Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 38 (2024) 22–28

Contents lists available at ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology

journal homepage: www.ap-smart.com

original article

ACL injury characteristics in badminton : A registry study with prospectively collected data on sports related epidemiology and injury mechanism of 539 badminton players

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ARTICLE INFO

Keywords:
ACL injury
Badminton
Injury mechanism
Lunge
Scissor kick jump

ABSTRACT

Background: Over recent years, more anterior cruciate ligament (ACL) ruptures in badminton players have occurred. Little is known about the injury mechanism in badminton. The hypothesis is that most ACL injuries occur with single leg landings on the non-dominant leg in the backhand side or with lunge movements in the forehand side on the dominant leg. To inform prevention strategies the aim of this study was to investigate the mechanism of ACL injuries in badminton, specifically if ACL injuries occur in certain positions on the badminton court and/or with certain movements. Secondary aims were to investigate differences among gender, age groups and between recreational and tournament players.

Methods: The study, ACL Denmark, investigate ACL ruptures in a cohort of 90.610 participants diagnosed between 2000 and 2018. Of those, 539 participants reported ACL rupture during badminton and filled in an online questionnaire in December 2021–January 2022 on the injury mechanism and other injury characteristics. Data is presented as numbers, percentage, means (SD) and median (IQR) with chi square test or Fischers exact test for dichotomous outcomes.

Results: Most participants played badminton (n = 435, 81 %) as primary sport and 155 (29 %) reported to play on a competitive level (Tegner score 8). The rear court (n = 285, 40 %) was the most frequent location of injury but with a high percentage on the front and midcourt (n = 154, 22 %). The rear court was more prevalent among players aged 18–29 ($p < 0.001$). The most prevalent movement preceding the ACL injury was the scissor kick jump on the rear court (100, 19 %) followed by lunge at the net (70, 13 %) and lunge at the rear court (69, 13 %). One hundred and six players (15 %) were injured preceded by a deceptive shot from the opponent. The dominant leg was mainly injured in the forehand side and the non-dominant leg mainly in the backhand side.

Conclusion: The most prevalent movement preceding the ACL injury was the lunge followed by the scissor kick jump. The rear court was the primary location of ACL injury in badminton and the dominant knee has a higher risk of injury in the forehand side and the non-dominant knee in the backhand side. More focus on the technical performance of lunge and scissor kick jumps and development of a badminton specific ACL injury prevention program is needed in badminton.

1. Introduction

ACL rupture in badminton has had little attention in the literature but over recent years more ACL ruptures in top badminton have attracted attention.[1,2] To be able to develop prevention strategies for ACL injuries in badminton it is important to understand the injury mechanism. Several biomechanical factors have previously been associated with the risk of ACL injury in a variety of sports. Stiff landings, often in relation with more extension at the knee and hip joint, hip joint adduction/internal rotation and knee joint abduction at initial contact, are all considered risk factors.[3–5] High quadriceps forces at extended knee transferred through the patella increase anterior translation force, thus straining the ACL.[6,7] Furthermore, stiff landings result in high impact forces which increase the joint compression, and

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https://doi.org/10.1016/j.asmart.2024.09.005
Received 31 May 2024; Received in revised form 18 August 2024; Accepted 1 September 2024

especially in situations with simultaneous knee abduction moments the posterior slope of the lateral tibia plateau will induce an internal rotation.[5] All these factors increase the strain of ACL and may result in injury. High activation of the medial hamstrings may mitigate these deleterious loading mechanisms and reduce the risk.[5]

In other sports like football, handball and basketball video analysis has shed light on ACL injury mechanisms.[8–10] In badminton the knowledge on ACL injury mechanism was until the design of this study based on a retrospective questionnaire study of 21 badminton players.[11] Based on the Japanese study by Kimura et al. the hypothesis is that ACL injuries primarily occur during a single leg landing on the non-dominant leg in the backhand side or when performing a lunge on the dominant leg and the location was primarily on the rear court.

The aim of the present study was to investigate the movements preceding ACL injuries in badminton, specifically if ACL injuries occur in certain positions on the badminton court and/or with certain movements. The secondary aims were to describe if there were any differences between gender, age groups and between recreational and tournament players.

2. Materials and methods

This was a registry study from the Danish National Patient Register (DNPR) with prospectively collected data on sports related epidemiology and injury mechanism.

Approval was granted from the Danish Data Protection Agency (P-2020-304), ethical board approval was not necessary since no intervention was performed.

2.1. The Danish National Patient Register (DNPR)

In Denmark it is mandatory in the public and private health care system to register an ICD-10 classification code when patients seek medical care. The code is registered with the patient's unique identifier in the DNPR. The DNPR was established in 1976 and since 1994 registration has been performed using the ICD-10 classification.[12] Validation of sports related injury codes has shown ACL injury with the ICD-code DS835E to have a positive predictive value of 96 %. This means that in 96 % of the cases the diagnosis registered in DNPR corresponds to the findings in the patient journal.[13]

2.2. Population

Patients aged 18 years and above registered in DNPR with the ICD-codes DS835, lesion of the cruciate ligament, and DM235, chronic instability of the knee, from 2000 to 2018 (included) were identified. Participants who were diagnosed from 2000 to 2018 but reported the time of the ACL injury before 2000 were also included in the analysis.

Only participants reporting badminton to be the sport at time of injury were included in the present study, however not all were playing badminton on a regular basis.

2.3. Acquisition of prospectively collected data

In December 2021 the above-mentioned cohort from DNPR was e-mailed through the national public digital post solution, e-Boks. The email contained a link to a questionnaire in an electronic data capture tool (Research Electronic Data Capture, REDCap) hosted at the Capital Region of Denmark.[14,15] REDCap is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.

If no reply was received, three reminders were sent during the following 3 weeks until the mid of January 2022. Written consent was obtained from the individuals.

2.4. The questionnaire

A questionnaire regarding badminton injury mechanism was developed with assistance from former world elite players and coaches and tested by former elite players and recreational players. The questionnaires were designed through repeated consensus meetings among the authors. The questionnaires were then tested on 10 patients and written feedback was obtained regarding understanding of the questionnaire. Relevant linguistic adjustments were made, and the questionnaire was finally tested by 10 medical or physiotherapy research students in regard to understanding, relevance and time.

High-risk movements were identified according to the coaches and players knowledge of the game and the literature. The most frequent movements in badminton are the preload jump (split step), a lunge to the front-, mid- or rear court, the scissor kick jump (SKJ) and the block jump to the side or to the rear court (Fig. 1).[16–18] SKJ is a unique badminton specific movement frequently performed on the rear court when playing drop shots to the net, clear to the baseline or the attacking shot (smash). The movement is typically preceded by a pre-load jump and a chassé. It begins with the dominant foot behind, and the upper body turned various degrees away from the net (a sidewards position). Then the player jumps towards the rear court performing a body-rotation along the players' longitudinal axis up to 180°, the legs are switched as scissors, the shuttle is hit and then the player lands with the non-dominant foot far behind the body center.[19]

The movements illustrated in Fig. 1 were included in the questionnaire and the players were asked in which situation the ACL injury occurred (Appendix).

The players were also asked to point out the injury location on a badminton court. The location on the court was divided in 9 areas (Fig. 2): A front court, a middle court and a rear court with a forehand side, a backhand side and a central zone in all three areas. The racket arm determined whether the injury was sustained in the backhand or forehand side (e.g. the left side of the court was the backhand side and the right side of the court was the forehand side for right handed players). The dominant leg was defined as the same leg as the racket arm.

2.5. Variables

1. Epidemiological data consisted of age at injury, sex, level of play and the primary sport. Definition of age groups followed The National Olympic Committee and Sports Confederation of Denmarks division of age groups. The Tegner activity score (Tegner score) was used to describe the level of play pre- and post-injury.[20] Tegner and Lysholm developed an activity scale with 11 gradients from 0 to 10 to describe a level of activity after an ACL injury. Scores of 0 represent the disabled patient and 10 represents soccer on a national or international level. Badminton played on a tournament level equals the score 8 and badminton played on a recreational level 6. In this study Tegner score of 8 or above (Tegner score $\geq$8) represents tournament players and Tegner score $<$8 represents recreational players. The primary sport was defined as the sport the participant normally performed, since some were not playing badminton on a regular basis.
2. Injury related variables consisted of movement type, location on court, floor type, match play or training at injury time and when the ACL injury occurred during the session. Speed at injury was rated by the participant as slow, intermediate or high. Low load was defined as merely pushing off at low speed or being stationary, whereas high load was defined as performing a movement as quickly and forcefully as possible. Furthermore, the players were asked if the foot was in

	Movement type	Description	Movement situations
	Preload-jump	The preload jump is a small jump to prepare the movement to the shuttle	Primarily performed at the center of the court preceding a movement or a change of direction.
	Lunge to the front court	The lunge is a movement towards the shuttle primarily on the dominant leg which corresponds to the racket arm. Depending on the distance to the shuttle the lunge can be performed with various degrees of flexion in the ankle, knee and hip.	The lunge is primarily performed in a defensive playing position all over the court.
	Lunge to the rear court	As above. When the player moves towards the rear court to hit the shuttle behind the body the dominant leg is externally rotated and abducted while the upper body is paralellel to the side line.	As above
	Scissor kick jump (SKJ)	SKJ is performed moving backwards starting with the dominant foot behind and then the player performs a body rotation and a landing with the non-dominant foot far behind the body.	SKJ is performed on the rear court during rallys or while returning a long serv
	Block jump	A jump to the side or to the rear court landing on two legs or the dominant leg in the forehand side and the non-dominant leg in the back hand side (round the head side). In the round the head side the player leans the trunk laterally to play the shuttle with the forehand [15,16] .	In offensive play, with little time to react, a block jump is often performed. It is a jump to the side or backwards, to either side of the court

Fig. 1. The most frequent movements in badminton
From top to buttom: Preload jump, lunge to the front court, lunge to the rear court, scissor kick jump to the round the head side (rear-court backhand side), block jump in the forehand side (mid to rear-court).

line with the movement and if the player was surprised by a deceptive shot from the opponent before the injury occurred.

2.6. Statistics

Demographic data is presented using descriptive statistics. Comparison between groups were made using the chi-square test for dichotomous or ordered categorical outcomes. A Fischers exact test was performed when numbers were lower than five. A p-value of <0.05 was selected as level of significance.

3. Results

A total of 90,610 patients were invited to fill in the questionnaire, 40,692 (45 %) responded and 26,198 reported an isolated ACL injury. Five hundred and thirty nine participants reported ACL injury during badminton play and constitute the population of the present study. Demographic characteristics of the population can be found in Table 1. 108 (20 %) experienced injury before 2000 and 415 (77 %) from 2000 to 2018. Thirty eight players experienced injury before the age of 18. 435 (81 %) played badminton as the primary sport in the 6 months preceding the injury, 155 (29 %) on a competitive level (Tegner score $\geq$8) and 358 (66 %) on a recreational level (Tegner $<$8).

3.1. Injury location on court

Five hundred and seventeen patients (96 %) provided data concerning location of the injury on the badminton court (Figs. 2–5). The rear court was the primary location of the injury (234 (45 %)) followed by the front (116 (22 %)) and the mid court (117 (22 %)). In the rear court the injuries were evenly distributed between the backhand side and the forehand side, but on the mid and front court the forehand side was dominant (Fig. 2).

Younger players (0–29) had an over representation of injuries on the rear court and elder players on the front court (<0.001) (Fig. 3). The dominant knee was more frequently injured in the forehand side at the net ($p < 0.001$), midcourt ($p = 0.042$) and rear court ($p < 0.001$). The non-dominant knee was more often injured in the backhand side corner at the rear court ($p < 0.001$) (Fig. 4). Competitive players have more ACL injuries in the backhand side corner on the rear court compared to the rest of the court ($p = 0.011$) (Fig. 5).

3.2. Injury mechanism

Four hundred and fifty one players (84 %) provided data concerning the movement preceding the ACL injury. The most prevalent movement is the scissor kick jump on the rear court (100 (19 %)) followed by the lunge at the net (70 (13 %)) and lunge at the rear court (69 (13 %)). Lunge at the net and to the rear court combined is the most frequent

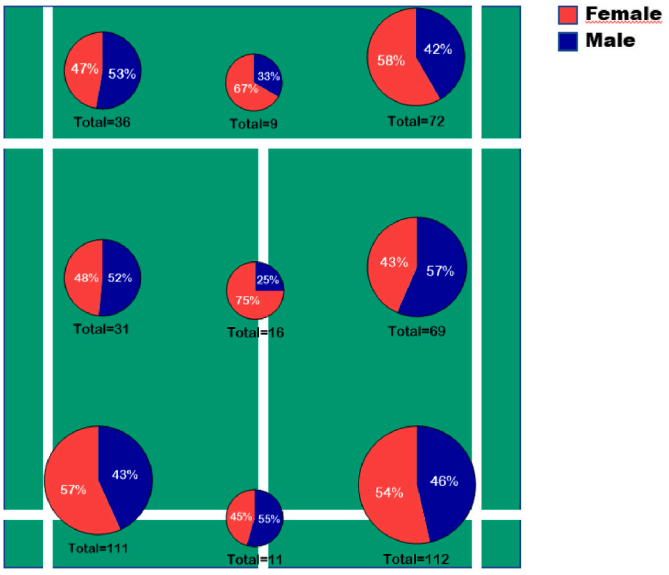

Fig. 2. The Gender distribution of ACL injuries on a half badminton court
The left side represents the backhand side and the right side represents the forehand side. Left-handed players have been converted to right-handed players for this illustration. The top represents the net and the bottom the base line.
ACL: Anterior cruciate ligament.

injury movement (139 (26 %)). If the block jump to the side and rear court are combined, they represent 81 (15 %) of the injuries. The distribution of the injury mechanism between sex and level can be found in the Appendix.

In the questionnaire, 32 players provided additional details about their injury mechanisms. Among them, jumping on the backhand side was frequently cited as a cause of injury (8/32, 25 %). Specifically, the player would land on the non-dominant leg while attempting to play the shuttle with a forehand stroke from the backhand side. Another commonly reported injury mechanism was knee twisting, which occurred when the shoe became caught on the ground (7/32, 22 %). Additionally, a small number of injuries were attributed to collisions with a partner during doubles play (3/32, 9 %).

Of the various playing situations in badminton, defensive situations seem to lead more frequently to injury than attacking situations (204 (38 %) vs. 145 (27 %)). Others represent a situation while playing drives where the shuttle is hit with a flat trajectory across the net (32 (6 %)), service situation (27 (5 %)) and not specified (44 (8 %)). There were no details from 22 players (4 %).

Five hundred and seventeen players (96 %) provided data concerning training or match exposure when sustaining the ACL injury. The ACL injury occurred evenly distributed between training and match play (217 (42 %) vs. 287 (55 %)). There was no information on the number of hours of training or match play. In both training and match play there was a tendency for the injury to occur in the last two-thirds of either training or match play (174 (80 %) and 175 (61 %) respectively.

In general, the speed of the movement was perceived as intermediate (169, 31 %) or high (292, 54 %). There did not seem to be a special foot position while sustaining the injury. 135 (25 %) reported the foot to be in line with the direction of movement and 165 (31 %) reported the foot not to be. However, 216 (40 %) did not recall it and 23 (4 %) did not answer the question.

Eighty players (15 %) were injured preceded by a deceptive shot from the opponent. Most of the injuries (384 (71 %)) occurred on wooden floors, while artificial floors were another frequently used surface material (120 (22 %)), but we have no information about how frequently the various types of flooring were used by the players.

4. Discussion

The rear court dominates as injury location and the movement preceding the ACL injury is most often the SKJ and the lunge. This confirms results in the previous mentioned smaller Japanese study and a new study on world elite players.[11,21]

4.1. Injury location on court

The ACL injuries occurred twice as frequent at the rear court compared to the mid court and the front court. This seems obvious for trainers and players since SKJs which is the dominant injury movement is not performed at the front court and very seldom at the midcourt. Furthermore, lunge (the second most frequent injury movement) was distributed fifty-fifty between the front court and the rear court. The players age seemed also to influence the injury location. A higher injury rate in the rear court among the younger players might be explained by a more forceful playing style with higher and more frequent jumps resulting in higher forces around the knee joint. Correct landing techniques may therefore be important to accommodate high loads well.

Kimura et al. found that almost 50 % (10/21) of patients sustained their ACL rupture when landing in the backhand side on their leg opposite to the racquet arm while playing an overhead stroke with the forehand.[11] Thirty eight percent (8/21) reported the ACL rupture in the same leg as their racquet arm while returning from a lunge. However, with the larger data set in this study it has been possible to show that ACL injuries occurs evenly distributed between the forehand side and the back hand side on the rear court. However, on the mid and front court the injuries are more frequent in the forehand side than in the back hand side. It is further shown that the dominant leg is more injured in the forehand side and the non-dominant leg in the back hand side. It is difficult to explain the forehand dominance of injuries at the net. At the mid court it may just refer to more jumps to the forehand side with the dominant leg at risk compared to the back hand side, where the number of jumps may be lower since many of the strokes is delivered with a back

Table 1
Characteristics of badminton players who have injured the ACL in badminton.

	Total	Males	Females	Age[c] <18	Age[c] 18–29	Age[c] 30–39	Age[c] 40–49	Age[c] 50+	Tegner ≥8[d]	Tegner <8[e]
ACL injury[a] (%)	539	261 (48)	278 (52)	38 (7)	131 (24)	109 (20)	164 (30)	81 (15)	155 (29)	358 (66)
Age (+-SD)	36.7 (12.9)	39.6 (12.5)	34.1 (12.7)	15.7 (1.1)	23.2 (3.6)	35.1 (2.7)	43.9 (2.6)	56.3 (6.2)	30.7 (12.8)	39.5 (12.1)
Badminton primary sport[b] (%)	435 (81)	206 (79)	229 (82)	34 (90)	108 (82)	82 (75)	133 (81)	67 (83)	141 (91)	275 (77)
Tegner score 6 months pre-injury, median (IQR)	6 (3)	6 (3)	6 (4)	8 (2)	7 (2)	6 (3)	6 (2)	6 (2)	8 (0)	6 (2)

[a] 16 players did not report an injury date and 26 players did not report pre-injury level of play.
[b] 19 players did not report pre-injury level of play.
[c] Age: Age at time of injury.
[d] Tegner ≥8: Competitive players.
[e] Tegner<8: Recreational players.

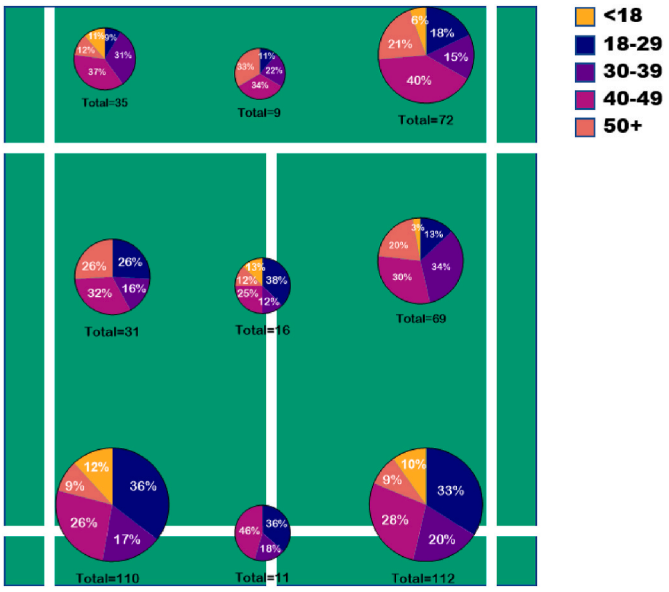

Fig. 3. The age distribution of ACL injuries on a half badminton court
The left side represents the backhand side and the right side represents the forehand side. Left-handed players have been converted to right-handed players for this illustration. The top represents the net and the bottom the base line.
ACL: Anterior cruciate ligament.

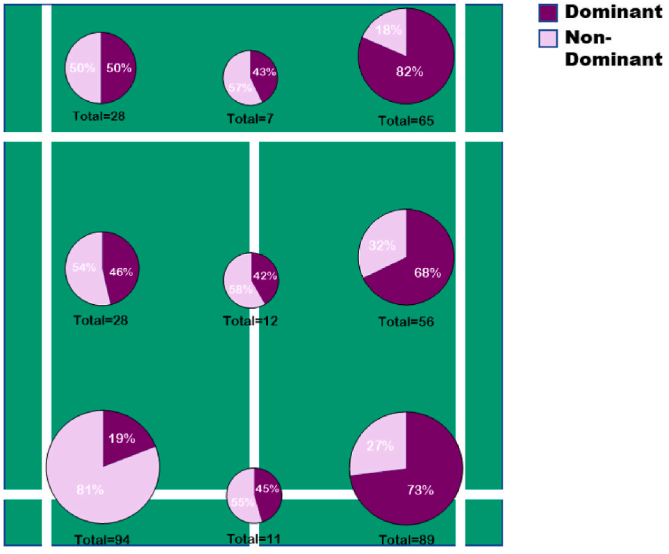

Fig. 4. Leg dominance and distribution of ACL injuries on a half badminton court
The left side represents the backhand side and the right side represents the forehand side. Left-handed players have been converted to right-handed players for this illustration. The top represents the net and the bottom the base line.
ACL: Anterior cruciate ligament.

hand stroke either on the dominant leg with the back turned towards the net or on the non-dominant leg with the front against the net. The two latter movements may imply less risk of ACL injuries.

The competitive players in this study sustained most ACL injuries in the back hand side at the rear court which is in line with the study on the world elite players where 70 % of the reported ACL injury movements were jumps.[21] This suggests that the movement to this corner should have further attention among coaches.

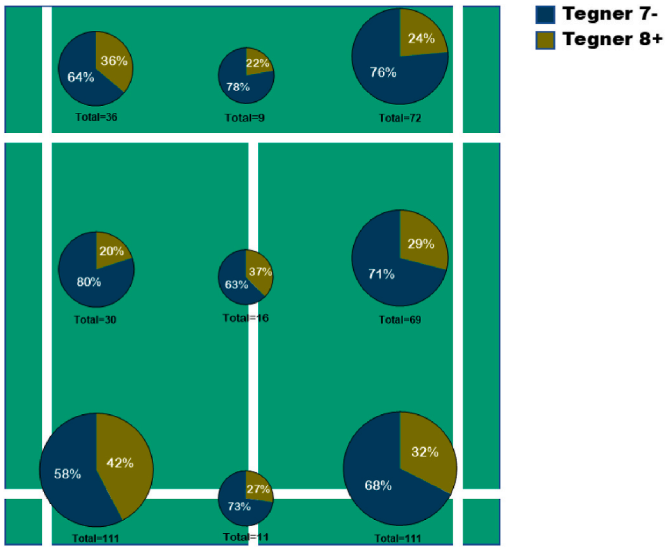

Fig. 5. Distribution of ACL injuries on a half badminton court divided by level of play
The left side represents the backhand side and the right side represents the forehand side. Left-handed players have been converted to right-handed players for better understanding. The top represents the net and the bottom the base line.
Tegner <8: Recreational players
Tegner ≥8: Competitive players
ACL: Anterior cruciate ligament.

4.2. *Jumps in the back hand side*

A SKJ or a block jump landing in the backhand side may be a challenging movement with a stiff landing with an almost full extended knee (Fig. 1). It is comparable to a side cutting in handball or sudden change of direction in football where the landing leg is in a knee valgus position and close to full extension with the tibia internally rotated.[9,22,23] Kimura et al. also showed a difference between scissor kick jump landings in the backhand and forehand side with higher hip abduction and higher knee angle valgus in the backhand side, which may resemble a plant-and-cut movement and suggest it could be a possible risk factor.[24] It may reflect the lower number of ACL injuries after scissor kick jumps in the forehand side.[24] Sasaki et al. further support the higher risk in the back hand side with higher hip and trunk angle as well as mediolateral- and vertical trunk acceleration in the backhand side as possible risk factors.[25] Searching the internet in *Google* and *YouTube combining ACL injury and badminton,* videos of 5 ACL injuries in elite badminton players show the injury location in the back hand side with an overhead forehand stroke in a close to full knee extension[26–30]. The competitive players in our study have a higher risk in the back hand side which may be explained by a powerful playing style with higher loading on the non-dominant knee in the landing phase and possible higher hip- and trunk angles than recreational players. However, this needs to be confirmed in further studies. To be able to hit the shuttle with a forehand overhead stroke in the backhand side the trunk must lean laterally over the landing leg, and this may create higher knee valgus forces and thereby increasing the risk of ACL ruptures (Fig. 1). From video analysis of ACL injuries in other sports knee abduction, lateral trunk lean and hip abduction were characteristics.[10,31] It may therefore be important to address trunk and hip muscle strength to counteract stressful forces around the knee, hip, and core. The more injuries of the dominant leg in the forehand side and the non-dominant leg in the backhand side corner on the rear court emphasize the need of analyzing the technique of these special movements. Our study demonstrates a similar frequency of ACL injuries on the rear court in the forehand and backhand side, and we therefore need to further analyze the risk factors in the forehand side as well.

4.3. The lunge movement

A significant number of injuries occurred during the lunge movement. Biomechanical studies on the lunge movement have shown very little load on the ACL performing this movement, but the badminton specific lunge movement may not resemble a standard lunge movement examined in most studies, as it is likely performed more explosively with high impact forces and possibly also with a more extended knee joint and a sideways movement.[32–35] During the standard lunge only limited hamstring activation is shown compared to other ACL injury risk movements like side cutting,[36] which may add to the injury risk, but this needs to be investigated in studies examining the badminton specific lunge.[37]

It could be expected that lunge at the rear court is a more critical movement than the lunge at the net since the upper body typically is turned away from the direction towards the rear court (facing the side line) and thereby increasing the risk of creating a higher knee valgus moment and a critical pivoting movement in the knee. However, there was no difference in the occurrence at the net and the rear court. If the players are fatigued or lack muscular strength, they may not be able to stabilize the knee during the eccentric loading phase of the lunge. Most of ACL ruptures occurred in the last 2/3 of matches suggesting fatigue to be an issue and may reduce the muscular control of the knee. Furthermore, Chaudhari et al. has described higher knee valgus moments in the dominant knee when players hold an object in the hand, and forward bending of the trunk to reach for a shuttle far away from the body center in the lunge movement may create even higher demands on knee stability.[38]

4.4. Prevention of ACL injuries in badminton

Since the number of registered male badminton players is twice the number of female players and the number of ACL injuries in this study is evenly distributed between male and females, the risk of an ACL injury among female badminton players in Denmark seems to be higher compared to males.[39] This is in line with a Japanese study on high school athletes reporting a 4–5 fold higher ACL injury risk in females compared to males.[40] It is important that we look at the female athletes separately and try to characterize risk factors among them.

An even distribution of injuries between training and competition in this cohort underlines that players are at higher relative risk in match play since they train more hours. It is difficult to introduce a true match like situation in training, however it seems important to train with the same intensity and exhaustion as in matches to prepare the players better for match. In handball and football it has been possible to reduce ACL injuries with injury prevention programs focusing on functional stabilizing exercises challenging the proprioceptive system and in handball furthermore teaching the players game like landing techniques.[41,42] It would be reasonable to focus on especially technical performance of lunge and scissor kick jumps and development of a badminton specific program similar to the FIFA11+ for football may be an instrument to prevent ACL injuries in badminton.[40,43,44]

5. Limitations

Since only few ACL injuries have been recorded on video it is necessary to interview players on the injury characteristics to gather information which can lead to injury prevention. However, this introduce recall bias. In this study patients were asked about injuries which in some cases occurred more than 20 years ago. The risk of recall bias may be high in this population even though an ACL injury is a life changing event which is captured well in the memory. The questions in the questionnaire were simple and the players were able to reply that they were not aware of the injury characteristics or could not recall it. This may improve validity of the answers. The response rate on the different questions was high (72–96 %). The lowest response rate was linked to the question on hand dominance which was necessary to define the "dominant leg". This lower response rate can be explained by the fact that the question was not included in the primary questionnaire and send out to only those who had accepted to receive further questions.

6. Conclusion

The most prevalent movement preceding the ACL injury was the lunge followed by the scissor kick jump. The rear court was the primary location of ACL injury in badminton and the dominant knee has a higher risk of injury in the forehand side and the non-dominant knee in the backhand side. More focus on the technical performance of lunge and scissor kick jumps and development of a badminton specific ACL injury prevention program is needed in badminton.

Conflicts of interests

The authors have no competing interests to declare that are relevant to the content of this article.

Funding statement

The study has been partly funded by Badminton World Federation and Amager-Hvidovre Hospital.

Author contribution

Niels Christian Kaldau, Peter Nyby Hersnaes, Kristoffer Weisskirchner and Per Hölmich contributed to the study conception and design. Material preparation, data collection and analysis were performed by Niels Christian Kaldau and Frederik Flensted Andersen. The first draft of the manuscript was written by Niels Christian Kaldau and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Approval was granted from the Danish Data Protection Agency (P-2020-304), ethical board approval was not necessary since no intervention was performed. Informed consent was obtained from all individual participants included in this study.

Data availability

On a reasonable request data can be shared from the corresponding author. The data are not publicly available, owing to restrictions on their containing information that could compromise the privacy of research participants.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Consent

Informed consent was obtained from all individual participants included in this study.

Data availability

On a reasonable request data can be shared from the corresponding author.

Acknowledgment

Images are brought with permission from BADMINTONPHOTO

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2024.09.005.

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