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Original Article

Impact of lower limb alignment abnormality (physiologic knee valgus) on the functional recovery outcome of athletes with meniscal injuries

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Abstract: Objective: This study aimed to investigate the impact of lower limb alignment abnormalities, specifically physiological knee valgus, on the functional recovery outcomes of athletes with meniscal injuries. It also examined the factors influencing these abnormalities to provide scientific evidence for treatment and rehabilitation of related sports injuries. Methods: We conducted a retrospective study of 118 athletes from Guizhou Normal University, who were divided into two groups based on the presence or absence of lower limb alignment abnormalities. The Simple group comprised athletes with isolated meniscal injuries, while the Combined group included athletes with meniscal injuries and concurrent lower limb alignment abnormalities. We assessed the functional status of both groups and analyzed factors influencing lower limb alignment abnormalities. Results: Of the 118 athletes, 46 (38.98%) exhibited lower limb alignment abnormalities, and 72 (61.02%) did not. No significant differences in general characteristics were found between the groups (all $P > 0.05$). The Combined group displayed higher Visual Analog Scale (VAS) scores and Functional Performance Test (FPT) results (coordinated contraction, shuttle run, CarioCa) compared to the Simple group ($P < 0.05$). Conversely, joint range of motion (ROM), knee muscle strength (flexors), and International Knee Documentation Committee (IKDC) scores were lower in the Combined group (all $P < 0.05$). Multivariate logistic regression analysis identified active ROM < 105.32°, passive ROM < 101.66°, and knee muscle strength (flexors) < 84.41 N as risk factors for lower limb alignment abnormalities ($P < 0.05$), while FPT acted as a protective factor ($P < 0.05$). The combined testing model demonstrated higher predictive efficacy (AUC = 0.903, 95% CI: 0.852-0.955, $P < 0.001$). Conclusion: Lower limb alignment abnormalities significantly affect the functional recovery outcomes of athletes with meniscal injuries. Factors such as ROM, knee muscle strength, and IKDC score may pose risks for these abnormalities, whereas FPT can provide protective benefits. Timely detection and correction of lower limb alignment abnormalities during the rehabilitation process from meniscal injuries are crucial to enhance recovery and improve prognosis.

Keywords: Meniscal injuries, athletes, lower limb alignment abnormalities, functional recovery, influencing factors

Introduction

The meniscus, a critical component of the knee joint, is situated between the femoral condyles and the tibial plateau. It is thicker on the outer side and thinner on the inner side, effectively filling the gap between these structures [1]. Composed of fibrocartilage, the meniscus primarily features circularly arranged collagen fibers, enabling it to withstand pressure from the femoral condyles and distribute it evenly across the tibia. This structural arrangement allows the meniscus to play a crucial role in transmitting and dispersing stress, thereby maintaining knee joint stability [2]. Meniscal injury is a prevalent sports-related knee injury, often resulting from dynamic twisting and rotational movements, such as during knee flexion and rotation [3]. A comprehensive study indicated that meniscal injuries comprise over 60% of all knee joint injuries in athletes [4]. Despite advancements in rehabilitation training and surgical interventions that improve symptoms and alleviate pain, some athletes still experience suboptimal recovery of functional abilities post-surgery. Cho et al. [5] identified severe valgus deformity as a risk factor for posterior horn or root tears of the medial meniscus.

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Additionally, Wesdorp et al. [6] assessed the extent of histologic degeneration in acutely traumatic meniscal tears compared to intact and osteoarthritic meniscal tissues. Their findings revealed that traumatically torn menisci exhibit a higher degree of degeneration than intact menisci, highlighting a link between acute traumatic meniscal injuries and degeneration, potentially exacerbated by lower limb alignment abnormalities.

Physiologic knee valgus is the normal inward inclination of the knee joint observed during a typical gait. When this inclination exceeds the normal range, it is considered abnormal. Statistical data indicate that approximately 20% of the population exhibits lower limb alignment abnormalities, with physiological knee valgus being the most prevalent [7]. An abnormal distribution of forces in the lower limbs can lead to knee joint instability and increase the risk of meniscal injuries. Treatment of these injuries typically focuses on the local aspects of the knee joint, with physicians mainly employing arthroscopic procedures to remove damaged meniscal fibers or to restore or enhance its structure. However, the overall condition of the lower limb is often neglected.

There is currently a shortage of research on the effects of combined lower limb alignment abnormalities on the functional recovery outcomes of athletes with meniscal injuries. Therefore, this study aims to explore the impact of combined lower limb alignment abnormalities on these outcomes and to analyze the factors influencing these abnormalities in athletes with meniscal injuries. This research seeks to provide scientific evidence to support the treatment and rehabilitation of related sports injuries.

Materials and methods

Subject selection

A total of 118 athletes from Guizhou Normal University were selected for this retrospective study. The participants, involved in various sports such as weightlifting, athletics, team sports (basketball, volleyball, handball), rugby, and martial arts, sustained injuries either during training or daily activities. The cohort included 85males and 33 females, ages ranging from 15 to 23 years, with an average age of 19 years. Symptom duration varied from 1 day to 6 months. This study received approval from the Ethics Committee of Guizhou Normal University and adhered to the ethical standards of the Declaration of Helsinki. The ethics committee granted a waiver for informed consent.

Diagnostic criteria

The diagnostic criteria for meniscal injuries were established based on the following: 1) A history of knee joint twisting injury with subsequent impaired knee function, affecting training and competition; 2) Symptoms post-injury including joint pain, swelling, reduced range of motion, tenderness on the medial and lateral sides of the knee joint, and potential quadriceps atrophy in later stages, with some patients exhibiting clicking and locking symptoms; 3) Pronounced chronic quadriceps atrophy, especially on the medial side; 4) Positive McMurray test and knee joint grinding test results; 5) Confirmation of meniscal injury via MRI. Lower limb alignment abnormalities were defined as an internal or external rotation angle exceeding 5°, as determined by preoperative full-length X-rays of both lower limbs.

Inclusion criteria

1) Age between 18 and 30 years old; 2) History of torsion injury to the knee joint, accompanied by evident joint pain, swelling, and restricted movement; 3) Clinical examination showing atrophy of the quadriceps muscle, indicating muscle imbalance around the knee joint; 4) Positive McGregor's sign and knee grinding test, suggesting the likelihood of a meniscus injury; 5) Magnetic Resonance Imaging (MRI) confirmation of meniscus injury, including but not limited to meniscus tear or displacement; 6) Patients with complete clinical data.

Exclusion criteria

1) Presence of other knee joint lesions, such as injuries to the anterior cruciate ligament or medial collateral ligament; 2) Presence of other diseases or serious psychological issues that may hinder the normal progression of rehabilitation training; 3) Previous knee surgery; 4) Non-compliance with prescribed treatment or discontinuation of treatment independently; 5) Unclear MRI results or findings showing abnormalities unrelated to meniscus injury; 6)

Serious systemic diseases, such as severe rheumatic diseases or autoimmune disorders; 7) Severe muscle atrophy or paralysis, which could impair the effectiveness of rehabilitation training.

Methods

Data collection: Data were collected on basic information of the athletes, including gender, age, body weight, injury location, initial training age, years of sports participation, years of professional training, symptom duration, history of knee joint trauma, joint range of motion (ROM), pain scores using the Visual Analog Scale (VAS), muscle strength, and subjective evaluation of knee joint function by the International Knee Documentation Committee (IKDC) score. Functional performance tests (FPT) score and the presence of lower limb alignment abnormalities were also recorded.

Grouping method: Athletes with isolated meniscal injuries were assigned to the Simple group, while those with both meniscal injuries and lower limb alignment abnormalities were categorized as the Combined group.

Measurement methods: Primary observation measures included ROM and VAS, with other data as secondary measures.

(1) ROM. Measurement tool: goniometer; Measurement method: The athlete lies prone. The goniometer is positioned with its axis aligned with the fibular head of the knee joint, the fixed arm parallel to the femoral long axis, and the moving arm parallel to the fibular long axis. Knee joint extension and flexion are measured from 0° to 135°.

(2) VAS [8]. Measurement tool: Visual Analog Scale; Measurement method: The scale ranges from 0 (no pain) to 10 (worst pain imaginable). Participants rate their pain based on personal perception.

(3) Muscle strength. Measurement tool: Isokinetic dynamometer; Measurement method: Before testing, participants warm up for 3-5 minutes. During the test, participants sit with the knee angle adjusted to 90°. The dynamometer's axis is aligned with the lateral condyle of the knee joint on the tested limb. The resistance pad is fixed on the inner side of the ankle, approximately three finger-widths above the ankle's upper edge. The angular velocity is set at 60°/s. The test includes 3 sets of 6 repetitions, with a 2-minute rest between sets. The primary parameter measured is the maximum muscle strength of the flexor and extensor muscles.

(4) IKDC score. The IKDC score is a reliable and effective system for assessing knee joint function. This study primarily utilized the third part of the IKDC subjective knee function evaluation, where the score is the sum of various items on the IKDC score sheet. The final score is calculated as a percentage with the formula: IKDC score = (total score - lowest possible score)/score range × 100. The lowest possible score is 18, and the score range is 87.

(5) FPT score. 1) Co-contraction Test: A semicircle with a radius of 244 cm is marked on the floor [9]. Participants wear a waist belt with one end of a 122 cm elastic band attached to a black elastic tube at a height of 154 cm, serving as the semicircle's center. The other end of the band is connected to the waist belt. Participants run along the semicircle, facing the center, three times from right to left and twice from left to right, completing five runs in total. The time taken for each run is recorded. 2) Shuttle Run: The shuttle run covers a distance of 6.1 m, with a line marked at the endpoint. Participants must touch this line with their hand upon reaching the endpoint. One round trip measures 12.2 m, and they must complete two round trips, totaling 24.4 m and including three directional changes. The test is performed three times, and the fastest time is recorded. 3) Carrioca Test: Participants run two 12 m distances using a crossover step, first from left to right and then from right to left. This test is also conducted three times, and the fastest time is recorded. A minimum 5-minute interval is maintained between each of the three functional tests to ensure adequate recovery.

Statistical analysis

Data analysis was performed using SPSS 27.0 statistical software. Continuous data are presented as mean ± standard deviation (SD), and t-tests were used for comparisons. Categorical data are presented as n (%) and compared using chi-square tests. Multiple logistic regression analysis was conducted to identify factors

Table 1. Comparison of general characteristics between the two groups [($\bar{x}$±s), n (%)]

	Simple group (n = 72)	Combined group (n = 46)	χ^2/t	P
Gender			0.615	0.433
Male	50 (69.44)	35 (76.09)		
Female	22 (30.56)	11 (23.91)		
Age (years)	21.32±2.15	22.09±2.23	0.912	0.371
Body weight (kg)	65.17±10.34	66.06±10.19	0.225	0.824
Location of injury			0.063	0.802
Left	39 (54.17)	26 (56.52)		
Right	33 (45.83)	20 (43.48)		
Initial training age (years)	11.54±2.32	11.21±2.15	0.384	0.705
Sports participation (years)	13.43±1.55	12.87±1.31	1.017	0.319
Professional training (years)	10.32±2.07	10.15±1.66	0.236	0.815
Duration of symptoms (weeks)	3.65±1.03	3.71±0.87	0.164	0.871
History of knee joint trauma			0.132	0.716
Yes	21 (29.17)	12 (26.09)		
No	51 (70.83)	34 (73.91)		

influencing lower limb alignment abnormalities in athletes with meniscal injuries. ROC curve analysis was performed to assess the predictive efficacy of motor functional performance-related indicators for lower limb alignment abnormalities in these athletes. A *p*-value < 0.05 was considered significant.

Results

Incidence of lower limb alignment abnormalities

Analysis revealed that 46 of the 118 athletes (38.98%) exhibited lower limb alignment abnormalities, while 72 (61.02%) did not.

Comparison of general characteristics between the two groups

There was no significant difference in general characteristics between the two groups (P > 0.05), as detailed in **Table 1**.

Comparison of motor functional performance-related indicators between the two groups

Group B exhibited higher VAS scores and FPT scores (Co-contraction, Shuttle Run, Carrioca) than Group A (P < 0.05). Conversely, Group A demonstrated higher ROM, both active and passive, affected-side knee muscle strength (flexors), and IKDC scores than Group B (P < 0.05), as shown in **Table 2**.

Multiple logistic regression analysis of factors influencing lower limb alignment abnormalities in athletes with meniscal injuries

Multiple logistic regression analysis was conducted using VAS score, ROM, affected-side knee muscle strength (flexors), ICDK score, and FPT as independent variables, with lower limb alignment abnormalities as the dependent variable. The results indicated that an active ROM of less than 105.32°, a passive ROM of less than 101.66°, and affected-side knee muscle strength (flexors) of less than 84.41 N were all significant risk factors for lower limb alignment abnormalities in athletes with meniscal injuries (P < 0.05). Conversely, FPT acted as a protective factor (P < 0.05). These results are presented in **Tables 3** and **4**. When compared to single indicators, combined detection showed higher predictive efficacy for lower limb alignment abnormalities in these athletes (AUC = 0.903, 95% CI: 0.852-0.955, P < 0.001), as detailed in **Table 5** and **Figure 1**.

Discussion

The meniscus is primarily composed of fibrocartilage with a matrix predominantly made up of collagen proteins, specifically type I collagen, which constitutes nearly 98% of the matrix content [10]. The collagen fibers in the meniscus are mostly circular, with lesser amounts in radial and oblique orientations. This structural con-

Table 2. Comparison of motor functional performance-related indicators between the two groups [($\bar{x}$±s)]

	Simple group (n = 72)	Combined group (n = 46)	χ^2/t	P
VAS score	4.57±0.44	5.22±0.85	2.465	0.021
ROM (°)				
Active	112.54±2.45	105.32±2.87	7.003	< 0.001
Passive	115.34±3.26	101.66±3.34	10.757	< 0.001
Affected-side knee muscle strength (N)				
Extensor	125.34±30.43	112.52±14.16	1.421	0.168
Flexors	95.32±15.57	84.41±11.19	2.103	0.046
ICDK score	75.44±5.23	63.11±6.12	5.606	< 0.001
FPT				
Co-contraction (s)	16.43±1.12	18.98±0.71	7.122	< 0.001
Shuttle Run (s)	7.65±0.31	8.96±0.54	7.648	< 0.001
Carrioca (s)	7.67±0.25	8.87±0.42	8.930	< 0.001

Note: VAS, Visual Analog Scoring; ROM, Range of Motion; ICDK, International Knee Documentation Committee; FPT, Functional Performance Test.

Table 3. Variable assignment scheme for multiple logistic regression analysis of lower limb alignment abnormalities in athletes with meniscal injuries

Factor	Value
Lower limb alignment abnormality	No = "0", Yes = "1"
VAS score	VAS score < 5.22 = "0", VAS score ≥ 5.22 = "1"
ROM (active)	ROM (active) ≥ 105.32° = "0", ROM (active) < 105.32° = "1"
ROM (passive)	ROM (passive) ≥ 101.66° = "0", ROM (passive) < 101.66° = "1"
Affected-side knee muscle strength (extensors)	Strength ≥ 112.52 N = "0", Strength < 112.52 N = "1"
Affected-side knee muscle strength (flexors)	Strength ≥ 84.41 N = "0", Strength < 84.41 N = "1"
ICDK score	ICDK score ≥ 63.11 = "0", ICDK score < 63.11 = "1"
FPT (Co-contraction)	FPT < 18.98 s = "0", FPT ≥ 18.98 s = "1"
FPT (Shuttle Run)	FPT < 8.96 s = "0", FPT ≥ 8.96 s = "1"
FPT (Carrioca)	FPT < 8.87 s = "0", FPT ≥ 8.87 s = "1"

Note: VAS, Visual Analog Scoring; ROM, Range of Motion; ICDK, International Knee Documentation Committee; FPT, Functional Performance Test.

figuration allows the meniscus to be elastic, capable of withstanding tension, pressure, and shear forces. When subjected to weight-bearing, the meniscus compresses, allowing its collagen fibers to bear and distribute pressure [11]. Acting as a "wedge", the meniscus fills the anterior and posterior aspects of the knee joint interface, thus enhancing joint stability. It also plays a critical role in limiting excessive extension, flexion, and rotation of the knee joint [12, 13].

Lower extremity alignment is defined by the line of force extending from the center of the hip joint to the center of the ankle joint, ideally passing near the center of the knee joint to optimize knee function. Deviations in knee joint alignment, such as varus or valgus, can lead to uneven stress distribution across the medial and lateral compartments of the knee, possibly resulting in joint degeneration [14]. Kim et al. [15] observed that middle-aged patients with disc meniscus tears were more prone to knee varus deformity and had a higher incidence of osteoarthritis compared to patients with normal lateral meniscus tears. Wang et al. [16] noted that after arthroscopic discoid meniscus plasty, the alignment of the lower limb force line changed immediately, significantly reducing knee varus deformity, with some patients even showing a tendency toward knee varus correction. Jiang et al. [17] identified knee varus (> 5°) as a critical risk factor for poor clinical outcomes in medial meniscus root injuries,

Table 4. Factors influencing lower limb alignment abnormalities in athletes with meniscal injuries by multiple logistic regression analysis

	β	SE	Wald	P	OR	95% CI
VAS score	0.753	0.098	6.234	0.112	2.125	1.511-2.998
ROM Active	-0.481	0.075	3.664	0.046	0.618	0.398-0.957
ROM Passive	0.269	0.064	2.312	0.029	1.308	0.942-1.816
Affected-side knee muscle strength	-0.532	0.109	4.217	0.041	0.587	0.384-0.898
FPT						
Co-contraction	-0.312	0.072	3.912	0.048	0.732	0.518-1.036
Shuttle Run	0.172	0.056	1.865	0.172	0.187	0.984-1.432
Carrioca	-0.201	0.064	2.694	0.101	0.818	0.619-1.081

Note: VAS, Visual Analog Scoring; ROM, Range of Motion; ICDK, International Knee Documentation Committee; FPT, Functional Performance Test.

Table 5. Predictive efficacy of motor function performance-related indicators for lower limb alignment abnormalities in athletes with meniscal injuries

	AUC	Sensitivity (%)	Specificity (%)	95% CI	P
ROM Active	0.780	0.806	0.696	0.694-0.865	< 0.001
ROM Passive	0.773	0.847	0.717	0.681-0.866	< 0.001
Muscle strength	0.733	0.847	0.522	0.643-0.823	< 0.001
FPT	0.687	0.652	0.750	0.586-0.788	< 0.001
Combined	0.903	0.913	0.764	0.852-0.955	< 0.001

Note: ROM, Range of Motion; ICDK, International Knee Documentation Committee; FPT, Functional Performance Test; AUC, Area under the curve.

as the high load in the medial compartment made healing difficult under such mechanical conditions. Goto et al. [18] found that medial meniscus injuries were closely related to the varus alignment. Okoroha et al. [19] determined that an increased varus angle and posterior inclination of the tibia elevated the risk of damage to the posterior root of the lateral meniscus. Lee et al. [20] investigated factors such as age, gender, body mass index, and force line alignment, discovering that outcomes of varus corrective operations were generally poor, whereas patients with well-aligned force lines experienced better long-term results post-surgery. They also cautioned against performing medial meniscectomy in patients with varus alignment, as the surgical outcomes might not be optimal. These findings underscore the complex relationship between meniscus injuries and lower limb force line alignment. Both meniscectomy and abnormal lower limb force lines can lead to meniscus injuries and influence their therapeutic outcomes.

This study aimed to explore the impact of concurrent lower extremity alignment abnormalities on the motor functional recovery outcomes of athletes with meniscal injuries and to analyze the factors influencing the combination of meniscal injuries with lower extremity alignment abnormalities. The findings indicated that athletes with meniscal injuries and concurrent lower extremity alignment abnormalities had higher VAS scores and FPT scores (coordinated contraction, shuttle run, and Carrioca) but lower ROM, both active and passive, affected-side knee muscle strength (flexor), and IKDC scores.

Possible explanations for these findings include the reduced stability of the knee joint due to lower extremity alignment abnormalities, which heightens the risk of meniscal damage and leads to unstable force lines acting on the knee joint during physical activity. This instability likely contributes to diminished performance in activities such as the coordinated contraction, shuttle run, and Carrioca tests [21]. Furthermore, lower extremity alignment abnormalities may impair muscle strength and control [22], affecting the normal alignment which is essential for maintaining muscle coordination and balance. These alignment abnormalities alter muscle function, resulting in

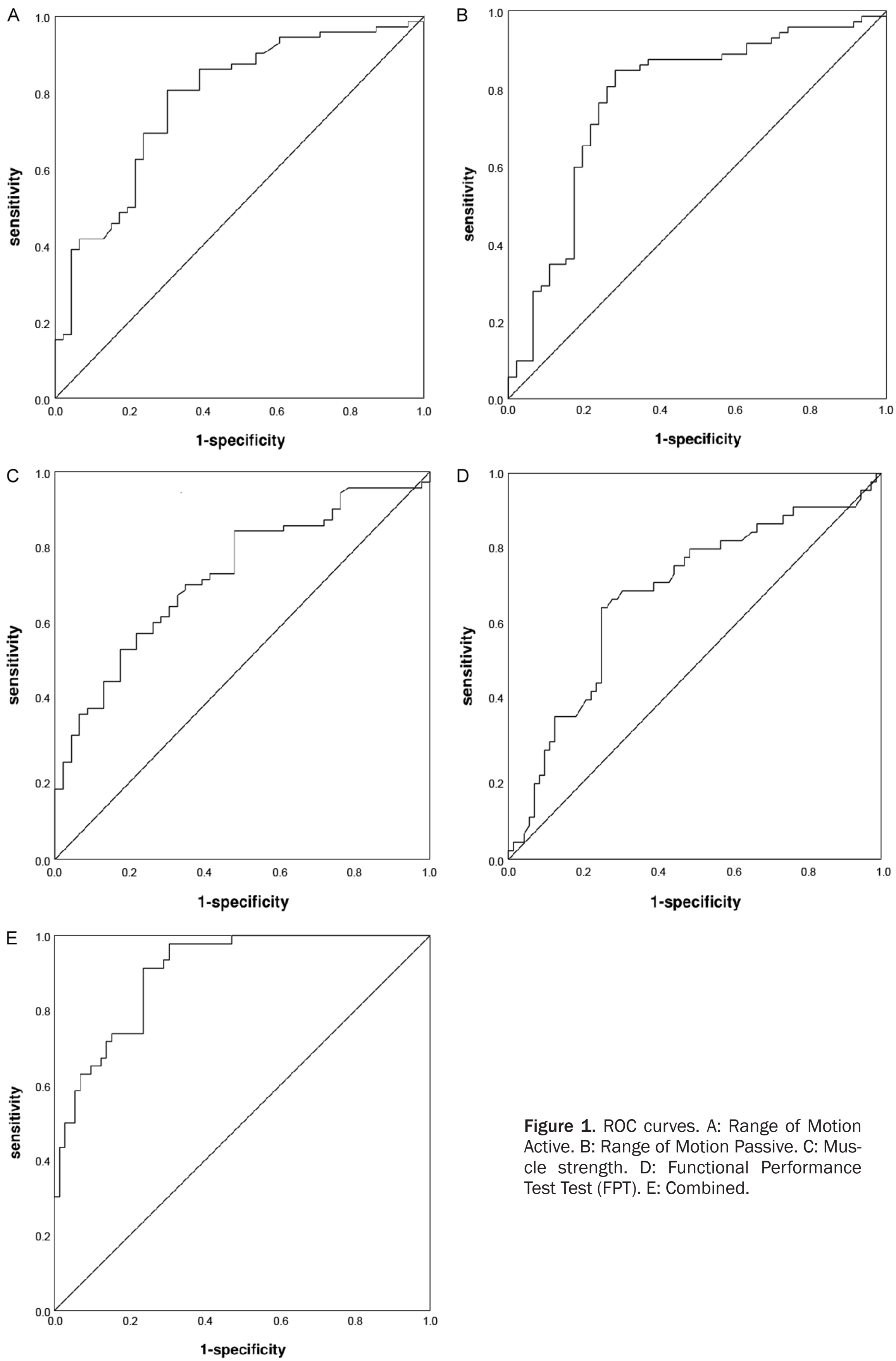

Figure 1. ROC curves. A: Range of Motion Active. B: Range of Motion Passive. C: Muscle strength. D: Functional Performance Test Test (FPT). E: Combined.

decreased or unstable muscle strength, which consequently leads to reduced active and passive ROM and lower affected-side knee muscle strength (flexor) in athletes with meniscal injuries [23]. Moreover, these abnormalities may restrict the knee joint's normal range of motion, increasing internal rotation which adversely affects normal knee flexion, extension, and rotation. This limitation can result in reduced ROM and compromised joint flexibility and function in athletes with these injuries [24].

Lower extremity alignment abnormalities may contribute to knee joint pain and functional impairment by increasing stress and pressure on the knee, which can lead to inflammation and pain reactions. This increased pain is often reflected in the severity assessments within athletes' VAS scores, negatively impacting their motor functional recovery. Moreover, multiple-factor logistic regression analysis revealed that active ROM < 105.32°, passive ROM < 101.66°, and affected-side knee muscle strength (flexor) < 84.41 N are risk factors for lower extremity alignment abnormalities in athletes with meniscal injuries ($P < 0.05$). Conversely, FPT scores were identified as a protective factor ($P < 0.05$).

Active and passive ROM assess the range of motion of the knee joint, both in active movements and when moved by an external force. Lower extremity alignment abnormalities may restrict the knee joint's normal range of motion, particularly in flexion and extension [25], leading to reduced active and passive ROM in athletes with meniscal injuries who also have these alignment issues [26]. The decrease in affected-side knee muscle strength (flexor) may indicate that lower extremity alignment abnormalities are impairing muscle function. These abnormalities alter the way muscles operate, resulting in reduced or unstable muscle strength, thereby decreasing affected-side knee muscle strength (flexor) in affected athletes. FPT evaluates performance in coordinated contraction, shuttle run, and Carrioca tests. Alignment abnormalities may alter athletes' movement patterns and action control, adversely affecting their performance in such tests.

In conclusion, lower extremity alignment abnormalities significantly affect the motor functional recovery outcomes of athletes with meniscal injuries. Factors such as subjective VAS scores, ROM, affected-side knee muscle strength, and IKDC scores may serve as risk factors for these abnormalities, while FPT appears to act as a protective factor. It is therefore crucial to identify and correct lower extremity alignment abnormalities during the rehabilitation process to enhance the recovery and prognosis of athletes with meniscal injuries.

The limitations of this study are as follows. The sample selection might be biased as it was drawn from specific institutions or populations, possibly limiting the generalizability of the results. The retrospective design could also affect data quality, including issues with missing data, measurement errors, and inconsistencies in data recording. Other potential influencing factors, such as athletic ability, were not considered in this study. Finally, the lack of temporal control does not eliminate the possibility of reverse causality. To more accurately assess the impact of lower extremity alignment abnormalities on athletes with meniscal injuries, a larger sample size and prospective study design are needed. Future research should address these limitations in a more detailed and comprehensive manner to elucidate the true mechanisms by which lower extremity alignment abnormalities affect athletes with meniscal injuries.

Disclosure of conflict of interest

None.

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