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Factors Associated with Knee Injury Occurrence Using Performance Tests in Male University Rugby Players

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Abstract

This longitudinal study aimed to determine the performance-related knee injury risk factors in male university rugby union players. Baseline performance measurements were taken in the pre-season and included: (1) strength tests–maximal isometric voluntary contraction (MVC) and single-limb hop test; (2) balance tests–Balance Error Scoring System and Y Balance Test–Lower Quarter; and (3) movement quality–Landing Error Scoring System. The Limb Symmetry Index (LSI) was calculated using strength tests. Knee injury surveillance data, including incidence, severity, and burden, were tracked and analyzed over 1 year. Of the 79 candidate players, 64 completed the test set, and 58 were included in the analysis. We observed 15 knee injuries in 13 players. The injury incidence was 0.4 injuries/1000 player-hours (1000 h) (95% confidence interval [CI], 0.2–0.5); severity was 51 days (95% CI, 0–104); and the burden was 19 days/1000 h (95% CI, 11–31). High LSI of hip internal rotation (odds ratio [OR], 1.09; 95% CI, 1.02–1.16) and MVC of hip extension (OR, 1.10; 95% CI, 1.00–1.20) were identified as significant factors associated with the occurrence of knee injury. In conclusion, the present study suggests that knee injuries are associated with the LSI of hip internal rotation and MVC of hip extension. Players with high performance levels are more exposed to higher injury risks during matches. Given that performance test results may predict knee injury incidence, regular monitoring of such tests may help prevent knee injuries.

Keywords: rugby union, injury prevention, performance, risk factor

男子大学ラグビー選手におけるパフォーマンステストを用いた膝関節外傷の関連要因

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要約

本研究は男子大学ラグビー選手における，パフォーマンスに関する膝関節外傷の危険因子を明らかにすることを目的とした．プレシーズンに下記のベースライン測定を行った：1) 筋力–maximal isometric voluntary contraction (MVC) と single-limb hop tes，2) バランス–Balance Error Scoring System と Y Balance Test–Lower Quarter, 3) 動作エラー–Landing Error Scoring System．筋力については，対称性指数（Limb Symmetry Index; LSI）を算出した．膝関節外傷調査については，１シーズンの incidence，severity，burden を算出した．79 人の選手のうち，64 人がすべての測定を受け，58 人が解析対象となった．58 人の選手のうち，15 件（13 名）の膝関節外傷が生じた．膝関節外傷の incidence は 0.4/1000 h（95% confidence interval [CI], 0.2–0.5)，severity は 51 days（95% CI, 0–104），burden は 19 days/1000 h（95% CI, 11–31）であった．股関節内旋筋力の高い LSI（odds ratios [OR], 1.09; 95% CI, 1.02–1.16）と高い股関節伸展最大筋力（OR, 1.10; 95% CI, 1.00–1.20）が膝関節外傷の有意な予測因子であった．結論として，本研究から膝関節外傷は，股関節内旋筋力の LSI と股関節伸展最大筋力と関連するこ

とが示唆された．高いパフォーマンスを持つプレイヤーは曝露時間の増加とともに，高い膝関節外傷リスクを伴う可能性がある．パフォーマンステスト結果が膝関節外傷の発生の予測因子になりうることから，定期的なパフォーマンスのモニタリングは膝関節外傷予防の一助となるかもしれない．

Keywords: ラグビーユニオン，外傷予防，パフォーマンス，危険因子

Introduction

Rugby union (rugby) players are required to perform high-speed running, engage in contact events, and use their strength and power during competition[1]. Owing to the high-intensity running and frequent collisions, rugby is considered one of the sports with the highest risk of injury[2]. Epidemiological studies have reported that the injury incidence and severity in rugby are substantially higher than those in many other popular sports, such as Rugby League[3], Football[4], and Australian Rules Football[5]. Given this elevated risk, identifying performance-related predictors of injury in rugby could provide valuable insights for targeted prevention efforts.

Notably, knee injuries have the highest burden, expressed as the product of incidence and days of absence (severity)[6], with severity rising over the last two decades despite unchanged incidence[7]. Therefore, we must rethink our approach to preventing knee injuries. Although injuries do not have a single cause, traditional sports injury prevention approaches focus on simple sequential models[8]. In alignment with the redefined paradigm for injury prevention, three components are outlined: first, conduct quantitative and qualitative analyses that identify injury risk factors; second, provide evidence-based solutions that reduce injury risk while maintaining peak performance; and third, implement guidelines and tools that ensure usability and accessibility.

Given that young athletes have the highest knee injury rate[9] and that previous knee injury increases the risk of recurrence[10], developing prevention strategies at the pre-professional level is crucial. Rugby knee injury mechanisms include direct, indirect, and non-contact types, each with distinct characteristics. Contact events require strength and power, and correlate with physical performance[11]. Non-contact actions, such as changes of direction and landing, require neuromuscular control, including balance and posture strategies[12]. However, the relationship between knee injuries and these factors remains unclear, making comprehensive performance testing necessary to clarify this relationship and identify risk factors in rugby players.

Although performance assessments for athletes returning to sports (RTS) after anterior cruciate ligament (ACL) injury have been extensively discussed, their utility in predicting general knee injury risk remains unexplored. The ACL RTS test battery comprehensively assesses multiple domains influencing knee injury risk[13-15]. Strength assessments such as maximal isometric voluntary contraction (MVC) and the single-limb hop test (SLH) calculate the limb symmetry index (LSI), which should reach 90% for RTS[16]. Low LSI causes compensatory movements that increase lower-limb injury risk[17], while muscle imbalance between the agonist-antagonist pair is a recognized ACL injury risk factor[18]. Balance assessment includes the Y Balance Test–Lower Quarter (YBT-LQ), which correlates with lower limb injuries[19], and the Balance Error Scoring System (BESS), which shows greater imbalance in ACL-injured compared to non-injured groups[19]. The Landing Error Scoring System (LESS) assesses movement quality by identifying high-risk errors. Poor performance on these tests correlates with increased lower-limb injury risk[20].

Given the comprehensive nature of this established test battery and its assessment of multiple injury-relevant domains, this study aimed to identify knee injury risk factors using ACL RTS performance measures in male university rugby players. We hypothesized that the injured group would demonstrate lower scores on strength and balance tests and increased dynamic movement errors on the LESS.

Materials and Methods

Study design

This study included 79 male rugby players during the 2023 season (February to December), comprising 42 forwards (FWs) and 37 backs (BKs). Players who were injured or undergoing rehabilitation at baseline testing were excluded to ensure consistency.

We obtained baseline measurements during the pre-season, with each player participating on two separate days. After completing the anthropometric test, players underwent performance tests of: 1) strength—MVC and SLH; 2) balance—BESS and YBT-LQ; and 3) movement quality—LESS. Each test was conducted by three to four members of the team's medical staff. Subsequently, the performance and knee injury surveillance data were combined for statistical analysis at the end of the season.

These longitudinal data, collected over one season, were originally gathered by the university rugby team for performance monitoring and conditioning data. Ethical approval for research use of these existing records was obtained from the Ethics Review Board of the Institute of Health and Sport Sciences at the University of Tsukuba (approval number: Tai 023-64) on 6 September 2023. Following approval and informed consents from all players, baseline data were combined with injury data for analysis.

Injury surveillance

Knee injuries were defined as those diagnosed by the team physicians that occurred during a rugby match or training session and resulted in ≥24 h of restricted participation in training or matches on the day after injury[21)]. Knee injury types were classified using the Orchard Sports Injury and Illness Classification System[22)], and the incidence was recorded. Injury mechanisms were categorized as direct, indirect, and non-contact. Exposure time was defined as an individual player's participation time in rugby, including matches and training sessions (rugby skills or physical conditioning conducted by team staff), and was recorded by the team medical staff. The incidence was calculated as the number of injuries per 1000 player-hours (1000 h) of exposure time. Mean severity was calculated as the total number of days of absence (from injury onset to the day of return to competition) divided by the total number of injuries. Further, injury burden was calculated as the product of incidence and mean severity, and reported as days of absence per 1000 h[6)]. Contest types were categorized as tackling, being tackled, scrum, ground collisions, stepping/cutting, other non-contact play, and unknown[23)].

Performance data

Baseline data included the following demographic information: height (cm), body mass (kg), age (years), rugby experience (years), playing position (FWs or BKs), injury history, and general joint laxity (GJL; maximum score of 7) assessed using the University of Tokyo GJL test[24)]. Players were categorized into two groups: university championship (U) and non-university championship (N) groups. Five performance tests were conducted: strength (MVC and SLH), balance (BESS and YBT-LQ), and movement quality (LESS).

MVC

The MVC was measured using hand-held dynamometry (Mobile; SAKAImed Co., Ltd.) and the MT-250 pull sensor (Sakai Medical Co., Ltd., Japan). Each measurement lasted between 3–5 s and ended when the maximal force stabilized[25)]. Two trials were conducted for each muscle group: hip flexion (Flex) and extension (Ext), external rotation (ER) and internal rotation (IR), abduction (Abd) and adduction (Add), and knee flexion (Flex) and extension (Ext). The maximal peak force data (Nm) were normalized to body weight (%BW)[25)]. The MVC ratio was calculated for agonist-antagonist muscle pairs: hip

Ext/Flex, IR/ER, Add/Abd, and knee Ext/Flex. These ratios were expressed as percentages.

SLH

For each hop test, participants performed two test trials following two practice trials, as described in a previous study[26)]. The SLH included: (1) single hop for distance (SHD); (2) triple hop for distance (THD); (3) crossover hop for distance (CHD); and (4) 6-m timed hop (6TH). Each test was performed with maximal effort, and the maximum distance for SHD, THD, and CHD, along with the fastest time of the 6TH, were recorded.

BESS

To assess balance, players were instructed to close their eyes and place their hands on their hips. The three BESS positions included: (1) feet together; (2) single-leg stance; and (3) tandem stance, each performed on two different surfaces (firm and foam) for a maximum of 20 s per position. The examiner recorded errors using an objective error list[27)]. The error list included: opening the eyes; lifting hands off the hips; stepping, stumbling or falling; lifting the forefoot or heel; moving the hip >30° into flexion or abduction; and remaining out of the test position for more than 5 s. Each error was assigned one point, with a maximum of 10 points per position[28)].

YBT-LQ

We measured three reach directions: anterior, posteromedial, and posterolateral, with two trials performed in each direction. Lower limb length was measured from the anterior superior iliac spines to the medial malleolus. Normalized reach distances were expressed as a percentage of lower limb length, calculated as: (sum of three reach directions ÷ [3 × lower limb length]) × 100[29)].

LESS

LESS is a validated predictor of knee injury risk[20]. For the jump-landing task, players stood on a 30 cm box placed at a distance equal to half their height from the landing area, jumped down and landed, and then immediately performed a maximal vertical jump. Three trials were conducted following two practice attempts. Two cameras were placed 10 feet in front of and to the right of the player to record sagittal and frontal plane movements.[20] Movement quality was evaluated using a dichotomous scoring rubric focused on the dominant leg.

Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test. Descriptive statistics included means and standard deviations for performance data. The LSI for MVC and SLH tests was calculated as the ratio of the involved limb to the uninvolved limb in injured players and the poor-performing limb to the well-performing limb in uninjured players[30]. Group differences between injured and uninjured players were analyzed using an independent t-test for normally distributed data and Mann–Whitney U tests for non-parametric data.

Knee injury–associated factors were evaluated using a forced-entry logistic regression analysis based on variables that showed significant differences in univariate testing (n = 15 injuries). Injury states served as the dependent variable (uninjured or injured), with performance and anthropometric data treated as independent variables.

Receiver operating characteristic (ROC) curves were constructed using predicted probabilities from logistic regression models. The area under the curve (AUC) was calculated to assess discriminative performance. Youden's index (sensitivity + specificity − 1) was used to determine optimal cut-off values. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Statistical analyses were performed using SPSS version 29 (IBM Corp., Armonk, NY, USA), and statistical significance was defines as $p < 0.05$.

Results

Of the 79 players evaluated as candidates, 64 completed the test set, and 58 were included in the analysis (Fig. 1). The baseline characteristics are presented in Table 1.

Fifteen knee injuries occurred during the season (Table 2). The most common injury types were ligament, meniscal/cartilage, and bone contusions, with a higher incidence during matches compared to training sessions.

Among contest types, ground collisions had the highest incidence, whereas stepping/cutting resulted in the highest burden. The incidences of direct and non-contact mechanisms were equal; however, direct mechanisms resulted in greater severity and burden than non-contact mechanisms (Table 3).

Fig. 1

Table 1.

Table 2.

Table 3.

Risk factors of knee injuries

Univariate testing revealed significant differences in the MVC of hip Ext, the MVC ratio of hip Ext/Flex, and the LSI of the 6TH, THD, hip Ext, ER, IR, Abd, and knee Ext (Table 4). Additionally, all performance scores in the injured group were higher than those in the uninjured group.

Based on univariate testing, nine variables were entered as independent variables: MVC of hip Ext, MVC ratio of hip Ext/Flex, LSI of the 6TH and THD, hip Ext, ER, IR, Abd, and knee Ext. Logistic regression analysis identified higher LSI of hip IR (OR, 1.09; 95% CI, 1.02–1.16) and higher MVC of hip Ext (OR, 1.10; 95% CI, 1.00–1.20) as factors significantly associated with knee injuries (Table 5).

ROC analysis revealed the following cut-off values: LSI of hip IR – 53.8% (sensitivity: 53.8%; specificity: 0.0%; AUC: 0.77; 95% CI, 0.59–0.94; $p = 0.004$). MVC of hip Ext – 35.0% (sensitivity: 46.2%; specificity: 11.1%; AUC: 0.70; 95% CI, 0.53–0.87; $p = 0.03$).

Table 4.

Table 5.

Discussion

This study examined performance-related knee injury risk factors in male rugby players. The main findings of this study are: (1) ligament injuries, meniscal/cartilage damage, and bone contusions were the most common; (2) direct mechanisms demonstrated greater severity and burden than those from non-contact mechanisms; and (3) a higher LSI of hip IR and greater MVC of hip extension were associated with an increased risk of future knee injury.

Injury surveillance (incidence, severity, and burden)

Consistent with previous studies, the incidence and burden of knee injuries during matches were higher than those during training, whereas the severity was similar for both.[31] The incidence in this study (9.6/1000 h) was lower than that reported in professional male rugby union (11.1/1000 h), whereas the severity and burden were higher (71 days vs. 45 days; 684 days/1000 h vs. 493 days/1000 h). These findings suggest that high severity and burden are independent of incidence rates. Therefore, university players experience longer recovery periods and more severe knee injuries. This suggests that university players possess less developed physical skills and experience notable differences in match and training intensity compared to professionals.

Knee injury type, contest type, and injury mechanism

Our findings, consistent with previous results, demonstrated that the most common types of knee injuries are ligament injuries, meniscal cartilage injuries, and bone contusions[32)]. Among these, MCL injuries were the most common ligament injuries, which aligns with findings in other contact sports such as American football[33)] and Australian rules football[34)]. This finding suggests that MCL injuries occur regardless of the level of play or type of competition.

Furthermore, the most common contest type was ground collisions, followed by stepping or cutting movements and other non-contact play. Regarding injury mechanisms, this study demonstrated a similar incidence rate for direct and non-contact mechanisms; however, direct contact was the most common among professional players[35)]. These results highlight the importance of non-contact mechanisms, suggesting that neuromuscular and biomechanical performance may affect modifiable risk factors. Additionally, Evans et al.[36)] found that players with low pre-season training loads and a history of previous injury face an increased risk of non-contact injury, specifically during the late season.

Therefore, enhancing performance and monitoring training loads throughout the season are crucial aspects of injury prevention. Interventions focusing on university players, who are at greater risk of non-contact injuries, could be beneficial.

Baseline performance measurements: injured vs. uninjured

Contrary to our hypothesis, we observed that the injured group had a significantly higher MVC ratio, MVC, and SLH LSI compared with the uninjured group. Results from a previous study support these findings[37)]. Furthermore, our findings indicate that injured players may exhibit better performance, making them more likely to be selected for matches, thereby increasing their exposure time. Previous studies have examined and modelled an association between high match and training exposures and injuries sustained in professional rugby [6,38,39)] and football[40)] players. Each additional match exposure increased the risk by 170 days/1000 h of match exposure. These results further verify that greater match involvement increases injury risk. Injury risk is multifactorial and influenced by factors such as performance, fatigue and workload. Future studies should incorporate both objective and subjective data to build comprehensive models. The use of pattern recognition analysis[41)] and artificial intelligence shows promise for identifying comprehensive injury risk in longitudinal cohorts.

Performance risk factors for knee injury

The main factors associated with knee-injury occurrence in this study were a high LSI of hip IR and the MVC of hip Ext. Given that hip IR can predispose athletes to ACL injury[42)], enhancing hip ER strength and moment could be a vital prevention strategy during dynamic movements[43)]. Additionally, weakness in hip ER strength may contribute to knee valgus[44)]. Although its association with knee-injury occurrence did not reach statistical significance, addressing the strength imbalance between hip ER and IR is crucial for effective knee-injury prevention strategies. Hip Ext strength serves as a key component of ACL injury prevention[45)], as it helps reduce loading on the ACL and the knee valgus moment during non-contact mechanisms[45)]. However, we observed a counterintuitive result: players with greater hip Ext strength had a higher incidence of knee injury. A possible explanation is that stronger players are more likely to be selected for matches and extended playing time, thereby increasing their injury burden[31)]. Furthermore, extended playing time may lead to increased fatigue, and neuromuscular factors can result in delayed activation or co-contraction of quadriceps and hamstring muscles[46,47)]. By contrast, low test scores could contribute to injury occurrence due to reduced impact absorption capacity[48)], impaired joint stability[49)], altered movement patterns under the fatigue[50,51)].

Although a recent study questioned the utility of LSI as an RTS criterion due to the overestimation of knee function[52)], LSI remains valuable for identifying strength asymmetries that may contribute to injury risk. Most RTS criteria have focused solely on quadriceps and hamstring strength[53)], often overlooking the role of the hip rotator muscles. Furthermore, the validity of knee injury prevention programmes has yet to be established[53)]. In rugby, the “Activate” programme, a rugby-specific injury prevention initiative, has been shown to reduce overall injury incidence[54)]. Therefore, it is essential to develop a knee-specific prevention programme that includes assessment of hip rotator strength alongside LSI of MVC, while recognizing that LSI should be part of a multifaceted evaluation.

Although this study provides new insights, it had some limitations. First, the study focused on a single university rugby team and tracked injuries over one season. The Rugby Injury Consensus Group[21)] recommends that injury surveillance studies include at least one team over a single season. Moreover, monitoring multiple teams over a longer period would facilitate the identification of injury trends and improve the generalisability of the findings. Second, this study involved a small sample size and limited number of injury events. a post hoc power analysis was performed using G*Power software 31 (Version 3.1.9.6, University of Düsseldorf, Dusseldorf, DEU)[55]. The analysis, based on the significant MVC of hip Ext (effect size: 0.81), yielded a power of 0.71 at an α-level of 0.05. Given that the recommended power (1 − β) of 0.8 is considered adequate, the required sample size was at least 72 participants (56 uninjured, 16 injured). Third, given the relatively small sample size and number of variables included, our multivariable models might be susceptible to potential overfitting. To minimise overfitting risk, univariable analysis was conducted to screen variables before inclusion in the multivariable model, thereby reducing the number of candidate associated factors[56]. Although this study identified significant associated factors, future studies should include larger multicentre cohorts or intervention studies and confirm the effectiveness of knee-specific injury prevention programmes, including hip rotator muscle exercises.

Conclusion

We found that a high LSI of hip IR and high MVC of hip Ext were the main factors associated with knee-injury occurrence. Players with better performance are more likely to be selected for matches, which are associated with a higher risk of injury. Furthermore, knee injuries in university players require longer recovery periods and tend to be more severe, suggesting that researchers should focus more on this area. Overall, field-friendly metrics with high clinical relevance may be valuable for managing performance and conditioning, as well as informing return-to-sport criteria.

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Conflict of interest

Not applicable.

Author contribution

AO, RO, and YN contributed to conceptualisation. AO and RO contributed to the methodology. AO contributed to formal analysis. TS contributed to resources. AO and YN contributed to data curation. AO and RO contributed to writing—original draft preparation. YN contributed to supervision and project administration. AO contributed to funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Table 1. Baseline characteristics of the participants

	All (n = 58)	Uninjured (n = 45)	Injured (n = 13)
Height (cm)	173.9 ± 14.4	173.1 ± 15.9	176.8 ± 5.7
Body mass (kg)	88.3 ± 16.0	88.2 ± 17.3	88.7 ± 10.4
Age (year)	20.0 ± 1.2	19.9 ± 1.3	20.2 ± 0.8
Rugby experience (year)	11.2 ± 4.1	11.1 ± 4.1	11.4 ± 4.3
Level U (n)	32	24	8
Level N (n)	26	21	5
Position FWs/BKs (n)	FWs (30) BKs (28)	FWs (22) BKs (23)	FWs (8) BKs (7)
GJL (/7)	0.6 ± 0.9	0.6 ± 0.9	0.6 ± 0.9
Current/Recurrent			C (7), R (8)

U; university championships level, N; non-university championships level

Table 2. Incidence, severity, burden, and types of knee injury

	n (%)	Incidence injuries/1000 h (95% CI)	Severity days (95% CI)	Burden days/1000 h (95% CI)
All	15	0.4 (0.2–0.5)	51 (0–104)	19 (11–31)
Match	9 (60.0)	9.6 (3.3–15.9)	71 (0–159)	684 (356–1314)
Training	6 (40.0)	0.1 (0.0–0.3)	20 (5–35)	3 (1–7)
Knee injury types				
Ligament	6 (40)	0.1 (0.0–0.3)	93 (0–224)	14 (6–30)
Meniscal/cartilage and bone contusion	6 (40)	0.1 (0.0–0.3)	27 (6–48)	4 (2–9)
Other soft tissue bruising/ haematoma knee	3 (20)			
Other	3 (20)	0.1 (0.0–0.2)	14 (0–29)	1 (0.3–3)

n, Number of cases; CI, confidence interval, Ligament: including medial collateral ligament rupture knee, lateral collateral ligament strain/rupture, anterior cruciate ligament strain/rupture with chondral/meniscal injury, and partial posterior cruciate ligament tear; Meniscal/cartilage and bone contusion: including lateral meniscal tear, knee articular cartilage damage; Other including patellar tendinopathy, popliteus tendinopathy, post knee surgery.

Table 3. Tackle event and mechanism of knee injuries

Contest type	n (%)	Incidence injuries/1000 h (95% CI)	Severity days (95% CI)	Burden days/1000 h (95% CI)
Tackling	1 (6.7)	0.02 (0.00–0.07)	–	0.5 (0.1–4)
Being tackled	2 (13.3)	0.05 (0.00–0.12)	24 (0–61)	1.2 (0.3–5)
Scrum	1 (6.7)	0.02 (0.00–0.07)	–	0.3 (0–2)
Ground collision	4 (26.7)	0.10 (0.00–0.19)	29 (10–48)	2.8 (1–8)
Stepping/Cutting	3 (20)	0.07 (0.00–0.16)	156 (0–423)	11 (4–35)
Other non-contact play	3 (20)	0.07 (0.00–0.16)	28 (0–65)	2 (1–6)
Unknown	1 (6.7)	0.02 (0.00–0.07)	–	0.2 (0–2)
Mechanism				
Direct	7 (46.7)	0.17 (0.04–0.30)	25 (11–39)	4 (2–8.9)
Indirect	1 (6.7)	0.02 (0.00–0.07)	22	1 (0.1–4)
Non-contact	7 (46.7)	0.17 (0.04–0.30)	19 (3–35)	3 (2–7)

n, number of injuries; %, proportion of all knee injuries; CI, confidence interval

Table 4. Baseline data of performance variables

		ALL	Uninjured	Injured	p
MVC (%BW)*	Hip Flex (%)	46.4 ± 10.7	45.7 ± 10.1	48.9 ± 12.8	0.349
	Hip Ext	32.0 ± 8.8	30.4 ± 8.0	37.7 ± 9.8	0.008
	Hip ER	27.9 ± 5.8	27.6 ± 5.9	28.8 ± 5.9	0.500
	Hip IR	31.6 ± 7.8	30.8 ± 7.9	34.4 ± 7.2	0.150
	Hip Abd	20.7 ± 4.8	20.5 ± 5.1	21.5 ± 4.2	0.506
	Hip Add	21.3 ± 6.7	20.9 ± 6.3	22.7 ± 8.5	0.570
	Knee Flex	37.4 ± 8.5	37.4 ± 9.2	37.5 ± 5.7	0.963
	Knee Ext	46.9 ± 15.5	45.4 ± 15.3	52.7 ± 16.1	0.153
Balance	BESS (/10)	13.6 ± 5.2	13.3 ± 4.9	14.6 ± 6.2	0.423
	YBT-LQ (%)	95.4 ± 6.4	95.8 ± 6.4	94 ± 6.8	0.450
Movement quality	LESS (/19)	5.3 ± 1.8	5.5 ± 1.9	4.9 ± 1.6	0.363
MVC ratio*	Hip Ext/Flex (%)	69.8 ± 14.5	67.1 ± 12.2	79.2 ± 18.6	0.008
	Hip IR/ER	114.5 ± 22.3	105.1 ± 31.1	120.6 ± 21.7	0.270
	Hip Add/Abd	105.1 ± 30.4	123.2 ± 35.4	105.3 ± 30.3	0.933
	Knee Ext /Flex	126.7 ± 35.6	95.8 ± 6.4	140.0 ± 36.2	0.104
MVC of LSI	Hip Flex (%)	92.8 ± 7.8	92.5 ± 6.2	94.0 ± 12.3	0.716
	Hip Ext	88.4 ± 11.2	86.5 ± 9.5	95.1 ± 14.4	0.020
	Hip ER	90.2 ± 12.4	89.0 ± 8.5	94.6 ± 21.3	0.043
	Hip IR	91.3 ± 15.9	87.0 ± 10.2	106.0 ± 23.0	0.012
	Hip Abd	88.9 ± 11.6	86.9 ± 9.2	96.0 ± 16.5	0.033
	Hip Add	87.4 ± 12.3	85.1 ± 9.7	95.2 ± 7.4	0.076
	Knee Flex	91.7 ± 21.1	90.2 ± 10.4	97.1± 41.3	0.081
	Knee Ext	88.5 ± 17.7	87.2 ± 9.9	93.1 ± 33.5	0.047
SLH of LSI	SHD (%)	95.3 ± 5.2	94.7 ± 3.9	97.5 ± 8.3	0.351
	THD	95.8 ± 7.0	94.7 ± 5.7	99.3 ± 10.2	0.027
	CHD	94.1 ± 7.9	93.6 ± 5.6	95.5 ± 13.4	0.092
	6TH	96.8 ± 8.0	95.2 ± 7.2	102.1 ± 9.0	0.006

MVC, maximal voluntary contraction; LSI, limb symmetry index; Flex, flexion; Ext, extension; ER, external rotation; IR, internal rotation; Abd, abduction; Add, adduction; YBT-LQ, Y balance test-lower quarter; BESS, balance error scoring system; LESS, landing error scoring system; SLH, single-limb hop test

*MVC (%BW) and MVC ratio revealed only right leg data.

Table 5. Logistic regression analysis for a modelling knee injury

Variables	B (S.E.)	Wald	OR (95% CI)	p
x1: LSI of Hip IR	0.09 (0.03)	7.17	1.09 (1.02–1.16)	0.01
x2: MVC of Hip Ext	0.09 (0.05)	4.03	1.10 (1.00–1.20)	0.04
Constant	-12.55 (3.44)	13.32	0.00	0.00

LSI; The limb symmetry index, MVC; maximal voluntary contraction, IR; internal rotation Ext; extension, B (S.E.); point estimation (standard error), Wald; Wald test, OR; odds ratio. Probability of the knee injuries = -12.55 + 0.09x1 + 0.09x2, Omnibus test of model coefficients ($p=0.000$), Hosmer and Lemeshow test (Chi square = 13.3, $p > 0.1$), Cox & Snell R2 = 0.288, Nagelkerke R2 = 0.44, Predictive value = 87.9%.

Fig. 1 Flow diagram of included/excluded players

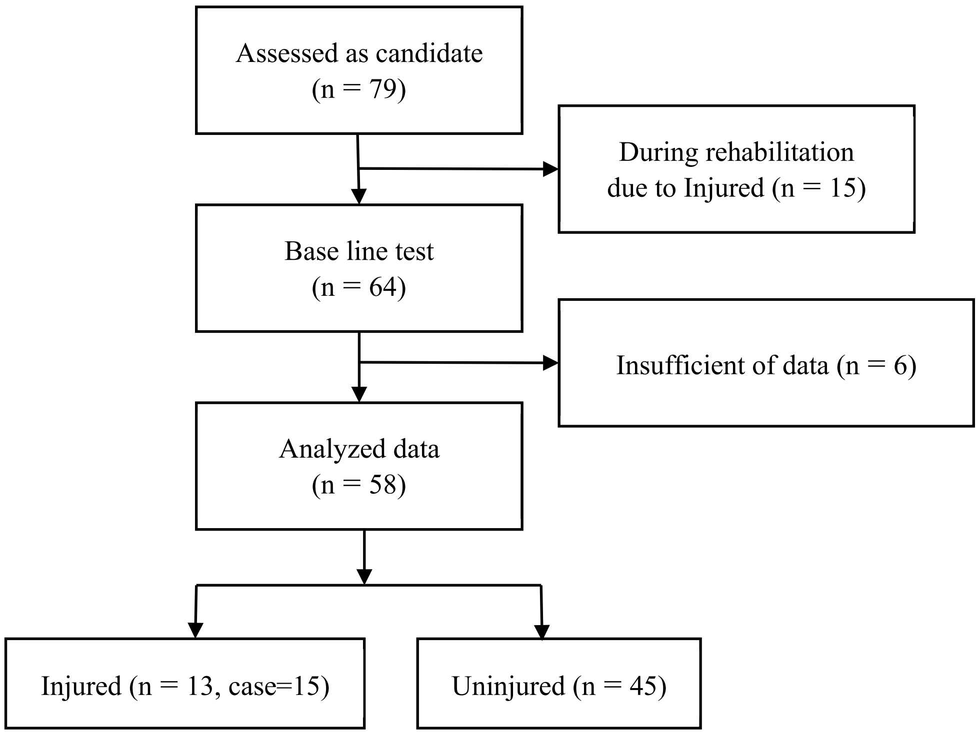

Figure legends

Fig. 1 Flow diagram of included/excluded players