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Injury Occurrence and Localization in Tennis: Perspectives on Prevention and Physiotherapy

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Abstract: Injuries happens in sports involving human movement, with the heightened demands of the sport often correlating with increased injury risk. Tennis, in particular, presents notable challenges as the repetitive motions involved can lead to muscle imbalances and varying levels of strain across different parts of the body. In this narrative literature review, we included 69 studies with the aim of providing a comprehensive overview of tennis-related injuries and offering insights into physiotherapy interventions for prevention and recovery. The first part of our review is on the most prevalent tennis injuries and their anatomical localization. It is noteworthy that injuries predominantly occur during matches rather than in training sessions. These injuries span a wide range, encompassing both acute and chronic conditions, affecting various parts of the body. Notably, muscle-tendon injuries are common, with frequent occurrences in areas such as the thigh, ankle, knee, and shoulder. Furthermore, it is observed that men suffer from back injuries compared to women. In the subsequent section, we delve into specific body regions and their associated injuries in greater detail. Our analysis leads to the recommendation that tennis players should engage with physiotherapists early in their sports careers for injury recovery and mainly for prevention measures. Collaboration with physiotherapists can significantly mitigate the risk of injuries and enhance overall performance and longevity in the sport.

Keywords: Incidence, Performance, Epidemiology, Recovery, Genders

1. Introduction

Tennis imposes high aerobic and anaerobic conditioning demands while subjecting players to intense repetitive stress and high demands for long matches (Pluim *et al.,* 2023). Consequently, injuries arise both chronically from overuse and acutely from traumatic incidents, the latter being significantly more common (Fu *et al.,* 2018). Tennis is characterized by intermittent loading, alternating between high-intensity movements and rest periods (Fernandez *et al.,* 2006). Carboch et al. (2019) say that, average point duration is 5 s and player has less then 3 s to intercept the ball after his own shot. Within this time frame, a player covers a distance of 3 meters per stroke and approximately 8-12 meters during a single point (Fernandez *et al.,* 2009; Reid & Duffield, 2014). The most significant differences between genders in tennis lie in men's higher service speed, running speed, and larger court coverage (Chow *et al.,* 2003; Reid *et al.,* 2016). Tennis matches can last several hours, necessitating players to be well-conditioned as performance may decrease due to fatigue, which can increase injury risk (Pluim *et al.,* 2018).

Muscle fatigue occurs during prolonged matches (Martin et al., 2016) and affects player performance. Although Gescheit et al. (2015) argue that fatigue in long matches does not affect stroke speed, it decreases overall explosive lower limb movement such as sprints or jumps. Movement deceleration is a preventive mechanism by the human body to avoid injury—there are alterations in range of motion, biomechanical forces (Kovacs, 2006; Myers *et al.,* 1999), and reductions in metabolic and physiological functions (Kovacs, 2006). Girard et al. (2006) stated that explosive strength decreases post-match. During multi-hour tennis matches, maximal voluntary contractions decrease while leg stiffness increases (Ojala & Häkkinen, 2013). Reid & Duffield (2014) found that court movement gradually decreases during matches and subsequent days. Tennis matches impose substantial speed and strength loads on the lower limbs, and even a day of rest post-tournament is insufficient for restoring muscle extensor explosive properties (Ojala & Häkkinen, 2013). Player court movement is a crucial factor for proper stroke execution and overall game performance (Reid & Duffield, 2014).

Tennis players frequently encounter numerous injuries due to the game's demands, including the high racket speed and court movement. The injury types differ in recreational players compared to competitive players (Kaiser *et al.,* 2021). Unlike some other sports, tennis match durations are not restricted, often lasting several hours, during which injuries predominantly occur compared to training (Fu *et al.,* 2018; Lynalla *et al.,* 2016). The players are sometimes unable to finish their matches because of injuries and need to retire or withdraw (Néri-Fuchs *et al.,* 2023). Fu et al. (2018) reported an increased injury risk with longer match durations. This is correlated with court surface characteristics; longer matches typically occur on slower surfaces like clay (Fernandez *et al.,* 2006). Early specialization can be one of the risk factors in later stages of players life (Vasenina *et al.,* 2023). The occurrence of injuries is influenced by player fatigue, stroke technique, sports equipment, and court surface, with hard, fast surfaces having high friction coefficients and low shock absorption (Kekelekis *et al.,* 2020; Pluim *et al.,* 2018).

On hard, fast surfaces, there is greater demand on upper limbs due to higher ball speeds. Damm et al. (2014) stated that hard surfaces pose higher injury risks, with up to 75% of tennis injuries occurring on such surfaces, notably increasing injury incidence in the male professional circuit (Maquirriain & Baglione, 2016). Abrams et al. (2012) argued that hard and grass surfaces pose the highest injury risk compared to clay, where risks are lowest among all surfaces. A comparison between playing on hard and clay courts (Damm *et al.,* 2014) revealed greater pressure on the player's leg and shorter braking steps, resulting in increased force exertion. Increased leg pressures on hard courts elevate overuse injury risks. The demanding nature of the game is evidenced by elite players' use of slides on hard courts despite their high friction coefficient, which becomes an integral part of the game. Slow clay surfaces have lower friction coefficients and less adhesion, resulting in different movement and player body demands, with ball speed decreasing upon impact with the court surface. Changing court surfaces is also a risk factor, with higher injury rates observed among players switching surfaces compared to those playing exclusively on one surface (Pluim *et al.,* 2018). McCurdie et al. (2017) recorded that up to 61% of injuries in Wimbledon occurred before the tournament start. Wimbledon follows the French Open with a one-month gap, transitioning from clay to grass surfaces. Based on the literature review, we aim to analyse injuries in detail in professional and high-performance tennis.

2. Materials and Methods

2.1. Research Design

We followed a similar methodology outlined by Ferrari (2015), relevant literature was initially identified (November 2021 – January 2022 and in February 2024) via databases Scopus, Web of Science – Core Collection, WoS PubMed, and Google Scholar. Topics specific to tennis incidence and injury were searched through these databases. Only available full texts were considered. Additionally, relevant studies in Czech language were added, such as those authored by Pavel Kolar, who is considered one of the top physio specialists in the country and collaborates with top male and female professional tennis players and the national team. Some literature was inaccessible due to restricted access, and duplicates were removed. In total, we utilized 69 studies of the relevant literature (figure 1).

2.2 Data Analysis

We conducted data analysis and text processing on all available full texts. The paper was divided into sections reflecting common themes. The findings were separated into sections, each represented by a subsection: 1) most common tennis injuries and localization – to analyse the injury incidence, type and to obtain crucial data; and 2) specific body areas and in injuries detail – to provide deeper insight to the specific injuries and possible physiotherapy intervention.

3. Results and Discussion

3.1 Most common tennis injuries and localization

The areas of the spine (back), thighs, ankles, and shoulders are the most frequent sites of injuries in tennis (Di Giacomo *et al.,* 2016). Acute traumatic injuries are most commonly observed in the lower extremities, while chronic overuse injuries affect the upper extremities and trunk. Chronic injuries, resulting from repetitive microtrauma, significantly outnumber acute injuries. In the upper extremities, the elbow and shoulder regions are most commonly affected, typically in the form of tendon injuries such as tennis elbow (epicondylitis). Lower extremity issues often manifest as ankle sprains and knee injuries, specifically patellar tendinopathy or jumper's knee. The repetitive loads in tennis lead to muscular imbalances, necessitating preventive measures to reduce injury risk. In the ATP circuit in 2013, the most common injuries were in the spine region (26% of all injuries), followed by thigh muscles (13%), ankles (11%), and shoulders (10%).

3.1.1 Injuries in junior categories

The incidence of acute injuries among tennis players aged 11 to 14 reached 1.2 injuries per 1,000 hours of tennis, predominantly affecting the ankle and thigh regions (Pluim *et al.,* 2016). Chronic injuries in this age group particularly affected the knee, back, and shoulder areas. Additionally, the study found that approximately one-eighth of junior tennis players reported playing with pain every week, averaging 9.1 hours of training and 2.2 hours of match play per week. Up to 48% of participants reported three or more health issues, with respiratory tract inflammations being the most common (almost 60%), followed by gastrointestinal infections (9%) (Pluim *et al.,* 2016).

Hjelm et al. (2010) studied 55 players aged 12 to 18, with 39 experiencing 100 injuries. They reported injury rates of 1.7/1,000 hours of tennis for boys and 0.6/1000 for girls. In terms of injury localization, 51% affected the lower extremities, 24% the upper extremities, and 24% the trunk. Common injuries included ankle sprains, knee injuries, and back pain. Back pain often recurred throughout individuals' tennis careers. Boys predominantly experienced ankle injuries and back pain, while girls experienced back pain and knee injuries.

Over 40% of injuries were severe, resulting in more than 28 days of activity restriction. Players who sustained injuries played more hours of tennis and more singles matches per year than uninjured players. They spent 70% of their time on hard courts, where 70% of injuries occurred, with the remaining 30% on clay courts, indicating no significant association between court surface and injury incidence. In a long-term study (Gescheit *et al.,* 2019), boys and girls aged 13 to 18 playing junior tennis sustained 2.7 and 2.8 injuries per 1,000 hours of tennis, respectively. The most common injury sites were the lumbar spine and shoulder. Moreover, the study found that injury rates increased with age, with injury rates per 1,000 hours being 2.0 at age 13, 2.3 at 14, 2.2 at 15, 2.9 at 16, 3.0 at 17, and 2.9 at 18. During a season, Moreno-Perez et al. (2020) recorded 40 injuries in 15 junior tennis players with an average age of 17, with an injury rate of 3.5 injuries per 1,000 hours of tennis training.

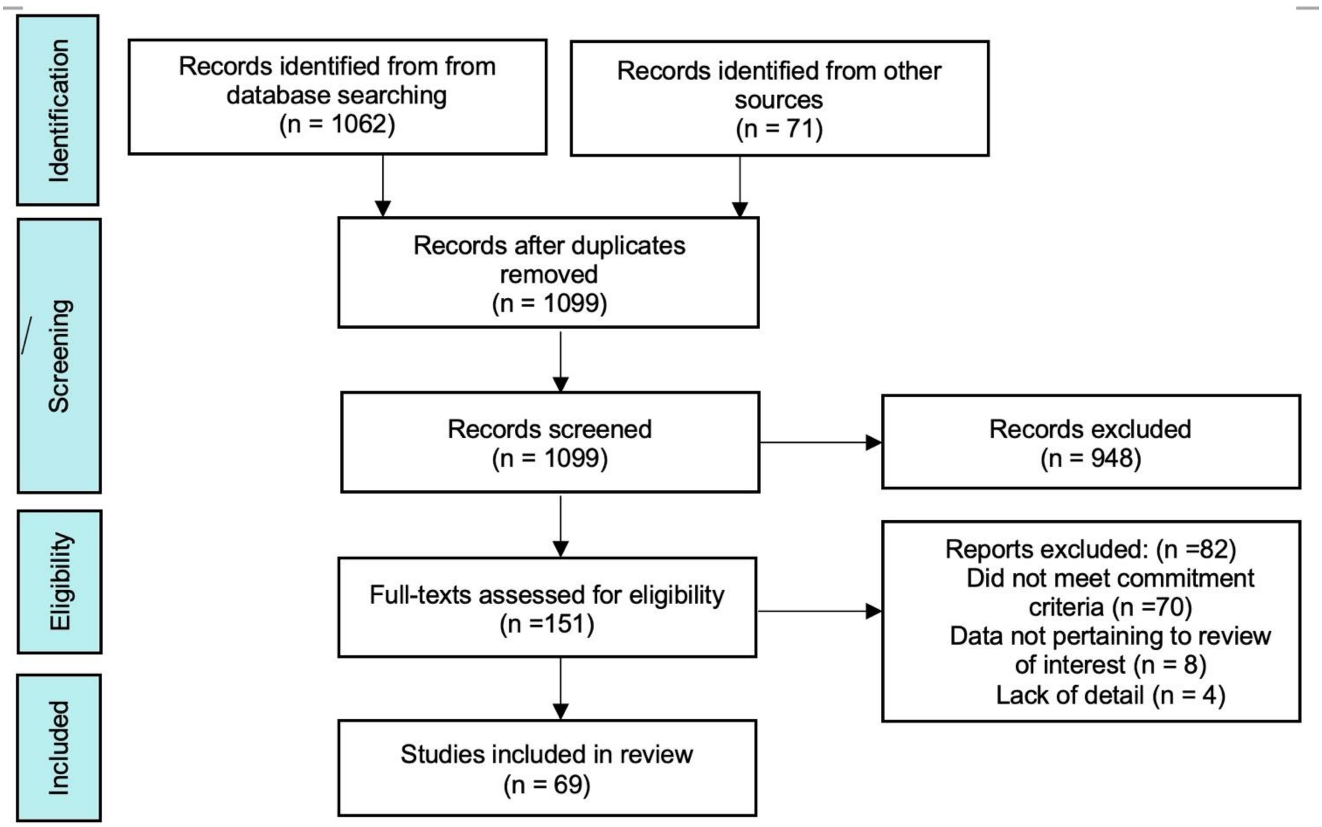

Figure 1 Flow chart of the literature selection process.

Most injuries required 8 to 28 days to heal. Approximately 50% of injuries involved ligaments, tendons, and bones, with 47.5% occurring in the lower extremities, particularly in the thigh area. Additionally, the lumbar spine and shoulder were commonly affected. The high number of lower extremity injuries may have been due to the extensive training hours, as players trained up to 35 hours per week.

3.1.2 Injuries in university tennis

Colberg et al. (2015) found that among 58 NCAA tennis players aged 18 to 21, the overall incidence of acute injuries throughout the season was 1.1/1,000 match hours. The highest injury occurrence was noted in the lower extremities, at 0.9/1,000 match hours, consistent with a study spanning 2009-2015 by Lynall et al. (2016) among collegiate tennis teams. Both genders experienced the highest number of injuries in the lower extremities, affecting men in 47% of all injuries and women in 52%. Upper extremity injuries followed, affecting men in 33% and women in 24%, with trunk injuries at 17% for men and 18% for women. Injury rates were similar for men and women, with more injuries occurring during matches than during training sessions. Valleser and Narvasa (2017) reported an average of 6 injuries per tennis player at an average age of 20. Of these, 39% were tendonitis (tendon inflammation), primarily affecting the shoulder, elbow, or knee; 32% were ankle sprains, and 22% were muscle strains in the hip, shoulder, or thigh.

3.1.3 Injuries in professional tennis

A study by Hartwell et al. (2017) in 2013 examined injuries and illnesses leading to withdrawals from professional tournaments in the USA that year. About 80% of health issues were injury-related, with muscle and tendon injuries occurring six times more frequently than other injuries. Women were up to four times more likely to sustain injuries on clay courts than on hard courts, particularly in the first half of the season. Overall, men had a higher injury rate than women. Data from Davis Cup matches from 2006 to 2013 showed only 12 match retirements out of 719 matches due to injuries, accounting for 1.7%. The overall injury rate was 6.1/1,000 match hours and 6.6/1,000 matches played, with 67% being muscle-tendon injuries and a higher prevalence of lower extremity issues than upper body issues. More matches were retired on hard courts than on clay courts, muscle cramps were not a reason for not finishing the match in any case (Maquirriain and Baglione, 2016).

Dakic et al. (2018) studied muscle-tendon injuries among WTA players in 2015, reaffirming their prevalence (50%) as reported by Maquirriain and Baglione (2016). The most common injury site remained the lower extremities (51%), especially the thigh, ankle, and knee, with the shoulder being the primary site of upper extremity injuries. From 2011 to 2016, injuries during the Australian Open were recorded, with women experiencing injuries more frequently than men. The dominant injury sites in women's tennis were the shoulder, followed by the leg, wrist, and knee, while men experienced knee, ankle, or thigh injuries. Generally, muscle injuries prevailed, although over the five years, stress fractures doubled in frequency during the tournament. During Wimbledon from 2003 to 2012, there were 21 injuries per 1,000 sets played, with 17.7/1,000 in men's and 23.4/1,000 in women's categories, consistent with findings from the Australian Open. Acute injuries predominated over chronic ones, with the shoulder, knee, and lumbar spine being the areas with the highest incidence of issues. The majority of injuries occurred in the lower extremities, ranging from 31-67%, followed by 20-49% in the upper extremities and 3-21% in the trunk (Abrams *et al.,* 2012; Maquirriain and Baglione, 2016; McCurdie *et al.,* 2017). Acute injuries like ankle sprains and chronic conditions like lateral epicondylitis were common, confirming the localization of acute issues in the lower extremities and chronic issues in the upper body (Abrams *et al.,* 2012). Data from the ATP circuit from 2012 to 2016 showed a gradual increase in injuries and a rise in spine-related issues. Lumbar spine injuries were the most common on the ATP circuit, followed by ankle, thigh, and shoulder injuries.

3.1.4 Injuries in tennis and their localization (summary)

In tennis, injuries predominantly occur during matches (Fu *et al.,* 2018; Lynall *et al.,* 2016). Acute injuries prevail over chronic overuse injuries, as indicated by previous studies (Di Giacomo et al., 2016; Fu *et al.,* 2018; McCurdie *et al.,* 2017). Acute injuries commonly affect the lower extremities, while chronic overuse injuries predominantly affect the upper extremities and trunk, with lower extremity injuries being more frequent than upper body injuries (Abrams *et al.,* 2012; Colberg *et al.,* 2015; Dakic *et al.,* 2018; Di Giacomo *et al.,* 2016; Lynall *et al.,* 2016; Maquirriain and Baglione, 2016; Moreno-Peréz *et al.,* 2020; Pluim *et* *al.,* 2016). The predominance of acute injuries is also associated with the dominance of muscle-tendon injuries (Dakic *et al.,* 2018; Hartwell *et al.,* 2017; Maquirriain and Baglione, 2016; Moreno-Peréz *et al.,* 2020).

Regarding injury occurrence between genders, results are inconsistent. Lynall et al. (2016) report nearly identical injury frequencies for both genders. However, Gescheit et al. (2017), Maquirriain and Baglione (2016), and McCurdie et al. (2017) found more frequent injuries among women. Conversely, Hartwell et al. (2017) reported a higher injury rate among men. Similarly, in junior categories, boys had a higher incidence of injuries than girls (Gescheit *et al.,* 2019; Hjelm *et al.,* 2010). These findings suggest that the injury rate is higher among boys under 18 years old, whereas over 18 years old, the injury rate shifts, and women have a higher risk of injury. Between the ages of 13 and 18, the risk of injury increases with age (Gescheit *et al.,* 2019), as well as with the duration of exposure (matches) (Fu *et al.,* 2018).

3.1.5 Injury localization in juniors

Hjelm et al. (2010) evaluated juniors and identified ankle sprains, knee injuries, and back pain as the most common injuries, with 51% of injuries occurring in the lower extremities, 24% in the upper extremities, and 24% in the trunk. The highest incidence of injuries on the lower extremities was reported by Colberg et al. (2015) and Moreno-Peréz et al. (2020) among tennis players aged 17-21, transitioning from junior to adult levels, specifically in the thigh, lumbar spine, and shoulder. Juniors experience the highest rate of acute injuries in the ankle and thigh and chronic injuries in the knee, back, and shoulder (Llanes *et al.,* 2023; Pluim *et al.,* 2016). Gescheit et al. (2019) reported the most frequent injuries in the lumbar spine, followed by the shoulder.

3.1.6 Injury localization in adults (professionals)

Of the injuries, 39% were tendonitis, most commonly affecting the shoulder, elbow, or knee; 32% were ankle sprains, and 22% were muscle strains in the hip, shoulder, or thigh (Valleser and Narvasa, 2017). Overall, issues are more common in the lower extremities than the upper body (Maquirriain and Baglione, 2016). Specifically, Dakic et al. (2018) specified the thigh, ankle, knee, and shoulder as the most frequently injured areas. Lynall et al. (2016) reported that the lower extremities were the most affected, accounting for 47% of all injuries in men and 52% in women, followed by upper extremity injuries, affecting men in 33% and women in 24%, with trunk injuries at 17% for men and 18% for women. According to Gescheit et al. (2017), shoulder injuries were most common in women's tennis, followed by leg injuries, wrist injuries, and knee injuries, while men's tennis usually involves knee, ankle, or thigh injuries. McCurdie et al. (2017) ranked shoulder, knee, and lumbar spine injuries as the most frequent. As previously mentioned, in the ATP circuit in 2013, the most common injuries were in the spine (26% of all injuries), thigh muscles (13%), ankles (11%), and shoulders (10%) (Di Giacomo *et al.,* 2016). Similar findings were reported by Fu et al. (2018), who highlighted the highest incidence of spine injuries in the ATP circuit. Abrams et al. (2012) reported injury rates of 31-67% in the lower extremities, 20-49% in the upper extremities, and 3-21% in the trunk, with ankle sprains being most common. From this, we can infer the four most commonly affected areas: ankles, thighs, shoulders, and the spine. We analyte the injuries in each body segment further.

3.2 Specific body areas and in injuries detail

3.2.1 Trunk/Spine area

In the trunk area, injuries often involve abdominal and intercostal muscles, but most commonly affect the back region (McCurdie *et al.,* 2017). There's a significant difference between genders in the professional ATP and WTA circuits. Among men, back injuries are the most frequent of all areas, which is not as common among women (7%), similarly to abdominal muscle injuries in both men and women (Dakic *et al.,* 2018; Di Giacomo *et al.,* 2016; Fu *et al.,* 2018). According to these authors, abdominal and intercostal muscle strains are most common, with strains of the paravertebral muscles in the lumbar spine area and degeneration or herniation of intervertebral discs in the lumbar spine region being frequent in the back area (Fu *et al.,* 2018). The lumbar spine area appears to be particularly problematic in terms of overuse, with frequent injuries occurring, especially in men, in professional tournaments (Di Giacomo *et al.,* 2016).

The spine area usually experiences excessive chronic overuse (Fu *et al.,* 2018). Long-term training focused on stroke technique and movement in tennis significantly influences and alters the structure and function of the musculoskeletal system. The most significant changes, especially asymmetrical ones, occur where the forces are most intense, leading to muscle imbalances (Frčová and Psalman, 2016). This is essentially a disorder in the interplay of deep stabilizing muscles, leading to muscle imbalances between the superficial and deep systems, resulting in spine-related issues such as back pain, intervertebral disc herniation, or functional blockages of individual spinal segments. Additionally, if the deep stabilizing muscles don't function properly, the superficial muscles take over their work, leading to increased resting tension in the muscles and hyperactivity of superficial muscles, and conversely, hypoactivity and decreased muscle tension of deep stabilizing muscles (Kolář *et al.,* 2012).

In tennis, strength is developed by transferring reaction forces from the ground through the ankle, shin, thigh, and trunk to the upper body and then to the racket (Kovacs, 2007; Roetert and Kovacs, 2014). Forces on the player's shoulder and arm are the result of the activity of the kinetic chain, starting, as mentioned above, from the ground reaction force and moving up through the legs to the racket. The center of rotation in tennis players is found in the pelvic and trunk area, which is also crucial for transferring the large forces created from the legs to the upper extremities and the racket. In elite tennis players, we find symmetrical trunk rotational force, where the abdominal muscles create, transfer, and decelerate forces on the trunk (Kovacs, 2007; Tubez *et al.,* 2015). Due to the transfer of reaction forces from the lower extremities through the trunk to the upper extremities, the trunk area can be a risky area for injuries, especially in the abdominal muscle region (Tubez *et al.,* 2015). In the trunk area, we often encounter strains of abdominal muscles, overload of back muscles, or degenerative changes in intervertebral discs (Fu et al., 2018).

Tennis, as a sport relying on rotational movement, often causes degenerative disc diseases. The back, trunk, and hips are the center of rotation and transfer forces to the upper and lower extremities. Due to repeated mechanical forces on the lumbar spine, repetitive traumatic discopathies occur, such as degeneration or herniation of intervertebral discs, especially at the L4/5 and L5/S1 levels. The focus of movement during tennis strokes is the lumbar spine, resulting in the most frequent issues. Modern tennis primarily utilizes flexibility, strength, and speed. Flexibility allows for a full range of motion in the joints, and if the range of motion in the joints is limited, prolonged muscle contraction in shortening can lead to musculoskeletal problems such as repetitive traumatic discopathy. Regarding basic strokes and movement in the lumbar spine, the backhand involves rotation to the left, and the forehand involves lateral flexion to the right. Ground strokes, compared to serving, create lower forces on the spine but are significantly more frequent during gameplay, up to 1.6 times, and can thus cause issues through accumulation (Fiani *et al.,* 2020).

The serve is one of the most frequent shot in tennis (Johnson & McHugh, 2006). The cervical spine of a tennis player undergoes considerable strain during the serve due to rotational movement in an extended position. This motion predisposes the player to injuries to the facet (intervertebral) joints, surrounding nerves, and soft tissues. Dysfunction in the cervical spine often negatively affects the upper extremities and their movement, potentially leading to secondary injuries (Di Giacomo *et al.,* 2016). Chow et al. (2009) show that beginners may be more susceptible to injury due to increased trunk extension resulting from improper coordination of lower trunk muscles, leading to relatively high loads on the lumbar spine. Besides the compressive load on the spine, increased extension and lateral flexion of the trunk during the serve can lead to shearing forces on the lumbar spine. Consequently, this shearing load on the spine can result in back pain or spinal injuries. The kick serve imposes the highest physical demands on a player's body among all three types of serves. It exerts the greatest force moment on the back and shoulder of the player compared to flat or slice serves, potentially increasing the risk of injury (Abrams *et al.,* 2011; Sheets *et al.,* 2011). The slice serve appears to be the most natural movement, as it imposes the least overall forces on the player's body. After wrist, elbow, or shoulder surgery or injury, the slice serve is therefore the most suitable technique to begin with upon returning to the court (Abrams *et al.,* 2011).

Studies have been conducted on tennis players' back pain to determine the prevalence of spinal radiographic abnormalities in these athletes. Alyas et al. (2007) performed MRI scans on 33 asymptomatic adolescent elite tennis players and found that over 80% had noticeable spinal abnormalities on MRI. In the study by Rajeswaran et al. (2014), lumbar spine findings were evaluated using MRI in asymptomatic elite junior tennis players. Facet (intervertebral) joint arthropathy was present in 90 % of players, with only 4% having no abnormalities. The presence of pathologies was lower in females compared to males and at a younger age, i.e., in those younger than 18 years compared to players older than 20 years. Although structural spinal pathology is commonly observed in tennis players, the most common cause of pain is muscle tension rather than direct spinal pathology (Perkins & Davis, 2006). Factors increasing the risk of injury are often associated with stroke technique, incorrect movement mechanics, or ball-racket contact (Zatsiorsky, 2000). Players rotating their shoulders before their pelvis have a higher risk of injury. Similarly, there is a higher risk of injury for players who maintain arm abduction (horizontal abduction) too long during external shoulder rotation, leading to increased strain on the shoulder joint (Myers, 2016). In the case of unilateral loading, it is necessary to distinguish scoliosis from scoliotic posture, which lacks a rotational component like scoliosis (Bessette & Rousseau, 2012; Kolář *et al.,* 2012; Weinstein *et al.,* 2008).

Physiotherapy should consider the correct technique and biomechanics of all strokes and related injuries. Overall rehabilitation has three phases: the acute phase, where symptoms are reduced; the recovery phase, which involves tissue healing; and the maintenance phase, aimed at preventing injury recurrence. In the acute phase, rest and icing often help alleviate pain. Once pain relief and flexibility return, strengthening weak links in the kinematic chain should follow to reduce the strain on the back. If nerve root compression occurs and pain radiates to the lower extremity, rest and pain and anti-inflammatory medications are necessary in the acute phase. In the subsequent phase, physiotherapy should focus on correcting body movement (technique) during play, exercises to improve joint flexibility, and especially exercises to strengthen the deep stabilization system of the spine, known as core exercises (Fiani *et al.,* 2020). Strengthening the muscles of the lower trunk should be part of conditioning and rehabilitation programs for tennis players. During the serve, eccentric contraction of lower trunk muscles occurs primarily, hence eccentric training is recommended in conditioning. Overall strengthening of this body part enables improved athletic performance and prevention of injuries and pain in the lumbar spine area (Chow *et al.,* 2009).

3.2.2 Upper extremity area

There's a unilateral strain on the body, especially in the dominant upper extremity, which is often chronically overused (Fu *et al.,* 2018). Injuries in the upper extremity account for up to 28% of all injuries in men and 23% in women (Kekelekis *et al.,* 2020). The frequency of injuries in this area significantly increases in the junior category of tennis players (Fu *et al.,* 2018). Regarding the frequency of upper extremity injuries in both men and women, overuse injuries most commonly affect the shoulder, where the main cause of injuries is the high number of serves and groundstrokes, which involve frequent repetitive movements (Abrams *et al.,* 2012; Dakic *et al.,* 2018; Fu *et al.,* 2018; Roetert and Kovacs, 2014). Professional tennis players with high-quality stroke technique are capable of achieving maximum serving speed with minimal kinetic load on the shoulder (Kekelekis *et al.,* 2020). Risk factors for upper extremity injuries include tennis racket characteristics and stroke technique.

3.2.3 Shoulder area

According to Dakic et al. (2018), shoulder injuries most commonly involve tendinopathy (overuse tendon pain) of the rotator cuff muscles (Fu *et al.,* 2018), but also the long head of the biceps (Di Giacomo *et al.,* 2016). Shoulder injuries are often associated with dysfunction of the kinetic chain, meaning dysfunction in the muscle coordination from the lower extremity through the core, upper extremity, to the racket and ball. They are also related to scapular dyskinesis, rotator cuff pathology, or glenohumeral internal rotation deficit (GIRD). The result of these pathologies is often impingement syndrome or SLAP lesions (labral injuries), which frequently lead to repeated injuries and sometimes even surgery (Abrams *et al.,* 2012; Di Giacomo *et al.,* 2016; Kekelekis *et al.,* 2020).

Scapulo-thoracic dynamic stability and deep spinal stabilization (core stability) play an important role in shoulder dysfunction. The coordination between the scapula and the humerus is called scapulo-humeral rhythm, which affects the mechanical energy delivered by muscles and the metabolic demand required to generate the desired force. The commonly known term "core" is the center of gravity and the starting point of movement; functional core allows for coordination between agonists and antagonists, spinal stability, and energy transfer from large to small parts of the body during movement (Di Giacomo *et al.,* 2016).

Fernandez-Fernandez et al. (2013) published the results of a study where junior tennis players aged 13 were tested for 6 weeks. This experimental group practiced exercises targeting the strength of the deep spinal stabilization system (core exercises), exercises with elastic resistance, and medicine ball exercises to improve tennis serving. Both groups regularly performed stretching after each training session, which increased the range of motion in the shoulder joint for internal and external rotation in both groups. Speed and accuracy of serving were improved only in the experimental group, indicating that a short-term training program for young tennis players using minimal equipment can result in improved tennis performance and reduced risk of overuse injuries. Fernandez-Fernandez et al. (2022) presented that tennis players reduced glenohumeral imbalances during a 12-week compensatory programme including isoinertial flywheel.

3.2.4 Elbow area

Another common site of frequent overuse injuries is the elbow, where the main causes are predominantly incorrect stroke technique or inappropriate equipment (Roetert and Kovacs, 2014). In the elbow area, we primarily encounter pain or inflammation of the medial or lateral epicondyle of the humerus (Fu *et al.,* 2018). Lateral epicondylitis, also known as tennis elbow, is a painful condition affecting the extensor carpi radialis brevis muscle. Tennis elbow can lead to significant functional damage, characterized by cellular changes associated with hypertrophy, angiofibroblastic hyperplasia (microtrauma healed by fibrous tissue), changes in muscle blood supply, and rearrangement of collagen within the tendon (Bhabra *et al.,* 2016). One explanation for the development of these difficulties is the excessive activity of wrist extensors during all strokes, where players with tennis elbow exhibit significantly higher wrist extensor activity upon ball contact with the racket than players without difficulties (De Smedt *et al.,* 2007). Rossi et al. (2014) found excessive activation of wrist extensors during forehand strokes, thus mechanical overloading is one of the possible risk factors. Additionally, the influence of grip size, which affects racket grip strength and therefore the load on wrist extensors, has been demonstrated. Grip size is thus another risk factor leading to overuse injuries. The greatest intensity of force developed by the extensor carpi radialis brevis and extensor carpi radialis longus muscles was with a small and large racket grip, and the lowest intensity was with a medium size.

The use of a vibration dampener has no effect on the occurrence of these difficulties, it does not reduce the amount of vibrations from the frame of the tennis racket received into the forearm, it has no effect on grip strength, nor on the activity of forearm muscles. Its effect is therefore only an acoustic impression and psychological support for the tennis player (Li *et al.,* 2014). Hennig et al. (1992) argue that stroke accuracy, match experience, and a suitable racket have a significant influence on reducing the amount of vibrations in the forearm of a tennis player. Less experienced tennis players absorb more vibrations into the forearm than experienced players. The suitability of the racket refers to its construction, where a larger racket head size reduces the amount of vibrations into the forearm.

In some cases, sufficient rest from the regularly repeated activity that caused pain, and possibly applying an ice pack for about twenty minutes two to three times a day, may be enough. In conservative treatment, many methods can be utilized such as medication, physiotherapy, or physical therapy. In preventing overloading of specific muscle groups and tendons, it is important to make appropriate choices in sports equipment, correct improper technique, and thus have knowledge of the correct biomechanics of strokes, stretching of wrist and forearm muscles, eccentric exercises to strengthen grip, and exercises focused on flexion and extension of the elbow and wrist (Verma, 2015). Exercises recommended for preventing elbow injuries should focus on increasing strength, particularly muscular endurance (resistance) of wrist and forearm muscles – it is important to realize that, contrary to the beliefs of some players and coaches, the energy for a stroke does not come from the wrist and forearm in properly executed tennis strokes, but from the entire kinetic chain (Di Giacomo *et al.,* 2016).

3.2.5 Wrist area

Wrist injuries commonly occur in tennis among both men and women, as well as in junior categories. Tendinitis (tendon inflammation) and subluxation of the extensor carpi ulnaris tendon or stretching of the carpal ligaments are frequent in this area (Fu *et al.,* 2018; Valleser and Narvasa, 2017). Two-handed backhand strokes, especially, impose excessive stress on the non-dominant upper extremity due to the recoil force of the stroke (Valleser and Narvasa, 2017). Pain in the wrist area on both the dominant and non-dominant upper extremities can be symptomatic of fatigue fractures of the distal part of the ulna bone or the radius bone, particularly the scaphoid bone in women (Dakic *et al.,* 2018; Maquirriain and Ghisi, 2006). Changes in the frequency of wrist injuries occur between the ages of 13 and 18 (Gescheit *et al.,* 2019). In junior players, wrist injuries may be caused by insufficient development of forearm and wrist muscle strength, inappropriate equipment, or a high number of ball hits during matches, with juniors playing up to 90 serves and 2.5-3 strokes per tennis exchange (Gescheit *et al.,* 2019).

3.2.6 Lower limbs

In both women and men, injuries in the lower limb most commonly occur in the thigh region, typically involving strains of the thigh muscles (Dakic *et al.,* 2018; Di Giacomo *et al.,* 2016; Fu *et al.,* 2018). The majority of thigh muscle injuries are of mild nature and do not affect competitive time (Dakic *et al.,* 2018). It has been demonstrated that injuries in the thigh region are less frequent on grass surfaces (McCurdie *et al.,* 2017). Acute traumatic injuries such as ankle sprains, knee injuries, or hip injuries are mainly encountered in the lower limbs. These injuries are common among elite tennis players, and over time, there is an increase in the frequency of these injuries (Fu *et al.,* 2018). A higher risk of lower limb injuries may be attributed to impaired balance of one lower limb (Wikstrom *et al.,* 2006). Injuries to the ankles, knees, and hips mostly occur in relation to player fatigue, slippery surfaces or constant rapid changes in movement direction (Di Giacomo *et al.,* 2016; Roetert and Kovacs, 2014). On hard surfaces, intense player movement across the court leads to greater pressure on their legs and shorter braking steps, resulting in increased force exertion (Damm *et al.,* 2014). Greater pressures on the foot during play on hard surfaces thus increase the risk of overuse injuries. Despite the high coefficient of friction on hard surfaces, elite players currently use sliding when chasing the ball.

3.2.7 Ankle area

Ankle injuries often occur due to rapid lateral movements, changes in direction, hard surfaces imposing high demands on the ankle (Gescheit *et al.,* 2017), and significantly, inappropriate sports footwear, where lateral stability and sole are particularly important (Stacoff *et al.,* 1996). Ankle sprain is the most common acute injury (Abrams *et al.,* 2012; Fu *et al.,* 2018; Pluim *et al.,* 2016; Vallesera and Narvasa, 2017), resulting from inversion causing damage to the lateral ligaments (Damm *et al.,* 2014). Ankle sprain involves stretching or damaging the structure of lateral ligaments or other surrounding soft tissues. As a consequence of these complications, ankle instability occurs, leading to a higher risk of repeated injury (Di Giacomo *et al.,* 2016). This injury affects both men and women equally (Gescheit *et al.,* 2017), and in the junior category, the frequency of ankle injuries is higher in boys (21.9%) than in girls (11.1%) (Hjelm *et al.,* 2010). Furthermore, ankle fractures can occur both due to injury and fatigue (Fu *et al.,* 2018; Maquirriain and Ghisi, 2006).

3.2.8 Knee area

The knee is affected by both acute injuries and chronic overuse issues, such as knee tendinopathy (Fu *et al.,* 2018). Acute injuries predominantly result from rotational movements and cause damage to the menisci or ligaments (Di Giacomo *et al.,* 2016), particularly stretching to rupture the knee ligaments (Dakic et al., Fu et al., 2018). In association with tennis, a high risk of lateral collateral ligament injury or medial meniscus injury has been found (Majewski *et al.,* 2006). Knee injury leads to damage to the anterior cruciate ligament in 10-13% of cases (Abrams *et al.,* 2012). Patellar tendinopathy, also known as jumper's knee, is a tendon pain of the patellar ligament and is the most common chronic injury from repeated overuse of the knee extensor mechanism. This injury occurs due to explosive muscle contraction required in sprinting, jumping, and rapid changes of movement direction during tennis. Poor flexibility of the quadriceps femoris, hamstrings, and pathological lower limb alignment can create higher stress on the quadriceps femoris tendon, leading to jumper's knee. The initial symptom is tendon inflammation manifested primarily after exertion, with pain gradually increasing, stiffness in the knee joint, crepitus, or swelling in the knee area. In extreme cases, tendon structure damage may occur (Di Giacomo *et al.,* 2016). Common injuries such as anterior cruciate ligament rupture in the knee or torn ligament in the ankle disrupt the integrity of joint mechanoreceptors, worsening proprioceptive feedback to the central nervous system. The result is reduced proprioception and neuromuscular control necessary for sports and movement (Jerosh and Prymka, 1996; Naylor and Romani, 2006).

3.2.9 Hip area

In the hip joint area, groin muscle strains often occur in tennis (Fu *et al.,* 2018). Troubles in the hip joint area arise from the action of large muscles around this joint, such as the hamstrings and quadriceps femoris (Di Giacomo *et al.,* 2016). Health problems in the hip joint area may affect tennis players due to asymmetric hypertrophy of the iliopsoas and gluteal muscles. Pain is primarily felt in the groin due to tendon inflammation or bursitis (Abrams *et al.,* 2012). This often leads to femoroacetabular impingement or labral tear. Exercises ensuring stabilization and flexibility of the hip joint are recommended for prevention (Di Giacomo *et al.,* 2016). Abrams et al. (2012) report that tennis increases the prevalence of osteophytes in the hip joint area.

3.2.10 Fatigue fractures

Maquirriain and Ghisi (2006) highlight the risks of fatigue fractures in elite tennis players, especially in the junior category. Fatigue fractures occur in 13% of elite tennis players, with the scaphoid bone (os naviculare) being the most frequently affected (27%), followed by pars interarticularis of the vertebrae (16%), metatarsal bones (16%), tibia (11%), and lunate bone (os lunatum) of the wrist (11%). The prevalence of fatigue fractures was higher in the junior category (20 %), i.e., in players under 18 years old, than in professional tennis players older than 18 years (8%).

3.3 Recommendations

We present general recomendations for injury preventions. They are based on the recomendations from Pluim and Drew (2016), who recommended several crucial points for load.

management and injury prevention in tennis, which we would like to reiterate. For further details, please refer to their work: 1. Establishing a baseline fitness level – incorporate basic strength and conditioning exercises alongside tennis training and maintain consistent during tournament periods; 2. Minimizing changes from week to week – gradually increase training load and longer preparatory period - at the start of the season, when initiating a new training program, or returning from injury; 3. Avoiding peak loads - unpredictable match lengths, carefully consider match frequency and whether to participate in both singles and doubles matches; 4. Balancing load and rest – reduce training intensity before tournaments, plan recovery training the day after demanding match or training session, ensure adequate rest between tournaments; 5. Ensure to keep minimal training load – continue training during holidays regularly. If injured any form off cross-training; 6. Avoiding excessive load – playing more than 3 matches per day or more than 8 matches per week (even lower for juniors), regardless of the player's fitness level, significantly increases the risk of injury.

4. Conclusions

This study offers an overview of the incidence of injuries in tennis to comprehend the demands of tennis on the human body and provide insights into the nature of injuries from a physiotherapy perspective. This information can be helpful to players, coaches, and medical or physiotherapy staff and can be utilized to recover or prevent injury. Injuries predominantly happen during the match compared to practice. Fatigue can be influenced by appropriate regeneration and conditioning. Considering the above, conditioning should have a long-term concept and cooperate with independent tennis training, including incorporating rest periods, to establish a balance between load and rest. The tennis player's body needs to be prepared for performance to endure not only multiple matches in a row but also multiple tournaments. Additionally, for the aforementioned points, we recommend that tennis players should cooperate with physiotherapists from an early age to prevent injuries and not use them only during injury recovery.

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