or WTA	Tennis played under modified rules Wheelchair tennis or table tennis
Comparison	Court surface (hard, clay, grass)	Focus on carpet surface
Outcome	Injury rate in the lower extremity; frequency of lower extremity injuries; incidence rate; Anatomical location of lower extremity injuries	Data related to injuries of the trunk and the upper extremities
Study design	Prospective or retrospective Cohort studies, cross-sectional studies, case-control studies	No full text available, editorials, notes, letters, case reports and reviews

Abbreviations. ITF International Tennis Federation, *ATP* Association of Tennis Professionals, *WTA* Woman's Tennis Association.

The search was restricted to English and German articles, published after 1968. This year has been chosen as it marks the beginning of the Open Era in tennis which allowed professional players to compete with amateurs and is the ongoing era today.

Information sources and search strategy

A systematic search of publications was conducted in March 2023 in the bibliographic databases PubMed, CINAHL (via Ebsco), and SPORTDiscus (via Ebsco) by one reviewer. The reason for selecting these three databases is their comprehensive coverage of biomedical (PubMed), rehabilitation (CINAHL) and sports medical (SPORTDiscus) sources (LibGuides, 2017), making them highly relevant to injury prevention research.

The search strategy included different combinations of the following terms: tennis, lower limb injuries, court surface, and epidemiology. All key search terms were searched independently and then combined (Higgins et al., 2022). To find additional studies, a backward citation search was conducted by scanning through bibliographics from included articles. All studies selected for analysis were already published, therefore no ongoing studies are included.

Table 4: Search strategy according to the focused question (PECO).

Database	**Search equation**
PubMed	tennis [MeSH Terms] AND ((lower limb [MeSH Terms]) OR (ankle injuries [MeSH Terms]) OR (foot injuries[MeSH Terms]) OR (leg injuries[MeSH Terms]) OR (knee injuries[MeSH Terms]) OR (athletic injuries[MeSH Terms]) OR (sport medicine[MeSH Terms]) AND OR (occurrence)) OR (prevalence)) OR (incidence)) OR (trend)
CINAHL and SPORTDiscus	Tennis AND Court surface OR playing surface OR hard OR clay OR grass OR acrylic
SpringerLink	(title contains: (tennis)) AND (Epidemiology OR incidence OR injury)

The Boolean Operator "AND" was used between population and exposure to ensure the inclusion of both, and "OR" was used between alternative terms. The entire search strategy for all databases can be found in Appendix E.

Study selection process

Articles were purged of duplicates and then checked for eligibility. The inclusion criteria specified that the articles had to have been published within the last 35 years (from 1968 to 2023) and include the frequency of lower extremity injuries per court surface for the results to be chosen.

The chosen abstracts were obtained in full text after the data had been screened, the extract had been obtained, and the inclusion criteria had been checked. Articles, where the title and abstract did not provide enough information about the inclusion criteria, were obtained in full texts. In the case where they met the inclusion criteria, full-text articles were selected.

Data collection process and data items

A single reviewer collected information about the characteristics of the studies that were included in the review. The authors of those studies were not asked for any additional information.
To provide a convenient side-to-side view, this information was subsequently distilled and presented in a comparison table. The following data were extracted from the included articles for further analysis: name of the first author; the year of publication; study location; study design; study population; age; sex; court surface; injury classification; injury definition; duration of injury surveillance; exposure type; the number of injuries and incidence rate with 95% Confidence interval of each study. As far as possible, total injury in absolute numbers, frequency of injury and injury rate were extracted. If absolute numbers were missing, they were calculated using the incidence rate and information about total injuries and athletic exposure or sets/time played.

Selection of sources for methodological quality assessment

One author assessed the studies' quality using the Strengthening the Reporting in Observational Studies in Epidemiology (STROBE) guideline for cohort, case-control, and cross-sectional studies. The STROBE checklist has been developed to improve the reporting of observational research. It consists of a total of 22 items including title, abstract, introduction, methods, results, and discussion. As there is no grading system available, there is no number linked to a quality grade. Still, the STROBE checklist gives an overview of the strengths and weaknesses of the included studies and is commonly used in studies about observational research in the field of epidemiology (Vandenbroucke et al., 2014). The tool has been chosen as it covers cohort studies as well as cross-sectional study designs in one tool regardless of the statistical methods used.

As traditional criteria lists for assessing the risk of bias within the included studies are not appropriate due to the cohort and cross-sectional design of the studies, a thorough search has been conducted to find a matching tool. Wang et a. (2019) aimed to describe and evaluate published tools that assess the methodological quality or risk of bias in observational human studies assessing the effects of exposure. They were not able to name a common tool. Therefore, they formulated the following take-home messages about the tools being used: the tool used should provide clear definitions and openly explain the reasoning behind each domain. The tool should include questions related to 9 specific domains: selection, exposure, outcome assessment, confounding, loss of follow-up, analysis, selective reporting, conflicts of interest and others. Instead of providing an overall score, the tool should report ratings for each domain repeatedly. Lastly, the tool should be thoroughly tested for usability and reliability by independent parties (Wang et al., 2019). Based on this the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies published by the National Heart, Lung and Blood Institute (NHLBI) has been chosen as it was specifically designed for observational study designs. The tool assesses the risk of bias based on multiple domains, such as the participation rate, the inclusion/exclusion criteria, whether the time frame was sufficient or if there was a follow-up (NHLBI, 2021). The tool has a guidance tool which provides details descriptions and examples of how to use the tool. Every item is evaluated with "yes", "no" or "cannot determine/not reported/not applicable". The reviewer Is instructed to assess the potential risk of bias that could arise from any flaws in the study design or implementation for each item where "no" was chosen. The presence of "cannot determine/not reported/not" will also be noted as a potential flaw. A "good" study was considered to have the least risk of bias and produce valid results, while a "fair" study was deemed susceptible to some bias that did not invalidate its findings. Studies with "poor" ratings are studies where a significant risk of bias was found and should therefore be excluded from the evidence considered (NHLBI, 2021).

Effect measures

In this systematic review, the primary outcome is the incidence of lower extremity injuries on different court surfaces. The secondary outcome is the location of the injuries to determine whether the court surfaces influence the location where injuries occur in the lower extremities. To present and synthesize the results, absolute numbers of injuries as well as the incidence rate (IR) and the frequency of numbers (%) were the effect measures used in this review. The incidence rate is a measure of the number of new cases of injuries over a given period, usually expressed as a rate per 1000 athletic exposure or 100 played hours. The risk rate ratio (IRR) was used to compare the risk of injury between the different courts.

If no absolute number of injuries was given, the expected number of events can be estimated from the incidence rate and the total exposure time (e.g., athletic exposure or hours played). The equation to calculate the expected number of events is:

$$expected\ number\ of\ events = \frac{incidence\ rate\ \times total\ number\ of\ AE}{1000}$$

This calculation assumes a constant incidence rate over the study period and may be affected by factors such as a change in exposure or the introduction of new preventive measures. Expected numbers of events will be rounded to the nearest whole number and will be labelled when used (LaMorte, 2022; Rothman et al., 2008). If the article categorizes injuries into those which are chronic (pre-existing before the study started) or acute (occurring during the study's period), the acute numbers will be used as they represent more likely the occurrence of injuries influenced by the court surface.

Data synthesis

First, the characteristics will be listed in a table. Then the data will be extracted by the outcome. The studies will be analysed using a narrative synthesis approach, focusing on the incidence rate and the frequency of lower extremity injuries across clay, hard and grass courts as well as the anatomic location in which these injuries occur.

Certainty assessment

According to the recommendation of the Cochrane Handbook for the Grades of Recommendation, Assessment, Development and Evaluation Working Group (GRADE Working Group), the approach will be used to assess the certainty of the evidence. The GRADE approach included five factors: risk of bias, inconsistency, imprecision, indirectness, and publication bias. At the starting point, it is assumed that the combined or overall results are of high quality. However, as the evidence will be reviewed, the quality will be lowered by 1 or 2 levels, resulting in a rating of moderate, low or very low depending on inconsistency, publication, indirect results, inconsistency or risk of bias (Balshem et al., 2011). In Appendix J, a summary of the GRADE approach to rating the quality of evidence is displayed.

Results

Study selection

The electronic literature search generated 506 references: 191 in PubMed, 131 in CINAHL and 84 in SPORTDiscus. After excluding duplicates and screening the title and abstract, 35 papers remained. Two articles were retrieved through a backward citation search. After the full-text screening, a further 30 articles were excluded due to lack of relevance, leaving 7 articles for the review. The literature screening process is presented in Figure 1.

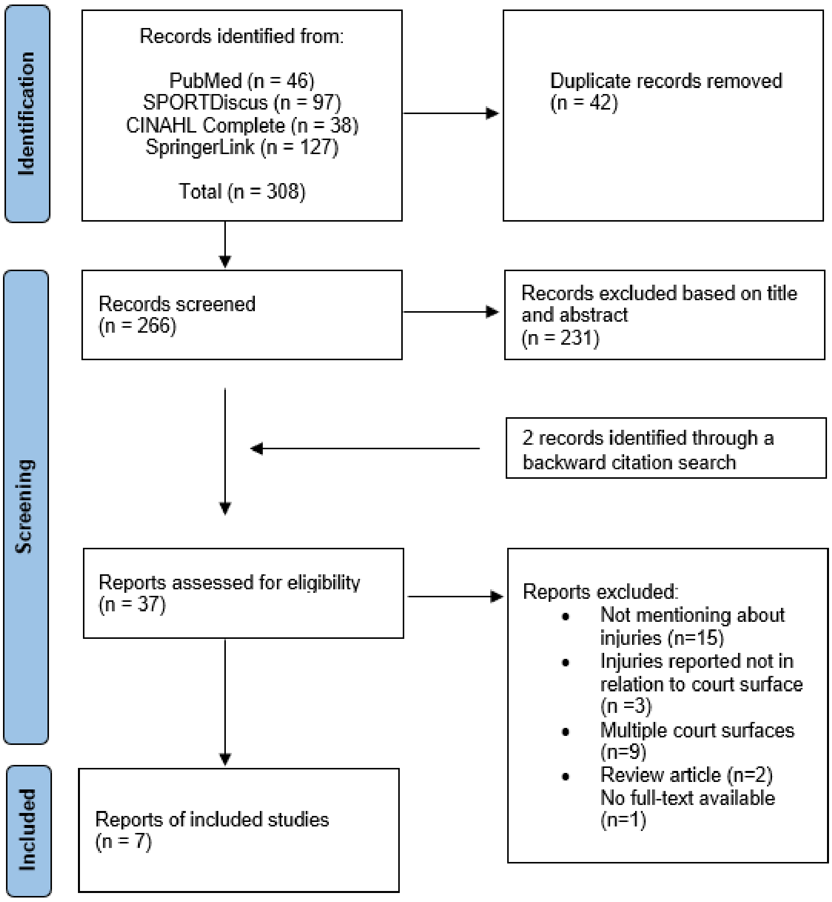


Figure 1: Flow chart of the screening process.

Note. Adapted from: Page et al., 2021.
Abbreviations. *ATP* Association of Tennis Professionals, *ITF* International Tennis Federation, *WTA* Woman's Tennis Association.

Characteristics of the included studies

A total of 7 articles were selected, of which 6 are cohort studies (Hutchinson et al, 1995; Sell et al., 2014; Maquirriain & Baglione, 2016; McCurdie et al., 2017; Moreno-Perez et al., 2019; Abadi et al., 2021) and one study in conducted in a cross-sectional design (Pluim et al., 2018). Out of these, 5 studies are in prospective design (Hutchinson et al, 1995; Sell et al., 2014 Pluim et al., 2018; Moreno-Perez et al., 2019; Abadi et al., 2021) and two in a retrospective design (Maquirriain & Baglione, 2016; McCurdie et al., 2017). The characteristics of the included articles are presented in Table 5.

Table 5: Characteristics of the interventions of the studies analysed.

Study No.	Author	Country	Journal (LTWA) & Year	Study design	Injury definition	Injury classification (n° of categories/ groups)	Duration of injury surveillance	Participants (n=)	Exposure type	No. of injuries (n=)	Incidence rates (CI 95%)
1	Hutchinson et al.	USA	MSSE (1995)	P Cohort	All injuries that required physical or medical assistance	Anatomic regions (17) Injury type (9) Onset (2) Ability to return to play	6 tournaments in 6 years	1440 participants at the ISTA Boys National Championships 1986-1988; 1990-1992	AE Participants	304	18.5/100 players 37/1000 AE
2	Sell et al.	USA	BJSM (2014)	R Cohort	Any injury that required medical evaluation by the tournament physician	Location (6 main, 16 sub-groups) Type (6 main, 17 sub-groups) Illness classification (16)	16 years	N/A	ME	1219	9.31/1000 MEs (8.12-10.50)
3	Maquirriain & Baglione	Argen-tina	EJSS (2016)	R Cohort	Injuries that led to retirement	Injury type (6) Illness (16) Injury severity	8 years	N/A	N/A	12	6.05/100h
4	McCurdie et al.	UK	BJSM (2017)	R Cohort	All presentations of injury to the sports	Anatomic regions (16) Onset (2)	10 years	N/A	Sets	700	20.7/1000 sets (14.3-25.8)

					physician through the main draw period						
5	Pluim et al.	Netherlands	BJSM (2018)	P Cross-sectional	According to Pluim et al. Pluim et al. (2009)	Injury type (2) Injury location (3) Severity Need for medical care or time-loss	6 months	3656	Hours	4,047	7.87/1000 hours (7.32-8.41)
6	Moreno-Perez et al.	Spain	J. Sports Med. Phys. Fitness (2019)	P Cohort	According to Pluim et al. (2009)	Location (6 main, 16 sub-groups) Type (6 main, 17 sub-groups) Illness classification (16)	11 months (1 season)	162	Matches	199	1.03/1000 games 1.25/1000 hours
7	Abadi et al.	Indonesia	J. Sport Sci. Med. (2021)	P Cohort	According to Pluim et al. (2009)	Onset (3) Location of injury (4 + exact location) Type of injury (9)	5 weeks	161	Hours	36	30.8/100 hours (28.2-33.5)

Abbreviations. LTWA List of Title Word Abbreviations, *USA* United States of America*, N/A* Not Available*, P* Prospective*, R* Retrospective, *AE* Athletic exposure, *BJSM* British Journal of Sports Medicine, *EJSS* European Journal of Sports Science, *J Sports Med Phys Fitness* The journal of sports medicine and physical fitness, *J. Sport Sci. Med.* Journal of sports science & medicine, *MSSE* Medicine and science in sports and exercise, *R* Retrospective, *P* Prospective.

Methodological quality assessment

The mean reporting quality obtained with the STROBE quality scale was 22 (minimum: 15, maximum: 27) out of 34 possible points. In general, more recent studies had more information reported than older ones (published before 2016). The detailed data are presented in Appendix I.

With regards to the risk of bias assessment, all included studies are of moderate quality. All studies fulfilled more than 60% of the criteria, but only three Sell et al., 2014; Moreno-Perez et al, 2019; Abadi et al. 2021) No high-quality or low-quality studies are included. The risk of bias across the studies was overall considered to be moderate. Appendix F supplies the Quality Assessment Tool and Appendix G shows the results. As a striking similarity, none of the included studies has indicated the study design in their title and in the studies designed with in a cohort design, no follow-up was conducted. Funding has not been mentioned in the studies.

Results of individual studies

Table 6: Studies reporting Lower Extremity Injuries by Court Surface.

Author (Year)	Participants number (n=)	Exposure	Injuries number (n=)	LE Injuries number (n=)
Hard court				
Hutchinson et al. (1995)	1440	6648 AE	304	71
Sell et al. (2014)	N/A	N/A	1219	583
Maquirriain & Baglione (2016)	N/A	N/A	9	4
Pluim et al. (2018)	N/A	19,799 hours	157	91
Moreno-Perez et al. (2019)	167	3,438 matches 90,912 games	71	29
Abadi et al. (2021)	161	1167.7 hours	36	12
Clay				
Maquirriain & Baglione (2016)	N/A	N/A	3	1
Pluim et al. (2018)	N/A	25,317 hours	205	121
Moreno-Perez et al. (2019)	167	4,601 matches 15,479 games	128	39
Grass				
McCurdie et al. (2017)	N/A	12,212 sets	700	336

Abbreviations. *LE* Lower Extremity, *AE* Athletic Exposure, *N/A* Not Available, *n* number.

Incidence rate

Table 7: Incidence Rate of Lower Extremity Injuries across Hard, Clay and Grass Court.

Author	Injuries per 100 athletes	Injuries per 1000 games	Injuries per 1000 hours	Injuries per 1000 sets	Injuries per 1000 AE
Hard court					
Hutchinson et al. (1995)	4.9	N/A	N/A	N/A	10.7
Sell et al. (2014)	N/A	N/A	N/A	N/A	23
Pluim et al. (2018)	N/A	N/A	4.6	N/A	N/A
Moreno-Perez et al. (2019)	N/A	0.26	N/A	N/A	N/A
Abadi et al. (2021)	N/A	N/A	10.3	N/A	N/A
Clay court					
Pluim et al. (2018)	N/A	N/A	4.78	N/A	N/A
Moreno-Perez et al. (2019)	N/A	0.42	N/A	N/A	N/A
Grass court					
McCurdie et al. (2017)	N/A	N/A	N/A	9.94	N/A

Abbreviations. AE Athletic Exposure, *N/A* Not Available.

Frequency of Lower extremity injuries

Figure one displays the distribution of lower extremity injuries across various studies, categorized according to the court surface: grass, clay, and hard court. The percentage of lower extremity injuries on each surface can be found in Figure 2, sorted by author. In Appendix M, the data can be found sorted by court surface.

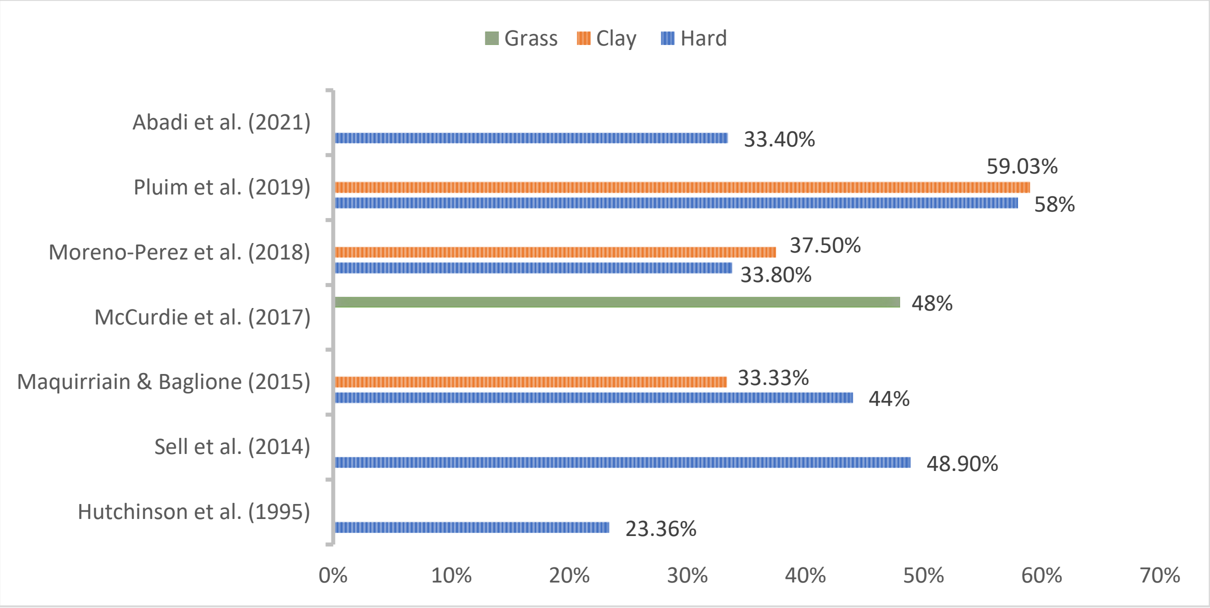


Figure 2: Frequency of Lower Extremity Injuries Across the Studies.

Lower Extremity injuries by anatomical regions

Table 8 displays the distribution of 670lower extremity injuries that occurred on hard court, categorized by anatomical regions.

Table 8: Lower Extremity Injuries by Anatomical Regions on Hard Court.

Body region	Hutchinson et al. (1995)	Sell et al. (2014)	Maquirriain & Baglione (2015)	Abadi et al. (2021)	Total (n)
Hip/groin	11	72	1	0	84
Thigh	26	74	1	6	108
Knee	3	166	1	1	171
Lower leg/AT	3	30	0	1	34
Ankle	10	117	1	1	129
Foot/toe	16	124	0	3	143
Total LE	71	583	4	12	670

Abbreviations. AT Achilles Tendon. *LE* Lower Extremity.

Results of syntheses

Across 7 studies, there were 670 lower limb injuries. Three articles report the gender of the participants (Hutchinson et al., 1995; Moreno-Perez et al., 2019; Abadi et al., 2021). Out of this sample, only 6.47% are female and 93.53% are male (see Appendix L). Three studies report on professional tennis tournaments, the US Open (Sell et al., 2014), the Championships, Wimbledon (McCurdie et al., 2017) and the Davis Cup (Maquirriain & Baglione, 2016). Two studies report on junior, elite tennis players (Hutchinson et al., 1995-2021) and one study analyses injury rates in recreational tennis players (Pluim et al., 2018) over 49 years (see Appendix L).

Incidence rate

Five studies (Hutchinson et al., 1995; Sell et al., 2014.; Pluim et al., 2018; Moreno-Perez et al., 2019; Abadi et al., 2021) have reported incidence rates specifically for injuries sustained on hard court surfaces, with rates ranging from 10.7 to 23 injuries per 1000 AE and 4.6 to 10.3 injuries per 1000 hours played. Hutchinson et al. (1995) reported an incidence rate of 10.7 injuries per 1000 AE, while Sell et al. (2014) found a higher incidence rate of 23 per 1000 AE. Pluim et al. (2018) reported an incidence rate of 4.6 injuries per 1000 hours of play, while Abadi et al. (2021 found a higher incidence rate of 10.3 injuries per 1000 hours of play. In terms of injuries per 100 athletes, Hutchinson et al. (1995) reported an incidence rate of 4.9. Moreno-Perez found an incidence rate of 0.26 injuries per 1000 games. According to Pluim et al. (2018), the incidence rate of injuries on clay court is 4.78 per 1000 hours of play, while Moreno-Perez et al. (2019) reported an incidence rate of 0.42 per 1000 hours played. McCurdie et al. (2017) reported an incidence rate of 9.94 injuries per 1000 sets on grass court.

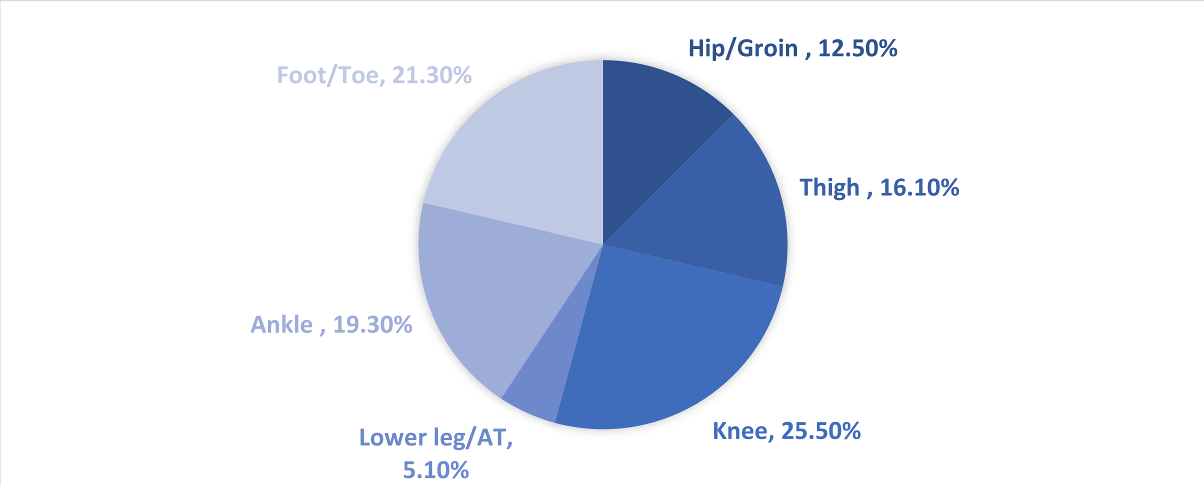
Frequency of injury across the court surfaces

All seven included studies were able to present a frequency of lower extremity injuries ranging from 23.36% to 58%. Overall, the mean injury frequency is 40.23% for hard courts, 43.28% for clay courts, and 48% for grass courts. Lower extremity injuries on hard court have been reported to occur with a frequency ranging from 23.36% to 58%, with an average frequency of 41.9%. On clay courts, the frequency ranged from 33.33% to 59.03%, while on grass courts it was reported to be 48%.

Anatomic location of injuries on hard court

Out of the studies available, four studies (Hutchinson et al., 1995; Sell et al, 2014; Maquirriain & Baglione, 2015; Abadi et al., 2021) reported the incidence and anatomical location of lower extremity injuries on hard court. These studies yielded a total of 670 lower extremity injury cases. The most affected areas were the knees, accounting for 25.5% of all lower extremity injuries. The foot region was in 21.3% of the cases injured, followed by the ankle with an injury frequency of 19.3%. Thigh injuries made up 16.1% of the injuries in the lower extremities while hip/groin injuries (12,5%) and lower leg/Achilles tendon (5.1%) both accounted for comparatively small injuries.

Figure 3: Frequency of injury by anatomical regions on hard court.



Certainty of evidence

The quality of evidence according to GRADE was downgraded to moderate for the articles reporting on lower extremity injury rates on hard court. The articles reporting on lower extremity injuries on clay courts are considered to be of low quality as well as the evidence for grass courts. When analysing the anatomical location of injuries on hard come, the articles are considered to be of moderate quality. Overall, the included evidence was downgraded due to inconsistency, risk of bias and indirectness. The detailed GRADE scale is presented in Appendix K.

Discussion

This systematic review sought to compare lower extremity injury rates across hard, clay and grass court among professional and recreational tennis players and to examine whether the location of lower extremity injuries differs depending on the court surface. The available data were analysed to determine whether the evidence supports a relationship between court surfaces and lower limb injuries.

Injury incidence and frequency

In most epidemiological studies of tennis lower extremity injuries occur nearly equal to or exceed upper limb injuries (Pluim et al., 2009). The findings of this systematic review suggest that grass courts have the highest frequency of lower extremity injuries, while hard courts have the lowest frequency. Multiple possible reasons for such differences related to court surfaces have been proposed in the literature.

The grass is one of the faster surfaces to play on, with a COR of 0.77 and a CPT value of 46 (Miller et al, 2006; Brody et al.; 2003). As a result of these characteristics, the player will have a shorter amount of time to reach the ball and prepare for their shot (Brody, 2003). This shortened reaction time can lead to physical exertion, increase the potential for awkward movements or falls and might explain the high injury rate on grass courts.

The frequency of lower extremity injuries on clay court seems to be higher than on hard court (see table M). This trend is also pictured when looking at the incidence rates across the studies. Pluim et al. (2018) found a 3.91% increase in injury rate on clay courts compared to hard courts, while Moreno-Perez et al. (2019) found a 3.8% increase in injury rate. Clay court is characterized by a higher COR (0.86) and a COF (> 0.71). The clay court surface is a slow surface (CPR=23) (Martin & Prioux, 2015). Traditionally, it has been suggested that the ability to slide on clay might reduce the risk of sudden stopping and overloading that can occur on hard courts (Starbuck et al., 2017), therefore it has been suggested that lower extremity injuries occur more prevalent on the hard court than on clay court. Still, some factors might explain why the frequency of lower limb injuries seems to be higher on clay courts than on hard courts. It has been suggested that sliding on clay courts can lead to increased muscle activity, which may explain the greater physiological response observed on clay courts (Pavailler & Horvais, 2015). Additionally to that, prolonged sliding with a low coefficient of friction between shoes and the surface may result in increased physiological demands (Starbuck et al., 2017). Girard et al. (2007) on the other hand have suggested that the lower frictional resistance on clay courts leads to reduced stress on joints and therefore a lower likelihood of sustaining lower extremity injuries compared to hard court.

The hard court has presented with the lowest frequency of lower extremity injuries in this review. As they have different ways of being constructed (E.g., concrete or asphalt), the COR values are ranging between 0.79 and 0.84, the COF values are between 0.56 to 0.70 and the CPR can be found between 35 to 39, which is considered to be a medium speed (Martin & Prioux, 2015). On hard court, rallies are shorter and less intense than on clay court (Girard and Miller, 2004) which might explain why the incidence of lower extremity injuries seems to be the lowest on hard court.

The consensus statement recommends presenting incidence rates in terms of the number of injuries per 1000 hours and 1000 games. However, none of the studies included in the analysis followed this recommendation. Only two studies published after the consensus statement (Pluim et al., 2018; Moreno-Perez et al., 2019) recorded instances of injuries over time. As not all studies worked with the hours played for defining exposure, it might be possible that the rally duration on the court surfaces influenced the results. Pluim et al. (2023) found an average rally duration for female and male players of 7.1 and 8.8 seconds and clay court, while the duration on the hard court was only 5.6 and 6.3 s and for grass court 4.3 and 5.7 seconds. Added to the characteristics mentioned before, these match characteristics might explain why the injury rates are higher on clay courts than on the hard court.

Anatomical location of lower extremity injuries

Due to the paucity of sources, the examination of the most frequently injured anatomical region was limited to hard court surfaces. The results indicate that the knee, foot/toe, and ankle are the most commonly injured body regions on hard court, accounting for 25.5%, 21.3% and 19.3% of the lower limb injuries, respectively. It is worth noting that the frequency of injuries in each body region varies among the studies included in this analysis. For example, Sell et al. (2014) reported a higher frequency of injuries in the thigh region, while Hutchinson et al. (1995) reported a higher frequency in the hip/groin region. This variability in findings might be due to differences in sample size, player characteristics and other factors that were not accounted for.

The knee seems to be at the highest risk to obtain injuries in the lower extremities when playing on hard court. More than a quarter of the lower extremity injuries in the assessed studies occurred in this anatomical region. This might be due to the characteristics of the hard court. Hard court is a medium-fast court surface. This requires rapid changes in direction and high acceleration/deceleration rates. It has been shown, that these movements can strain muscles and tendons. Especially cutting tasks on high-friction surfaces result in lower knee flexion angles, increasing the risk of anterior cruciate ligament injuries (Yu & Garrett, 2007; Dowling et al., 2010). Activities that require rapid changes in direction and high acceleration/deceleration rates can strain muscles and tendons, while cutting tasks on high-friction surfaces can result in lower knee flexion angles, increasing the risk of anterior cruciate ligament injuries (Dowling et al., 2010). Lower knee flexion has been proven to increase the risk of anterior cruciate ligament injuries (Yu & Garrett, 2007; Brukner et al., 2017).

Around 21% of the injuries occurred in the foot area and 19% in the ankle. Research has shown that injuries involving blocking movements, such as strains in the ankle or knee, are most likely to occur on hard surfaces. This can be explained when looking at the characteristics of sudden ankle inversion sprains. They are deemed to be a result of fixation of the foot, which occurs on surfaces with a high COF (Newton et al., 2002). Another reason for a high frequency of injuries in the foot and ankle region can be the loading in the foot that occurs while playing on hard court. Hard courts have been shown to increase the loading on the lateral parts of the foot which is thought to increase the risk of ankle inversion as less force is needed to invert the ankle (Willems et al, 2005; Girard et al., 2007).

Since the distribution of injuries across the anatomical locations has only been analysed on hard court, no conclusion regarding the influence of the court surface can be drawn as there is no comparison.

Strengths and Limitations

This review supplies the first overview of lower extremity injuries in tennis. The evidence considered in this study covers multiple tournaments and different countries, which enhances the generalizability of the findings and reduces potential biases. This study primarily focuses on acute injuries in male professional tennis players, providing a comprehensive overview of the literature on this subject. However, the several limitations of the studies included should be considered when interpreting the results.

Firstly, the distribution of the study sample across the court surfaces varied a lot. The participant number ranged from 161 participants (Abadi et al., 2021) to 3320 participants (Pluim et al., 2018). This might influence the generalizability of findings, as these limits the participants per court surfaces in some studies. Additionally, only one article (Pluim et al., 2018) focused on recreational tennis players, limiting our understanding of injury patterns in this population. Moreover, older studies had variations in injury and severity definitions, resulting in inconsistencies in the reported incidence rates of tennis injuries. Only acute injuries were included in the analysis, neglecting the impact of repetitive stress on courts, which can lead to significant overuse injuries. The reported incidence rates of tennis injuries to varying due to several factors such as injury definition, study design, population under study, and data collection methods. Lastly, no data was available on other modifiable risk factors or confounding factors. The previous sections have shown how fictional characteristics, speed etc. influence the game and can therefore contribute to tennis injuries.

To deter a reporting bias, the PRISMA guideline as well as the Cochrane Handbook for systematic reviews were used as a guide when writing this systematic review. The assessment of quality was limited, as there are no validated checklists for observational studies. The risk of bias has been judged to be moderate across all studies. This might be due to the study design. Randomized-controlled trials are considered to be the most reliable form of evidence in evidence-based medicine. However, RCTs were initially designed for drug trials and can pose challenges when conducting research in epidemiology (Song and Chung, 2010). Only already published data was used. Only half of the studies ever conducted are published, often only when presenting positive/statistically significant results. Therefore, a publication bias should be considered.

Implications

Based on the findings, a few implications for practice can be made. The most important is education. Coaches, athletes, and referees as well as physiotherapists and physicians working in tennis should be aware of the properties the court surfaces present. The athlete should know how to safely use and navigate different court surfaces. A proper warm-up can be important to reduce the risk of injuries. Additionally to that, suitable footwear is an important factor influencing the friction between foot and court and should therefore be considered to adapt to the court surface playing on. Especially on clay courts, where friction plays an important role, the choice of shoes is important. On hard court, injury prevention efforts should be focused on the knee and the foot/ankle regions. When reading about incidence rates, it is important to understand the different metrics and to be able to differentiate between the reported injury rates. Validated methods for monitoring workload and extended reporting and monitoring of injuries on various tennis court surfaces are necessary. Technology advancements can potentially aid in future studies, building upon existing research in other sports.

To be able to identify the risk of injury for lower extremity injuries across the court surfaces and then develop proper injury prevention programmes further research is needed. When conducting this research, it is important to attempt to employ standardized injury incidence metrics to provide more reliable comparisons between studies and to better inform injury prevention efforts in the sport of tennis. The Consensus statement developed by Pluim et al. in 2009 should be used with the extension made by the International Olympic Committee in 2020.

Especially on national and regional levels should be researched as most previous research focus on professional tennis players, with a particular emphasis on gathering more data on female players due to the current imbalance in available information. To be able to analyse research in this field, more details are needed. The court characteristics seem to influence the risk of injuries, only that higher CPR does not mean more injuries. There is a need for research to understand the correlation between CPR and injury rate. Researchers should try to report injuries with the date, type, and duration of each exposure together with the playing/training court surface used. Overall, it is important to prioritize high-quality research that can contribute to the development of effective injury prevention strategies. To reduce the risk of recall bias, studies should employ a prospective study design.

Conclusion

Tennis players are at substantiated risk of experiencing lower extremity injuries while playing on any type of court. Lower extremity injuries seem to occur most often on grass courts, followed by clay courts and hard courts. According to the analysis of injury locations on hard court, the anatomical regions with the highest frequency of injuries seem to be the knee, the foot/toe area, and the ankle. The choice of shoes seems to be important in risk reduction when playing on clay court, while preventive work for playing on the hard court should be focused on knee, foot and ankle area training shock absorbing movements. Future studies should focus on using standardized injury incidence metrics and target more population groups, namely female and recreational tennis players.

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Appendices

Appendix A: List of tables

Appendix B: List of figures

Appendix C: PRISMA IPD Checklist

Table 9: PRISMA Checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	10
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	10
Search strategy	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	11, 39
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	11
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	11
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g., for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	11
	10b	List and define all other variables for which data were sought (e.g., participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	11
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	11
Effect measures	12	Specify for each outcome the effect measure(s) (e.g., risk ratio, mean difference) used in the synthesis or presentation of results.	12
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g., tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	13

	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	13
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	13
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	13
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g., subgroup analysis, meta-regression).	-
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	-
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	-
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	13
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	14
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	-
Study characteristics	17	Cite each included study and present its characteristics.	14
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	17
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	17
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	19
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	19
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	-
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	-
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	-
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	20
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	21
	23b	Discuss any limitations of the evidence included in the review.	22
	23c	Discuss any limitations of the review processes used.	23
	23d	Discuss implications of the results for practice, policy, and future research.	23

OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	10
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	10
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	-
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	-
Competing interests	26	Declare any competing interests of review authors.	-
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	-

Appendix D: WMO testing flowchart

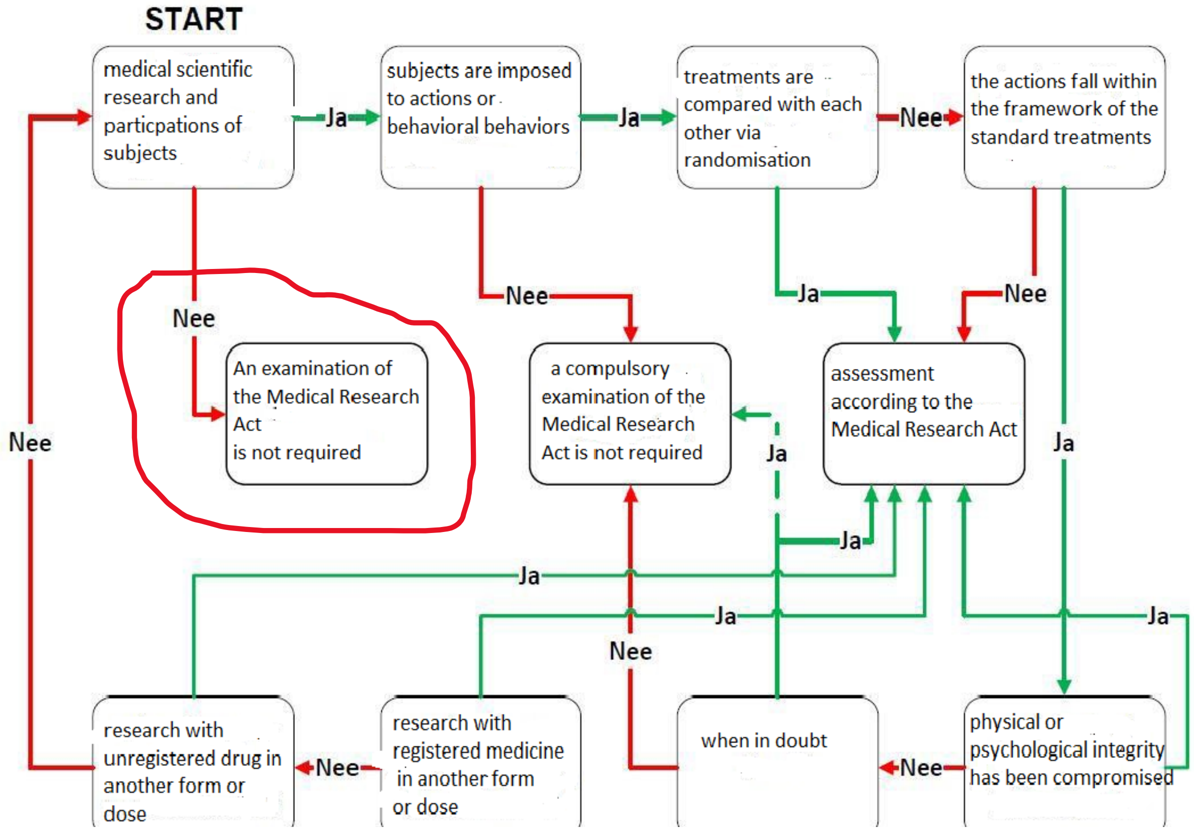

Figure 4: Ethical Testing Flowchart.

Appendix E: Search string

Table 10: Search strings sorted by Database.

PubMed	**20th of March 2023**	**#1**	**tennis [MeSH Terms]**
		#2	((court) OR (surface) OR (hard) OR (clay) OR (acrylic) OR (grass))
		#3	((lower limb[MeSH Terms]) OR (ankle injuries[MeSH Terms]) OR (foot injuries[MeSH Terms]) OR (leg injuries[MeSH Terms]) OR (knee injuries[MeSH Terms]) OR (athletic injuries[MeSH Terms]) OR (sport medicine[MeSH Terms]) OR (epidemiology[MeSH Terms]) OR (lower extremities[MeSH Terms]))
		#4	#1 AND #2
		#5	#4 AND #3
		#6	#3 OR (occurrence)) OR (prevalence)) OR (incidence)) OR (trend)
		#7	#4 AND #6
		#8	(((lower limb[MeSH Terms]) OR (lower extremities[MeSH Terms])) OR (leg[MeSH Terms]))
		#9	((((((injuries[MeSH Terms]) OR (athletic injuries[MeSH Terms])) OR (occurrence[MeSH Terms])) OR (prevalence[MeSH Terms])) OR (incidence[MeSH Terms])) OR (trend)) OR (epidemiology[MeSH Terms])
		#10	#8 AND #9
		#11	#10 AND #5
		#12	#8 OR #9
		#13	#4 AND #12
		#14	#13 Filters: Timeline 2003-2023
		#15	#13 Filters: Timeline 2003-2023, Article language: English, German
CINAHL and SPORTDiscus (via Ebsco)	21th of March 2023	#1	Tennis
		#2	Court surface OR playing surface OR hard OR clay OR grass OR acrylic
		#3	#1 AND #2
		#4	Epidemiology OR prevalence OR incidence OR statistics OR injury
		#5	#3 AND #4
		#6	#4 OR lower leg OR lower extremity
		#7	#3 AND #6
		#8	#7 Publication date between 2003 and 2023

		#9	#8 Language: English
			Exact duplicates removed from the results
			CINAHL: 97 SPORTDiscus: 38
SpringerLink	22th March 2023	#1	Title contains: (tennis)
		#2	#1 and with at least one of the words: (epidemiology, incidence, injury)
		#3	#2 exclude pre-view only content
		#4	#3 published between 2003 and 2023
		#5	#4 discipline: medicine & public health

Appendix F: Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies

Table 11: Quality Assessment Tool - Checklist.

1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?

11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

Appendix G: Risk of bias Assessment Outcomes

Table 12: Outcome Risk of Bias Assessment.

Study (year)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total present
Hutchinson et al. (1995)	Y	Y	Y	Y	N	Y	Y	N	Y	N/A	Y	N	N/A	N/A	8
Sell et al (2014)	Y	Y	NR	Y	N	Y	Y	Y	Y	CD	Y	N	N/A	Y	9
Maquirriain & Baglione (2016)	Y	Y	NR	Y	N	Y	N	Y	Y	N/A	Y	N	N/A	Y	8
McCurdie et al. (2017)	Y	Y	NR	Y	N	Y	Y	Y	Y	N/A	Y	N	N/A	Y	8
Pluim et al. (2018)	Y	Y	Y	N	N	N	Y	Y	Y	N/A	Y	N	N/A	Y	8
Moreno-Perez et al. (2019)	Y	Y	NR	Y	N	Y	Y	Y	Y	N/A	Y	N	N/A	Y	9
Abadi et al. (2021)	Y	Y	NR	Y	N	Y	Y	Y	Y	N/A	Y	N	N/A	Y	9

Abbreviations. *Y* Yes, *N* No, *N/A* Not Available, *CD* Can't Determine, *NR* Not

Appendix H: STROBE Checklist

Table 13: STROBE Checklist of Items.

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Note. From: von Elm et al. (2008)
Abbreviations. *No* Number.

Appendix I: STROBE Checklist Outcome

Table 14: STROBE Outcomes individual studies.

Study (year)	1a	1b	2	3	4	5	6a	6b	7	8	9	10	11	12a	12b	12c	12d	12e	13a	13b	13c	14a	14b	14c	15	16a	16b	16c	17	18	19	20	21	22	Score
Hutchinson et al. (1995)	-	+	+	+	+	+	-	+	-	-	-	+	+	+	+	-	-	+	-	-	-	+	-	-	+	-	-	-	+	+	-	-	-	-	15
Sell et al (2014)	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	-	+	+	-	-	+	-	-	+	+	+	+	-	+	+	+	-	-	22
Maquirriain & Baglione (2016)	-	+	+	+	+	+	-	+	+	+	-	+	+	+	+	-	-	+	+	-	-	+	-	-	-	-	+	-	+	+	-	+	-	-	19
McCurdie et al. (2017)	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	-	+	+	-	-	+	-	-	+	+	+	+	-	+	+	+	-	-	22
Pluim et al. (2018)	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	-	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-	26
Moreno-Perez et al. (2019)	+	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	-	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-	27
Abadi et al. (2021)	-	+	+	+	+	+	-	-	+	+	-	+	+	+	+	-	-	+	+	+	-	+	-	-	+	+	-	+	+	+	+	+	+	-	23

Appendix J: GRADE approach

Table 15: Summary of the GRADE's approach to grading body of evidence

Study design	Initial quality of a body of evidence	Lower if	Higher if	Quality of a body of evidence
RCT	High	Risk of Bias - 1 Serious - 2 Very serious Inconsistency - 1 Serious - 2 Very serious Indirectness - 1 Serious - 2 Very serious Imprecision - 1 Serious - 2 Very serious Publication bias - 1 Likely - 2 Very likely	Large effect + 1 Large + 2 Very large Dose response + 1 Evidence of a gradient All plausible residual confounding + 1 Would reduce a demonstrated effect + 1 Would suggest a spurious effect if no effect was observed	High (four plus) Moderate (three plus) Low (two plus) Very low (one plus)
Observational studies	Low			

Abbreviations. *RCT* Randomized Controlled Trail.

Appendix K: GRADE approach – summary of findings

Table 16: GRADE approach - summary of findings.

N° of studies	**Certainty assessment**					**Effect**			
	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	N° of events (injuries)	N° of individuals	Frequency of LE injuries (%)	Certainty
Injury incidence on hard court									
6 (Hutchinson et al., 1995; Sell et al., 2014; Maquirriain & Baglione, 2016; Pluim et al., 2018; Moreno-Perez et al., 2019; Abadi et al., 2021)	Observational studies	Serious	Very serious	Not serious	Not serious	1,796	N/A	40.23	Moderate
Injury incidence on clay court									
3 (Maquirriain & Baglione, 2016; Pluim et al., 2018; Moreno-Perez et al., 2019)	Observational studies	Serious	Very serious	Serious	Not serious	161	N/A	43.28	Low
Injury incidence on grass court									
1 (McCurdie et al., 2017)	Observational studies	Serious	Very serious	Serious	Serious	700	N/A	48	Low
Distribution of lower extremity injuries across anatomical locations on hard court									
4 (Hutchinson et al., 1995; Sell et al., 2014; Maquirriain & Baglione, 2016; Abadi et al., 2021)	Observational studies	Serious	Very serious	Not serious	Not serious	670	N/A	N/A	Moderate

Abbreviations. *N°* Number, *LE* Lower Extremity, *N/A* Not Available.

Appendix L: Participants details

Table 17: Details about Participants Across the Included Studies.

Author (year)	Sex			Level	Age
	Female	Male	Total		
Hutchinson et al. (1995)	-	1440	1440	Elite	16-and-under 18-and under
Sell et al. (2014)	N/A	N/A	N/A	Professional	N/A
Maquirriain & Baglione (2016)	N/A	N/A	N/A	Professional	N/A
McCurdie et al. (2018)	N/A	N/A	N/A	Professional	N/A
Pluim et al. (2018)	N/A	N/A	3320	Recreational	Average 49.3 years
Moreno-Perez et al. (2019)	43	119	162	Elite	114 x 16-20 years 23 x 21-25 years 15 x > 25 years
Abadi et al. (2021)	71	90	161	ITF ranked	Average 22 years

Abbreviations. *N/A* Not Available, *ITF* International Tennis Federation

Appendix M: Frequency of injuries across hard, clay and grass court surface

Table 18: Frequency of Lower Extremity Injuries across Hard, Clay and Grass Court Surfaces in Tennis.

Study	Frequency of lower extremity injuries		
	Hard court	Clay court	Grass court
Hutchinson et al. (1995)	23.36%	--	--
Sell et al. (2014)	48.9%	--	--
Maquirriain & Baglione (2015)	44%	33.33%	
McCurdie et al. (2017)	--	--	48%
Moreno-Perez et al. (2018)	33.8%	37.5%	--
Pluim et al. (2018)	58%	59.03%	--
Abadi et al. (2021)	33.4%	--	--
Mean injury frequency	40,23%	43,28%	48%