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Badminton-related musculoskeletal injuries in senior players: Epidemiology and preventive strategies for common injuries

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ABSTRACT

Badminton is a popular sport with numerous health benefits but carries the risk of injury. Limited research is available on badminton-related injuries among senior Asian players. This cross-sectional study used a questionnaire to gather data on demographics, exercise habits, injury history, injury mechanisms, affected body parts, symptoms, and injury severity from 254 participants. Most participants were male (70.6%), with a median age of 46 years (inter-quartile range [IQR] = 16.0). The median injury incidence was 4.3 per 1,000 hours played (IQR = 6.5). The most commonly injured body parts on the dominant side were the knees (51.1%), ankles (36.3%), and shoulders/clavicles (25.5%). On the non-dominant side, the knee (34.2%) and ankle (25.5%) were frequently injured. The most common mechanism of knee and ankle injuries occurs during changes in direction. Common injuries included ankle sprains (23.5%), patellar tendinopathy (20.3%), and muscle cramps (31.6%). Most injuries (60.6%) were mild. Future studies should focus on comprehensive prevention methods to reduce injuries.

Keywords: badminton, athletic injuries, knee injuries, ankle injuries, elderly, musculoskeletal diseases

INTRODUCTION

Badminton, recognized as the fastest racket sport with a record-breaking shuttlecock speed of 565 km/h [1], continues to hold its status as one of the world's most popular sports. It boasts over 700 million enthusiasts globally and has experienced a particularly significant surge in interest in Asia [2, 3]. It is the third most-followed sport in more than 20 countries, engaging 16% of sports fans. This level of engagement is impressive, closely following football and basketball, with fan bases of 35% and 17%, respectively. The expansive influence of social media continues to play a crucial role in enhancing global recognition and appeal of badminton. In Thailand, the surge in the popularity of badminton has been largely due to the success of prominent players who have secured victories in international competitions [4].

It has been proven that badminton not only enhances physical health but also mental and social well-being across numerous age groups [5]. However, similar to other sports, it is also associated with musculoskeletal injuries. Badminton injuries make up approximately 1-5% of all sports injuries. According to previous studies, the risk of injuries in badminton is approximately 0.9 injuries per annum and 1-7 injuries per 1,000 hours of play [6-8]. The lower limb is the most commonly affected in such injuries, with an estimated 58-92% of cases involving it. The knee is the most commonly injured part of the lower limb, followed by the ankle, with common injuries including strains, sprains, tendinopathy, and stress fractures [7-9]. However, with most injuries categorized as mild to moderate in terms of severity, at least 20% of schoolchildren missed at least one day of school in a given year due to sports injuries. Furthermore, it was estimated that one in three working adults lost at least one day per year because of injuries from sports-related activities [10]. Therefore, comprehensive preventive strategies must be implemented to mitigate adverse outcomes. It was proposed a four-step model for injury prevention [11]. This model begins with the critical step of establishing the magnitude of the injury, followed by identifying the etiology and mechanisms of the injury. Subsequently, it involves the introduction of preventive measures and evaluation of their effectiveness. Population aging is a phenomenon that affects many countries worldwide, including those in Asia [12]. The population aged over 60 years increased from 5% in 1995 to 17.1% in 2017 and is projected to increase to 30% by 2035 [13]. This demographic shift has led to an increase in the number of elderly patients with sports-related trauma, potentially increasing its morbidity and mortality [14]. To the best of our knowledge, there is a scarcity of studies focusing on badminton-related injuries, particularly among Asian senior players, encompassing both elite and non-elite levels [7, 15]. Understanding this could be instrumental in developing prevention strategies for vulnerable groups through routine exercise, training, and competition.

MATERIALS AND METHODS

Participants

The study was conducted between November 2023 and June 2024. The inclusion criteria were an age range of 35-85 years, Thai nationality, and regular participation in badminton (at least 2 hours per week for a minimum of 12 months). The exclusion criteria were unwillingness to participate in the study; incomplete responses; a medical history of disabilities related to vision, hearing, speech, motor, or physical functions; mental or behavioral health; autism; intellectual abilities; or learning disorders.

Questionnaires and Study Design

The questionnaire was modified with permission based on the study in [16]. This revision was carried out in consultation with experts, including orthopedic physicians, sports medicine specialists, and badminton coaches. The questionnaire gathered comprehensive data, including demographic information such as sex, age, weight, height, preexisting medical conditions, and educational background. Details regarding exercise habits, injury history, mechanisms of injury, affected body parts, symptoms, and severity of injuries were also collected. All assessment measures were thoroughly reviewed and validated by two sports science experts utilizing the index of item objective congruence (IOC). An IOC index score exceeding 0.5 affirmed the content validity of the questionnaire [17]. Prior to the initiation of the study, the preliminary questionnaires were pilot tested with 30 adult volunteers at the Walailak Sports Center and adjustments were made to clarify ambiguous wording. The internal consistency of the questionnaire was evaluated by calculating the Cronbach's alpha coefficient with a value of 0.70 or higher deemed acceptable [18]. A one-time questionnaire was distributed online using Google Forms to collect data. Cochran's sample size formula was utilized [19]:

$$n = Z^2 \frac{p(1-p)}{e^2}. \quad (1)$$

Based on the results reported in [20], the specific parameter set for this calculation included a confidence level of 90%, margin of error of 0.05, and a prevalence rate of 0.36. The initial calculations yielded a sample size of 250 individuals. However, to accommodate the potential 5% rate of incomplete data, the sample size was revised to 262. This study complied with the principles of the Declaration of Helsinki and the International Conference on Harmonization of Good Clinical Practice. The study was registered in the Thai Clinical Trials Registry (TCTR20231110008).

Statistical Analysis

Statistical data analysis was conducted by calculating the frequency, percentage, mean, median, standard deviation (SD), and inter-quartile range (IQR), and comparing the data (in the case of subgroup analysis). To determine associations between continuous variables and ordinal data, you can use Spearman's rank correlation coefficient (Spearman's rho, ρ). This nonparametric test measures the strength and direction of the association between two ranked variables, making it suitable for evaluating the relationship between continuous and ordinal variables. To compare the values of the two independent sample groups, we used either an independent t-test or the Mann-Whitney U test, depending on the data distribution. To determine associations between variables, Pearson's correlation (r) was applied for continuous variables, while Spearman's rho (ρ) was used for ordinal data and for associations between continuous variables and ordinal data. A p-value less than 0.05 was considered statistically significant.

RESULTS

After distributing the questionnaire, we received a 74.3% response rate. Six participants were excluded because they chose not to disclose their data or decided not to participate in the study, resulting in 254 participants included in the final analysis. Most patients were male (n = 180, 70.6%). Median age was 46 years (IQR = 16.0), weight 68.5 kg (IQR = 15.0), height 168 cm (IQR = 10.0), and BMI 23.8 (IQR = 3.8). The following numbers of participants graduated with less than a bachelor's degree, bachelor's degree, master's degree, and Doctor of Philosophy (PhD): 37 (14.5%), 125 (49.0%), 64 (25.1%), and 28 (11.0%), respectively. Most participants were right-handed (230, 90.6%) and had a dominant right leg (223, 87.8%). In the jumping posture, the participants took off from the floor with their dominant leg (45.7%), non-dominant leg (21.3%), and both legs (33.1%). In the landing posture, they landed on their dominant leg (49.2%), non-dominant leg (20.1%), and both legs (30.7%). The reasons for playing badminton were recreational activity (75.6%), regional competition (16.5%), national competition (6.3%), and international competition (1.6%).

The median duration of playing badminton was 13.0 years (IQR = 17.3). The median frequency of play was 3.0 times per week (IQR = 2.0), and the median duration per session was 2.0 hours (IQR = 1.0). The median duration of on-court training was 9.0 hours per week (IQR = 17.0), and off-court training, including strength and endurance exercises, was 1.0 hour per week (IQR = 4.0). They reported warming up before playing badminton, as follows: never (0.8%), sometimes (36.2%), mostly (31.5%), and always (31.5%). The median warm-up time was 7.5 minutes (IQR = 5.0). Among those who warmed up, the specific areas targeted were the hands (77.6%), arms/shoulders (94.5%), neck (48.8%), back (55.9%), hips/legs (77.6%), and feet (74.4%). Only 37.4% reported warming in all parts of the body. Regarding cooling down, participants reported the following frequencies: never (5.5%), sometimes (44.1%), mostly (26.0%), and always (24.4%). The median cool-down time was 7.5 minutes (IQR = 5.6). Among those who cooled down, the specific areas targeted were the hands (51.2%), arms/shoulders (82.7%), neck (40.9%), back (66.9%), hips/legs (82.3%), and feet (58.7%). Only 28.3% reported cooling down all parts of the body.

Injury Profile

Of the participants, 196 (77.2%) had experienced badminton-related injuries in the past year, with 394 reported injuries (292 in men, 102 in women). The median incidence of injuries was 4.3 injuries per 1,000 hours played (IQR = 6.5). Men experienced a median of 4.4 injuries per 1,000 hours (IQR 6.3), while women experienced a median of 4.1 injuries per 1,000 hours (IQR = 7.8). There was no statistically significant difference in the incidence of injuries between the sexes (p = 0.595). These injuries were diagnosed by their coach (43.7%) and medical staff (33.9%); the remaining 22.4% were identified by the participants themselves. The details of badminton-related injuries in the past year are shown in **Table 1**.

Table 1. Badminton-related injuries (n = 196)

Injury details	n (%)
Injured body part	
Head/face	0 (0.0)
Neck	7 (3.6)
Injured body parts on the dominant side	
Shoulder/clavicle	50 (25.5)
Upper arm	31 (15.8)
Elbow	37 (18.9)
Forearm	17 (8.7)
Wrist	26 (13.2)
Hand/finger/thumb	8 (4.0)
Upper trunk	2 (1.0)
Abdomen	2 (1.0)
Lower back	39 (20.0)
Pelvis/sacrum	7 (3.6)
Hip/groin	16 (8.2)
Thigh	26 (13.2)
Knee	100 (51.1)
Lower leg	15 (7.6)
Ankle	71 (36.3)
Achilles tendon	17 (8.7)
Foot/toe	16 (8.2)
Injured body part on the non-dominant side	
Shoulder/clavicle	16 (8.2)
Upper arm	4 (2.1)
Elbow	5 (2.6)
Forearm	2 (1.0)
Wrist	4 (2.1)
Hand/finger/thumb	6 (3.1)
Upper trunk	3 (1.6)
Abdomen	0 (0.0)
Lower back	22 (11.3)
Pelvis/sacrum	4 (2.1)
Hip/groin	11 (5.6)
Thigh	21 (10.8)
Knee	67 (34.2)
Lower leg	11 (5.6)
Ankle	50 (25.5)
Achilles tendon	14 (7.1)
Foot/toe	22 (11.3)
Joint/ligament injuries	
Dislocation/subluxation	3 (1.6)
Anterior cruciate ligament rupture	6 (3.1)
Meniscus injury	22 (11.3)
Cartilage injury	8 (4.0)
Ankle sprain	46 (23.5)
Other ligament injury	30 (15.3)
Tendon injuries	
Tear	29 (14.8)
Rupture	3 (1.6)
Patella tendinopathy	40 (20.3)
Achilles tendinopathy	6 (3.1)
Achilles rupture	2 (1.0)
Other tendinitis/tendinosis/tendinopathy	8 (4.0)
Muscle injuries	
Tear	39 (20.0)
Rupture	1 (0.5)
Muscular cramp	62 (31.6)
Bursitis	9 (4.5)
Others*	7 (3.6)

Note. *Other muscle injuries include myositis, muscle tightness, and mild discomfort

The most commonly injured body parts on the dominant side were knees (51.1%), ankles (36.3%), and shoulders/clavicles (25.5%). On the nondominant side, the most frequently injured regions were the knee (34.2%), ankle (25.5%), lower back (11.3%), and foot/toe (11.3%). The most common joint/ligament injuries were ankle sprains (23.5%), in tendon injuries were patellar tendinopathy (20.3%), and in muscle injuries were muscle cramps (31.6%).

Table 2. Injury mechanism (n = 196)

Injury mechanism details	n (%)
The sport gesture most likely to cause injury	
Impact/traumatic	96 (49.0)
Non-traumatic	100 (51.0)
Injury onset	
Sudden	74 (37.8)
Gradual	122 (62.2)
Common injury locations	
On-court	181 (92.3)
Off-court	13 (6.7)
Unspecified	2 (1.0)
Common on-court injury location	
On the front court	50 (25.5)
On the mid court	35 (17.9)
On the back court	105 (53.6)
Unspecified	6 (3.1)
Injury related to a fall	
Yes	37 (18.9)
No	157 (80.1)
Uncertain	2 (1.0)
Injury related to slippery floor	
Yes	67 (34.2)
No	128 (65.3)
Uncertain	1 (0.5)
Injury related to shoes	
Yes	73 (37.2)
No	112 (57.1)
Uncertain	11 (5.6)
Badminton shots most commonly associated with injuries	
Backhand net shot	2 (1.0)
Forehand net shot	4 (2.0)
Backhand net lift	13 (6.6)
Forehand net lift	8 (4.1)
Backhand net kill	4 (2.0)
Forehand net kill	12 (6.1)
Backhand drive	7 (3.6)
Forehand drive	5 (2.6)
Backhand return-smash	8 (4.1)
Forehand return-smash	3 (1.5)
Forehand clear	8 (4.1)
Backhand clear	10 (5.1)
Forehand smash	56 (28.6)
Backhand smash	7 (3.6)
Forehand dropshot	2 (1.0)
Backhand dropshot	3 (1.5)
Others*	3 (1.5)
Unspecified shots	41 (20.9)

Note. *Others included cross-court forehand smash and overhead forehand clear

Injury Mechanism

In participants who experienced badminton-related injuries in the past year, the majority of injuries were non-traumatic (51.0%). Most patients showed gradual onset (62.2%). The most common injury location was the badminton court (92.3%), specifically the back court (53.6%). Details of the injury mechanisms are presented in **Table 2**. The most common mechanism of knee injury was changing direction (21.9%). Achilles tendon injuries occurred during high-speed movements (5.1%). Ankle sprains were commonly associated with changing direction (26.5%). Wrist injuries were most

Table 3. Pain details (n = 196)

Pain details	n (%)
Grade of severity	
Minor (1-7 days of recovery)	119 (60.6)
Moderately serious (8-28 days of recovery)	55 (28.1)
Serious (> 28 days-6 months of recovery)	16 (8.2)
Long-term (> 6 months of recovery)	6 (3.1)
Pain management	
Self-limiting	22 (11.2)
Oral analgesics	93 (47.4)
Intramuscular analgesics	10 (5.1)
Intra-articular drug injection	1 (0.5)
Physical rehabilitation	78 (39.8)
Massage	116 (59.2)
Warm/cold compression	3 (1.5)
Acupuncture	4 (2.0)
Surgery	0 (0.0)

associated with the forehand smash (4.1%), as were elbow injuries (4.1%) and shoulder injuries (14.3%). Details of the specific body injury areas and their possible mechanisms are provided in **Appendix A**.

Regarding Pain

Among the injured participants, 94 (48.0%) experienced pain in the same region as their actual injury on most days of the previous month. Additionally, 39 (19.9%) participants had experienced pain in a different region for most days in the previous month. The other most common regions included the lower back (8.2%), knee (5.6%), and shoulder/clavicle (4.6%). A total of 134 participants (68.4%) still experienced pain upon returning to partial practice, whereas 124 (63.3%) experienced pain upon returning to full practice. In addition, 78 participants (39.8%) experienced pain upon returning to their matches. Notably, 168 participants (85.7%) had a previous injury of the same type as the current injury. The severity of pain and participant management of pain are shown in **Table 3**.

Correlation Analysis of Injury Frequency and Participant Characteristics

Pearson's correlation was used to determine the relationship between the frequency of injuries and the participants' characteristics using continuous data. Our analysis found no significant association between the frequency of injuries and age ($r = -0.015$, $p = 0.818$), weight ($r = 0.072$, $p = 0.254$), BMI ($r = 0.086$, $p = 0.170$), duration of playing badminton ($r = 0.062$, $p = 0.323$), warm-up duration ($r = -0.113$, $p = 0.073$), and cool-down duration ($r = -0.064$, $p = 0.306$). Spearman's rho was used to determine the relationship between the frequency of injuries and participant characteristics measured using ordinal data. There was no significant association between the frequency of injuries and the purpose of playing badminton. However, there was a significant inverse association between the frequency of injuries and the frequency of warm-up ($\rho = -0.273$, $p < 0.001$), as well as between the frequency of injuries and the frequency of cool-down ($\rho = -0.238$, $p < 0.001$).

DISCUSSION

Badminton is a sport that can cause injuries, although most are not caused by body-to-body contact [6, 21]. This may result in increased morbidity and mortality, particularly in older populations [14]. Understanding the incidence and mechanisms of injuries can be beneficial for planning injury prevention strategies. To the best of our knowledge, there is a scarcity of studies focusing on badminton-related injuries, particularly among Asian senior players. Our findings demonstrated that approximately 77% of the participants had experienced badminton-related injuries in the past year. The incidence of injuries was approximately 4 injuries per 1,000 hours played. The most commonly affected body parts were the knee and ankle, regardless of the dominant or nondominant side. The mechanism of these injuries is associated with changing direction while playing. Forehand smashes are the most common badminton shots that cause injuries. However, most injuries were classified as minor and required less than one week for recovery. Common pain management methods include massage, oral analgesics, and physical rehabilitation.

The epidemiology of badminton injuries is not well documented and there is a lack of data in Thailand, particularly among senior players, given the country's aging population [20, 22]. It was analyzed 44 badminton athletes in Hong Kong [23]. The overall incidence of injuries was 5.04 per 1,000 player hours. The highest incidence was among elite senior athletes (7.38), followed by elite junior athletes (5.03), and potential athletes (2.07). Elite senior athletes had a higher incidence of recurrent injuries, whereas elite junior athletes and potential athletes had higher incidences of new injuries. Most new injuries were strains (n = 80), with the most frequently injured body sites being the back (21.3%), shoulder (18.8%), thigh (18.8%), and knees (18.8%). It was conducted a retrospective case review in Malaysia [24]. Over a period of 2.5 years, a total of 469 musculoskeletal injuries were diagnosed. Of these, 276 (58.8%) injuries occurred in badminton players aged < 20 years old. The majority of injuries, 406 (86.6%) occurred during training or practice sessions, while only eight (1.7%) occurred during competitions. Overuse injuries were the most common type of injuries diagnosed at NSI clinics. In terms of injury severity, 429 (91.5%) were mild, 7 (1.5%) moderate, and 33 (7.0%) severe. Most injuries (296 or 63.1%) affected the lower extremities, with the knee being the most common location (37.1%), followed by the ankle (28.3%), thigh (13.2%), heel (11.2%), toes (5.7%), and other areas (4.4%). It was performed a prospective study in Malaysia involving 69 adolescent badminton players over a one-year period [25]. During this period, 63 injuries were recorded, resulting in an incidence of 1.09 injuries per player per year and 0.9 injuries per 1,000 training hours. The lower limbs were predominantly affected (69.8%), with the knee being the most common injury site, followed by the back, spine, and ankles. Most injuries were considered mild, with approximately 30% of players returning to play within one week. It was conducted a prospective longitudinal survey in Japan that included 133 badminton players from junior high schools, high schools, and universities who competed at the national tournament level [26]. The distribution of injury severity was, as follows: slight (83.8%), minimal (4.1%), mild (3.4%), moderate (6.8%), and severe (1.9%). The injury rate per player per 1,000 h ranged from 0.9 to 5.1. The injury rate during practice was significantly higher in women than in men and increased with age. It was conducted a 12-month prospective cohort study in France involving 20 elite international players [27]. They documented a total of 35 injuries, corresponding to an incidence of 3.4 injuries per 1,000 hours of play, with 11.6 injuries per 1,000 hours of play during competition. Most injuries were lower limb injuries (54.3%), whereas upper limb injuries were less frequent (37.1%). The foot was the most frequently affected location in lower limb injuries. The most common location of upper limb injuries was the shoulder, accounting for 38.5% of upper limb injuries and 14.3% of all injuries, with rotator cuff tendinopathies comprising 80% of shoulder injuries. The smash was the shot with the highest risk of upper limb injuries (46.2%), and the lunge was the footwork with the highest risk of lower limb injuries (31.6%). It was performed a retrospective study in France involving 135 emergency department patients, totaling 140 admissions and 146 injuries [28]. The majority were male (73, 54.1%) with a mean age of 28 ± 13.8 years. Most injuries (88.3%) affected the lower limbs, followed by the upper limbs (11%) and the head (0.7%). Sprains were the most common type of injury (60.9%), followed by tendino-muscular injuries (21.9%), fractures (8.9%), dislocations (3.4%), painful contusions (2.1%), meniscal injuries (2.1%), and wounds (0.7%). Lateral ankle sprains were the most frequent lower limb injury (43.4%), followed by Achilles tendon ruptures (13.9%), tennis leg injuries (8.5%), and mid-foot sprains (6.9%). Our findings align with the aforementioned studies, as our incidence data were at the upper end of the previously reported range–4.2 injuries per 1,000 hours, where the incidence from previous studies ranged from 0.9 to 5.1. Similarly, the most commonly affected site is the lower extremities [24, 25, 27, 28].

According to our findings, the knees and ankles are the most commonly affected body parts, particularly when changing direction during play. This emphasizes the importance of high-quality footwork in badminton [29, 30]. Effective badminton footwork relies on several key factors including strength, agility, flexibility, balance, coordination, and reaction time [31, 32]. All major leg muscles, including the gluteus, quadriceps, hamstrings, and gastrocnemius, are involved in badminton footwork, particularly the lunge and landing techniques [33]. This may explain the prevalent involvement of these two joints in common injuries as they are directly associated with the aforementioned muscles. While lunges are a fundamental movement and an essential skill in badminton that enhances court coverage and shot execution [34, 35], they carry the risk of lower limb injuries because of the complexity of executing an effective lunge [36]. Lunging generates significant vertical and horizontal forces, leading to high joint torque, especially at the knee. These forces are especially pronounced during extreme lunges and can contribute to injuries, such as anterior cruciate ligament (ACL) tears and patellar tendinosis [34, 37].

It investigated the biomechanics of three badminton-specific lunges: kick, step-in, and hop [39]. They found that the step-in lunge has lower horizontal reaction force at drive-off and lower peak hip joint power compared to the kick lunge, suggesting it may reduce muscle fatigue. Conversely, the hop lunge exhibited higher reaction forces and peak ankle joint moments and powers than the other lunges. It was recommended mastering the lunge technique, which includes forceful knee extension with internal rotation, ankle muscle strengthening, and optimal joint coordination, to prevent injury. Muscle fatigue may contribute to increased injury risks [30]. It significantly affects the biomechanics of badminton athletes, particularly the range of motion (ROM) in the hip and ankle joints. A reduction in hip ROM elevates the risk of adductor and abductor injuries. While muscle fatigue does not substantially impact ankle ROM, it still alters lunge and landing biomechanics, thereby increasing the risk of posture-related injuries [40]. It was found that while fatigued, there was a significant increase in ankle inversion at foot strike (+2.6°) and peak ankle inversion (+2.5°) [41]. Additionally, electromyography pre-activation within 100 milliseconds (ms) before foot landing decreased significantly in the soleus (-23.4%), gastrocnemius lateralis (-12.2%), gastrocnemius medialis (-23.3%), and peroneus brevis (-17.4%). As muscle fatigue impairs coordination and increases stress, potentially leading to injuries, the step-in-lunge technique may be beneficial for reducing the muscular demands of lunge recovery, thereby minimizing muscle fatigue [38]. In addition, effective fatigue management through a well-structured recovery plan and balanced training is essential to prevent muscle fatigue, poor performance, and injury risks [42].

According to [43], a stiffer landing technique significantly increases the risk of developing overuse and acute lower limb musculoskeletal injuries. The problematic techniques identified include a heel-strike position, greater ankle inversion, greater knee dynamic abduction, reduced hip flexion angle, higher external hip rotation strength, and reduced hip abduction strength. Players with ACL injuries had hip flexion angles below 20° at initial contact, which were significantly more common in females compared to males [44]. In addition, injured athletes exhibited significantly lower hip abduction strength and higher external hip rotation strength compared to non-injured athletes, suggesting that reduced hip abduction strength is associated with a higher risk of ACL injury [45]. According to knee biomechanics, reduced knee flexion angle (≤ 20°) at initial contact and greater knee moments are key risk factors for knee injuries, while a higher peak knee flexion angle decreases this risk [46]. Increasing dynamic knee valgus angle is a critical factor in knee injury during landing. Players with knee injuries exhibited an 8.4° greater knee valgus angle at initial contact and significant increases in peak knee abduction moment, significantly elevating the risk of knee injuries [47]. Regarding ankle biomechanics, the injured player landed in a heel-strike position with a mean dorsiflexion of 2° at initial contact and transitioned to a flat-foot position over the next 20 ms, increasing the plantarflexion angle by an average of 12° [48]. Moreover, ankle inversion during landing significantly increases the risk of lateral ankle injuries, which account for over 80% of such injuries [49]. This inward rotation of the ankle can damage the lateral collateral ligaments, particularly the anterior tibiofibular and calcaneofibular ligaments. Ankle sprains are more likely when the ankle is in greater inversion.

To our knowledge, no comprehensive guidelines exist for preventing lower limb injuries in badminton. It was identified several effective preventive strategies, including biomechanical evaluations, which reduced the injury rate from 20.0% to 18.0%; customized warm-up routines, which lowered the rate from 34.5% to 20.0%; and recuperation management, such as ensuring adequate rest and therapy, which decreased the rate from 32.0% to 19.0% [50]. Safe lunge-landing biomechanics include several key elements. Proper foot positioning, where the foot lands flat or on the forefoot [48], helps reduce impact forces on the joints. Controlled ankle inversion is crucial to minimize excessive inward rotation and prevent ankle sprains [49]. Maintaining good knee flexion [51] and alignment [52] ensures that the knee aligns with the toes, reducing strain on the knee ligaments, particularly the ACL. Adequate hip flexion [44] helps absorb landing forces, thereby reducing the load on the knee and ankle joints. Additionally, strong and coordinated muscle activation across the hip, knee, and ankle joints stabilizes these areas and absorbs impact forces effectively. Finally, balanced force distribution across the lower limb joints prevents overloading any single joint, thereby reducing the risk of overuse injuries. It is also important to avoid landing with a heel-strike position, excessive ankle inversion, greater knee dynamic abduction, inadequate hip flexion angle, higher external hip rotation strength, and insufficient hip abduction strength to further reduce injury risks [43]. Prevention training programs, therefore, should focus on hip abductor strength, core stability, knee stability, and proper ankle positioning during landing to reduce injury risks. Additionally, neuromuscular activities such as warm-up exercises, plyometrics, and balance training have proven effective in reducing lower extremity injuries. Warm-up exercises have been shown to reduce perceived muscle soreness after exercise and prevent exercise-related injuries [51, 53]. Integrating both static and dynamic stretching can improve flexibility, reduce muscle stiffness, and lower the risk of acute muscle injuries [54]. In contrast, active cool down does not appear to diminish the long-term adaptive response or prevent injury [52]. Our findings show that only one-third of the participants always warmed up before playing badminton, which may explain the high incidence of injuries observed. Emphasizing the importance of warm-ups is crucial for senior players. Sport-specific plyometric exercises not only improve change-of-direction speed, enhance agility, muscle strength, and overall performance but also play a crucial role in injury prevention [55, 56]. Proprioceptive training programs significantly enhance neuromuscular control and joint stability, effectively reducing the incidence of ankle injuries. The program benefits all athletes, regardless of their history with ankle sprains [57]. Finally, It was found that match play imposes greater and less predictable strain on players than practice [58]. To help players avoid injuries, incorporating match-like drills in training can help athletes adapt to the high demands of competition.

The strength of this study lies in its large sample size, which includes senior badminton players. However, this study has several limitations. First, as this was a cross-sectional, questionnaire-based study, participants may have had inaccurate recollections and misunderstandings, leading to inconsistent data. Additionally, lengthy questionnaires can cause participant fatigue and reduce response quality. Second, this study focused on the musculoskeletal injuries related to badminton. Patients with injuries to other organs, such as the eyes, were not included. Further research is necessary to identify the incidence and severity of these injuries and develop effective injury prevention plans. Third, although our study identified the knee and ankle as the most commonly affected body parts, particularly during direction changes in play, we recognize the need for more comprehensive preventive strategies against these injuries. We are optimistic that future studies focusing on comprehensive methods will help fill this knowledge gap and improve the prevention and minimization of badminton-related injuries.

CONCLUSIONS

The knees and ankles are the most commonly injured body parts on the dominant side, irrespective of whether they are on the dominant or non-dominant side. Both types of injuries are frequently associated with direction changes during play. There was a significant inverse association between the frequency of injuries and warm-up and cool-down exercises. Most injuries were mild in severity. Common pain management strategies include massage, oral analgesics, and physical rehabilitation. Landing with a heel-strike position, excessive ankle inversion, greater knee dynamic abduction, reduced hip flexion angle, higher external hip rotation strength, and lower hip abduction strength can increase the risk of lower limb injuries. Future studies focusing on comprehensive methods are essential to fill this knowledge gap and enhance prevention and reduction of badminton-related injuries.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: SUPPLEMENTARY MATERIAL

Table A1. Mechanism of injury in selected body parts (n = 196)

Mechanism details	n (%)
In cases of knee injury history, the most likely mechanism of injury	
It happened when returning from a lunge.	25 (12.8)
It happened in my non-dominant leg when jumping in the round the head.	13 (6.6)
It happened when changing direction.	43 (21.9)
It happened due to a deceptive shot from my opponent.	17 (8.7)
Uncertain	2 (1.0)
In cases of Achilles tendon injury history, the most likely mechanism of injury.	
My foot was parallel to the direction of movements.	1 (0.5)
My foot pointed towards the sideline.	1 (0.5)
It happened while jumping.	6 (3.1)
It happened with low speed (acceleration).	2 (1.0)
It happened with high speed (acceleration).	10 (5.1)
In cases of ankle sprain history, the most likely mechanism of injury	
It occurred while jumping.	24 (12.2)
It occurred while lunging.	8 (4.08)
It occurred while changing direction.	52 (26.5)
It occurred due to a deceptive shot.	7 (3.6)
In cases of wrist injury history, the most likely mechanism of injury is related to badminton shots	
Backhand net shot	1 (0.5)
Forehand net shot	0 (0.0)
Backhand net lift	1 (0.5)
Forehand net lift	0 (0.0)
Backhand net kill	1 (0.5)
Forehand net kill	3 (1.5)
Backhand drive	3 (1.5)
Forehand drive	1 (0.5)
Backhand return-smash	2 (1.0)
Forehand return-smash	0 (0.0)
Forehand clear	1 (0.5)
Backhand clear	3 (1.5)
Forehand smash	8 (4.1)
Backhand smash	1 (0.5)
Forehand dropshot	0 (0.0)
Backhand dropshot	0 (0.0)
In cases of elbow injury history, the most likely mechanism of injury is related to badminton shots	
Backhand net shot	1 (0.5)
Forehand net shot	1 (0.5)
Backhand net lift	3 (1.5)
Forehand net lift	0 (0.0)
Backhand net kill	2 (1.0)
Forehand net kill	1 (0.5)
Backhand drive	3 (1.5)
Forehand drive	2 (1.0)
Backhand return-smash	3 (1.5)
Forehand return-smash	2 (1.0)
Forehand clear	2 (1.0)
Backhand clear	6 (3.1)
Forehand smash	8 (4.1)
Backhand smash	2 (1.0)
Forehand dropshot	0 (0.0)
Backhand dropshot	0 (0.0)
In cases of shoulder injury history, the most likely mechanism of injury is related to badminton shots	
Backhand net shot	0 (0.0)
Forehand net shot	0 (0.0)
Backhand net lift	1 (0.5)
Forehand net lift	1 (0.5)
Backhand net kill	0 (0.0)
Forehand net kill	7 (3.6)
Backhand drive	1 (0.5)
Forehand drive	2 (1.0)
Backhand return-smash	2 (1.0)
Forehand return-smash	0 (0.0)
Forehand clear	5 (2.6)

Table A1 (Continued). Mechanism of injury in selected body parts (n = 196)

Mechanism details	n (%)
Backhand clear	3 (1.5)
Forehand smash	28 (14.3)
Backhand smash	2 (1.0)
Forehand dropshot	1 (0.5)
Backhand dropshot	1 (0.5)

Table A2. Pain in a different region than the actual injury on most days in the last month (n = 196)

Body parts	n (%)
Head/face	0 (0.0)
Neck	3 (1.5)
Shoulder/clavicle	9 (4.6)
Upper arm	2 (1.0)
Elbow	2 (1.0)
Forearm	2 (1.0)
Wrist	0 (0.0)
Hand/finger/thumb	1 (0.5)
Upper trunk	0 (0.0)
Abdomen	0 (0.0)
Lower back	16 (8.2)
Pelvis/sacrum	0 (0.0)
Hip/groin	1 (0.5)
Thigh	6 (3.1)
Knee	11 (5.6)
Lower leg	8 (4.1)
Ankle	3 (1.5)
Achilles tendon	0 (0.0)
Foot/toe	7 (3.6)