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Can Ankle Sprains Be Prevented in Football? Clinical Evidence and Rehabilitation Recommendations

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Abstract: Ankle sprains (AS), particularly grade II lesions, represent one of the most frequent injuries in football and are associated with a high risk of recurrence and long-term functional instability. Recent advances in rehabilitation emphasize the role of technology-assisted interventions in restoring neuromuscular control and preventing re-injury. This study aimed to compare the effectiveness of a modern, device-assisted rehabilitation protocol versus a traditional physical therapy program in reducing recurrence rates and improving functional outcomes in young football players with recurrent AS. A randomized controlled study was conducted on 30 male football players (aged 17–20 years) diagnosed with recurrent grade II AS. Thirty football players were randomized (15 per group). Following attrition due to non-compliance and incomplete datasets, 22 participants (11 per group) completed the study and were included in the per-protocol analysis. The experimental group (EG) followed a personalized rehabilitation program using Biodex System 4 Pro and Biodex Balance System, while the control group (CG) underwent a conventional exercise-based protocol. Functional outcomes, including joint mobility (°), gait symmetry (%), cadence (steps/min), and muscle strength (Nm), were assessed at baseline, intermediate, and final evaluations using PodoSmart and isokinetic testing. Statistical analysis included Mann–Whitney U and Friedman's χ^2 tests, with significance set at $p < 0.05$. Both groups demonstrated significant improvements over time ($p < 0.001$); however, the EG showed superior outcomes across all parameters. Affected limb flexion increased from 24.6° to 65.3°, while gait symmetry improved from 83.3% to 98.1% and cadence from 75.7 to 106 steps/min. In contrast, the CG showed lower gains (symmetry: 81.2% to 92.2%; cadence: 75.2 to 89.6 steps/min) and persistent inter-limb differences at final evaluation ($p < 0.01$). No significant differences between healthy and affected limbs were observed in the EG at the final stage ($p > 0.05$), indicating complete functional recovery, whereas deficits persisted in the CG ($p < 0.001$). Importantly, no recurrence of AS was recorded in the EG during the follow-up period, compared to a mean of 1.46 recurrences in the CG. Technology-assisted rehabilitation using Biodex System 4 Pro and Biodex Balance System resulted in superior restoration of joint mobility, gait symmetry, and neuromuscular control, while significantly reducing recurrence rates compared to conventional therapy. These findings support the integration of individualized, device-based rehabilitation protocols in sports medicine to enhance recovery and prevent re-injury in young athletes.

Keywords: Ankle sprain, football, rehabilitation, Biodex System 4 Pro, gait symmetry, injury prevention

1. Introduction

Ankle sprains (AS) are among the most common musculoskeletal injuries in sports, particularly in high-impact and multidirectional activities such as football [1]. Lateral ankle sprains account for a substantial proportion of these injuries and are frequently underestimated in terms of severity and long-term consequences. Although grade II sprains are generally considered manageable through conservative treatment, recurrent episodes significantly impair athletic performance, joint stability, and functional capacity. Evidence suggests that up to 70% of individuals may develop chronic ankle instability (CAI) in the absence of appropriate rehabilitation, leading to proprioceptive deficits, muscular imbalance, and reduced neuromuscular control [2,3,4].

The biomechanical and functional demands of football—including rapid acceleration, deceleration, directional changes, and repetitive jumping and landing—further increase the risk of both primary and recurrent ankle sprains. This is particularly relevant for young athletes in the developmental phase, for whom effective rehabilitation and prevention strategies are essential not only for recovery but also for long-term performance optimization and injury avoidance [4,5,6].

Traditional rehabilitation programs, while widely used, may lack the precision required to address the neuromuscular deficits associated with recurrent ankle sprains fully. Consequently, recent advances in sports medicine have shifted toward technology-assisted rehabilitation approaches, integrating devices such as the Biodex System 4 Pro (BS4P) and the Biodex Balance System (BBS). These systems enable objective assessment and individualized training through real-time feedback on joint mobility, muscle strength, and postural control, supporting targeted neuromuscular re-education [7,8].

From a biomechanical perspective, recurrent ankle sprains are associated with altered joint kinematics, disrupted plantar pressure distribution, and impaired gait parameters, including reduced symmetry and cadence [9]. The use of wearable technologies, such as the PodoSmart system, has been validated for accurately assessing these parameters and detecting subtle functional asymmetries during recovery [10].

Moreover, the combination of isokinetic strengthening and proprioceptive training has been shown to significantly enhance joint stability, balance performance, and muscle symmetry compared to conventional rehabilitation approaches [9]. Proprioceptive re-education, particularly when facilitated by balance platforms such as the Biodex Balance System, promotes sensorimotor integration and neuromuscular adaptation, thereby reducing recurrence risk and supporting safe return-to-play decisions [8,11,12]. Balance training protocols have demonstrated significant effects on dynamic balance and neuromuscular control in young populations, with direct implications for sport rehabilitation and injury prevention [13].

Recent bibliometric trends indicate a transition from descriptive biomechanical analyses toward data-driven, individualized rehabilitation models incorporating wearable sensors, dynamometry, and feedback-based balance systems. In this context, secondary kinetoprophylactic programs have emerged as effective strategies for minimizing the risk of re-injury and enhancing long-term functional outcomes [9,10].

Overall, current evidence supports the integration of isokinetic and proprioceptive technologies into rehabilitation protocols, demonstrating superior improvements in balance, gait parameters, and neuromuscular control, alongside reduced recurrence rates. These developments highlight the importance of personalized, technology-assisted rehabilitation in modern sports medicine.

Although several studies have reported beneficial effects of isokinetic and proprioceptive training in patients with ankle instability, important limitations remain. Most available studies have focused on isolated outcomes such as balance performance or muscle strength, while few have simultaneously evaluated gait symmetry, cadence, joint mobility, and recurrence rates in young football players. Furthermore, evidence regarding individualized rehabilitation protocols combining objective isokinetic assessment with feedback-based balance training remains limited. Therefore, additional controlled studies are needed to clarify the clinical effectiveness of integrated technology-assisted rehabilitation programs in this population.

We hypothesized that football players undergoing technology-assisted rehabilitation based on the BS4P and BBS would demonstrate greater improvements in joint mobility, gait symmetry, cadence, and muscle strength, together with lower recurrence rates, compared with those receiving conventional physiotherapy

2. Materials and Methods

2.1. Study Design

This randomized controlled trial was designed to rigorously evaluate the comparative effectiveness of a technology-assisted rehabilitation protocol versus a conventional exercise-based approach for reducing AS recurrence among young football players.

The study was conducted over 10 months (April 2022 to January 2023) at the FC Rapid Football Academy, Bucharest, within a structured sports performance environment. Participants underwent standardized, repeated assessments at three predefined time points: baseline, intermediate, and post-intervention—using validated biomechanical and functional evaluation protocols to ensure consistency and reliability of measurements.

The study was conducted in accordance with the principles outlined in the Declaration of Helsinki and received approval from the Ethics Commission of the National University of Physical Education and Sport, Bucharest (approval no. 33/27.09.2021). All participants provided written informed consent before study enrollment.

2.2 Participants

A total of 30 male football players aged 17–20 years, clinically diagnosed with recurrent grade II lateral AS, were assessed for eligibility and enrolled in the study. Participants were randomly allocated into two groups (n = 15 per group), corresponding to either a technology-assisted rehabilitation protocol or a conventional exercise-based program.

During the study period, eight participants were excluded from the final analysis due to non-compliance with the rehabilitation protocol, missed follow-up assessments, or incomplete outcome data. Consequently, only participants with complete outcome measurements were included in the final per-protocol analysis (n = 22; 11 participants per group).

Due to the nature of the rehabilitation interventions, participants and physiotherapists could not be blinded to group allocation. However, all assessments were performed according to standardized protocols using objective instrument-based measurements, thereby minimizing observer-related bias.

Eligibility criteria were defined to ensure sample homogeneity and clinical relevance. Inclusion criteria comprised: (i) age between 17 and 20 years, (ii) clinically confirmed recurrent grade II AS, and (iii) active participation in organized football training. Exclusion criteria included: (i) age below 17 or above 20 years, (ii) first-time or non-recurrent ankle sprain, (iii) grade I or III sprain severity, and (iv) the presence of musculoskeletal or neurological conditions affecting lower limb function.

All participants provided written informed consent before inclusion. The participant flow throughout the study screening, allocation, follow-up, and analysis was structured according to CONSORT recommendations.

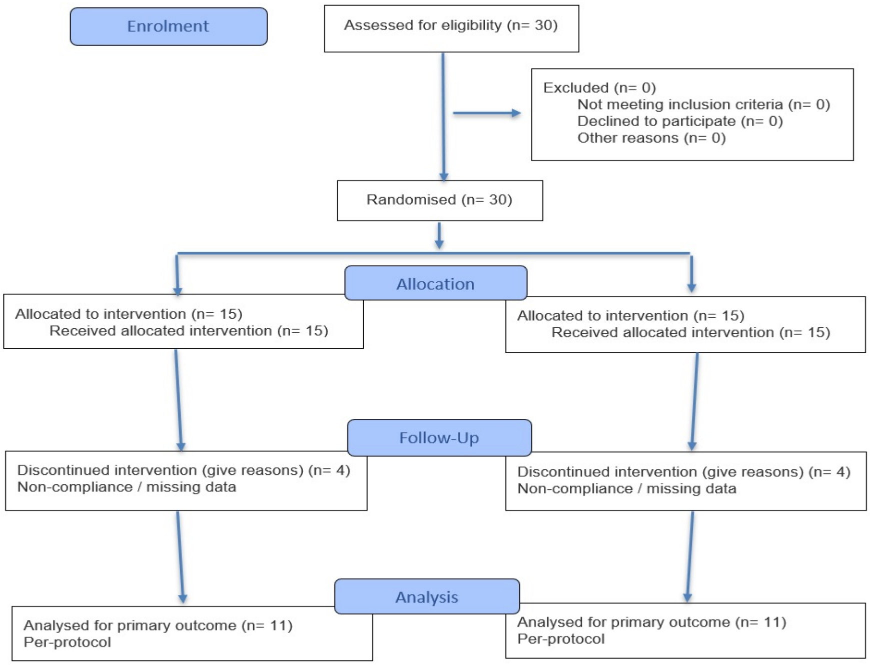

Figure 1: CONSORT Flow Diagram

2.3 Instruments and Equipment

The assessment and rehabilitation protocols were supported by advanced biomechanical and neuroproprioceptive equipment to ensure objective evaluation and individualized intervention.

The BS4P isokinetic dynamometer was employed for the quantitative assessment and targeted training of ankle flexor and extensor muscle groups. Testing and training were performed at controlled angular velocities ranging from 90°/s to 120°/s, enabling precise identification of strength deficits and inter-limb asymmetries.

The BBS was utilized for proprioceptive and postural control training under both stable and unstable surface conditions. Exercises were conducted with eyes open and closed, facilitating sensory integration and enhancing neuromuscular coordination.

Gait analysis was performed using the PodoSmart wearable system, a validated sensor-based technology that provides objective measurements of cadence (steps/min) and inter-limb symmetry (%), allowing for accurate monitoring of functional recovery.

Additionally, the Dsmotec plyometric device was incorporated during the advanced stages of rehabilitation to improve lower-limb strength, power output, and explosive capacity, supporting sport-specific performance restoration.

2.4. Procedures

2.4.1 Testing Protocol

Participants underwent standardized biomechanical and functional assessments at three time points: baseline (initial), intermediate, and final evaluation.

Balance performance was assessed using the Biodex Balance System under four testing conditions: (i) eyes open on a stable surface, (ii) eyes closed on a stable surface, (iii) eyes open on an unstable surface, and (iv) eyes closed on an unstable surface. Each trial lasted 30 seconds, and participants were instructed to maintain the lowest possible sway index throughout the test.

Gait parameters, including cadence (steps/min) and inter-limb symmetry (%), were recorded using the PodoSmart wearable system, ensuring objective and reproducible measurement of locomotor function.

Participants were positioned in an upright stance on the testing platform, with feet placed in standardized positions (D6 for the left foot and D16 for the right foot). A consistent alignment of approximately 10° between the calcaneus and hallux was maintained. The base of support was adjusted according to individual anthropometric characteristics to ensure optimal postural alignment and measurement reliability.

2.4.2 Intervention Protocols

All participants completed a structured rehabilitation program over a period of 2 months, with a frequency of four sessions per week.

Control Group (CG) - conventional rehabilitation. Participants in the CG followed a standardized physiotherapy (PT) protocol based on established rehabilitation principles for AS recovery. The program included:

- Stretching exercises targeting the gastrocnemius and soleus muscles
- Eccentric, concentric, and isotonic strengthening of ankle and lower-limb musculature
- Proprioceptive and balance training
- Sport-specific exercises aimed at restoring coordination, explosive strength, and reaction time

Experimental Group (EG) - technology-assisted rehabilitation. The EG followed an individualized rehabilitation protocol guided by initial assessments performed with the BS4P and the BBS.

The intervention protocol included:

- Isokinetic evaluation to identify agonist–antagonist muscle imbalances
- Progressive training at angular velocities ranging from 90°/s to 120°/s
- Introduction of resistance following the achievement of pain-free active movement
- Targeted strengthening of anterior, posterior, and lateral muscle compartments

Proprioceptive training using the BBS consisted of 30-second trials, performed in 10 repetitions per set, across three sets, with 2-minute rest intervals between sets.

The rehabilitation program emphasized restoration of joint stability, inter-limb symmetry, and neuromuscular control through real-time feedback and adaptive resistance mechanisms.

2.5. Outcome Measures

Primary and secondary outcome measures included:

- Joint mobility (flexion/extension, degrees)
- Gait symmetry (%)
- Cadence (steps/min)
- Muscle strength (Nm)

All parameters were recorded bilaterally (affected and unaffected limbs) at each evaluation time point.

Recurrence of ankle sprain was recorded as a secondary outcome measure. A recurrence was defined as any new grade I or II AS affecting the previously injured ankle that resulted in interruption of sports participation and required medical evaluation. Participants were monitored for 6 months following completion of the rehabilitation program through monthly clinical follow-up visits and communication with the team medical staff. The total number of recurrent AS per participant was recorded during the follow-up period.

3. Results

3.1 Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics 26. Data were analyzed using both descriptive and inferential methods to evaluate intra- and inter-group differences between the two rehabilitation protocols: technology-assisted (EG) and conventional PT (CG).

Descriptive statistics were calculated for all outcome variables, including joint mobility (flexion and extension, expressed in degrees), gait symmetry (%), cadence (steps/min), and muscle strength (Nm). The following indicators were reported: mean (M), median (Me), and standard deviation (SD), for both the affected and unaffected limbs across all evaluation stages (initial, intermediate, and final) (Table 1).

Table 1. Descriptive statistics for the affected limb

Parameter	Group	Initial (M ± SD)	Final (M ± SD)
Flexion (°)	Experimental	24.6 ± 1.61	65.3 ± 2.66
Flexion (°)	Control	24.3 ± —	60.1 ± —
Symmetry (%)	Experimental	83.3	98.1
Symmetry (%)	Control	81.2	92.2
Cadence (steps/min)	Experimental	75.7	106
Cadence (steps/min)	Control	75.2	89.6

The descriptive analysis revealed a consistent improvement across all parameters in both groups, with substantially greater gains observed in the EG. For example, ankle flexion in the affected limb increased from 24.6° (SD = 1.61) at baseline to 65.3° (SD = 2.66) at the final evaluation. Similarly, gait symmetry improved from 83.3% to 98.1%, and cadence increased from 75.7 to 106 steps/min. Comparable improvements were observed for extension and muscle strength, indicating progressive restoration of functional symmetry (Table 1).

Given the relatively small sample size (n = 11 per group) and the non-normal distribution of the data, non-parametric statistical tests were applied.

The Mann–Whitney U test was used to compare differences between the affected and unaffected limbs within each group. In the EG, statistically significant differences were identified at baseline and intermediate assessments for both flexion and extension ($p < 0.001$). However, these differences were no longer significant at the final evaluation ($p > 0.05$), indicating restoration of joint symmetry and functional balance (Table 2).

In contrast, the CG exhibited persistent statistically significant differences at the final assessment ($p < 0.01$), suggesting incomplete recovery. Effect sizes (r) ranged between 0.80 and 1.18, corresponding to strong to very strong effects of the intervention.

Table 2. Mann–Whitney U test – Healthy vs. Affected limb comparison

Parameter	Group	Stage	U	Z	p-value	Effect size (r)	Interpretation
Flexion	Experimental	Initial	0	3.939	<0.001	1.18	Significant deficit
Flexion	Experimental	Intermediate	0	3.939	<0.001	1.18	Partial recovery
Flexion	Experimental	Final	59.5	-0.369	0.71	—	No difference
Extension	Experimental	Final	59.5	0.032	0.97	—	Symmetry achieved
Flexion	Control	Final	17.5	2.79	0.005	0.83	Persistent deficit
Extension	Control	Final	19.5	2.659	0.007	0.80	Persistent deficit

The experimental group demonstrated complete recovery ($p > 0.05$ at final), while the control group retained significant inter-limb differences ($p < 0.01$).

Friedman's χ^2 test for repeated measures was employed to evaluate intra-group changes across the three time points (initial, intermediate, and final). Both groups demonstrated statistically significant improvements ($p < 0.001$) in all measured parameters, including joint mobility, gait symmetry, and cadence (Table 3).

Table 3. Friedman's χ^2 test – Intra-group evolution

Parameter	Group	χ^2	p-value	Interpretation
Flexion	Experimental	22	<0.001	Significant improvement (+159%)
Extension	Experimental	11	<0.001	Significant improvement (+149%)
Symmetry	Experimental	22	<0.001	83.3 → 98.1%
Cadence	Experimental	11	<0.001	75.7 → 106
Flexion	Control	22	<0.001	Improvement (+147%)
Extension	Control	11	<0.001	Improvement (+139%)
Symmetry	Control	22	<0.001	81.2 → 92.2%
Cadence	Control	11	<0.001	75.2 → 89.6

Both groups showed statistically significant improvements; however, the magnitude of change was consistently higher in the experimental group.

However, the magnitude of improvement was consistently greater in the experimental group. For instance, flexion increased by approximately 159% and extension by 149% in the EG, compared to 147% and 139%, respectively, in the CG.

Isokinetic testing revealed no significant differences between the affected and unaffected limbs in the experimental group at the final evaluation ($p > 0.05$), confirming the restoration of muscular balance (Table 4).

Table 4. Muscle strength comparison (final evaluation)

Parameter	Group	U	Z	p-value	Effect size (r)	Interpretation
Flexion strength	Experimental	53	-0.459	0.64	—	Balanced
Extension strength	Experimental	45	-0.984	0.32	—	Balanced
Flexion strength	Control	5	3.611	<0.001	1.08	Deficit persists
Extension strength	Control	0	3.939	<0.001	1.18	Deficit persists

Conversely, the CG continued to exhibit significant inter-limb differences ($p < 0.001$), particularly in extension strength ($r = 1.18$), indicating persistent neuromuscular deficits in the affected ankle.

A p-value < 0.05 was considered statistically significant. Effect sizes were interpreted using the correlation coefficient (r), with values > 0.8 indicating strong to very strong effects.

Recurrence analysis revealed no cases of recurrent AS in the experimental group during the follow-up period. In contrast, participants in the control group experienced a mean of 1.46 recurrent ankle sprains per participant. These findings suggest that the technology-assisted rehabilitation protocol may contribute to a lower risk of re-injury following return to sport.

4. Discussion

Although football has major health and longevity benefits, it has a high rate of injuries due to the physical contact and intensity of the game. These injuries fall into two categories: acute (occurring suddenly following an impact, such as fractures or sprains) and chronic (developing gradually through repeated overuse [14].

AS represents one of the most prevalent injuries in football, occurring frequently during both training sessions and competitive matches [15]. The high physical demands of the sport, including rapid changes in direction, jumping, and player-to-player contact, significantly increase the mechanical stress applied to the ankle joint. In young athletes, ongoing musculoskeletal maturation—particularly collagen remodeling under repetitive loading—may further contribute to increased susceptibility to injury [16]. Performance and physical parameters are also conditioned by the rigor of the training process and the efficiency of physiological systems in managing the workload [17].

From a biomechanical perspective, AS result from excessive stretching or rupture of the lateral or medial ligament complexes when external forces exceed the physiological limits of ligament elasticity [16,17]. These injuries are most commonly associated with inversion or eversion mechanisms, depending on the direction of force application [18]. In football-specific contexts, such mechanisms frequently occur during landing, sudden deceleration, or improper foot placement on uneven surfaces or an opponent's foot [19,20].

The high recurrence rate of AS has prompted extensive research into both prevention and rehabilitation strategies. Reduced ROM, increased muscle stiffness, and impaired neuromuscular coordination have been identified as key contributors to injury risk and recurrence [21]. Consequently, interventions aimed at improving ROM and optimizing muscle function, including myofascial techniques, have been widely recommended [22].

In addition to soft tissue interventions, several rehabilitation approaches have demonstrated effectiveness in improving functional outcomes. Fascial manipulation has been shown to improve dorsiflexion and reduce gait-related pain [23], while dry needling has been associated with improvements in muscle strength and proprioception [24]. Manual joint mobilization has also been reported to reduce inflammation and enhance joint mobility in acute phases [25].

A consistent finding across the literature is the critical role of proprioceptive and balance training in both rehabilitation and secondary prevention. Structured proprioceptive training has been shown to significantly improve ROM, reaction time, and balance performance [26], while postural control exercises remain among the most effective strategies for reducing recurrence risk [27]. This is particularly important given that inadequate rehabilitation may lead to chronic ankle instability in up to 70% of cases [28,29].

Over time, rehabilitation paradigms have shifted from predominantly quantitative approaches focused on strength and ROM toward functional, neuromuscular-oriented models. Early mobilization combined with progressive loading and proprioceptive training has been shown to restore functional stability more effectively [28]. Furthermore, early initiation of dynamic, weight-bearing exercises accelerates recovery and improves return-to-sport outcomes [30].

Epidemiological evidence further underscores the clinical importance of AS. The reported incidence reaches approximately 2.15 cases per 1,000 individuals annually, with higher prevalence in adolescent and young adult populations [31]. Additionally, previous injury and increased body weight significantly elevate the risk of recurrence, emphasizing the need for targeted and individualized rehabilitation strategies [32].

Within this evolving rehabilitation framework, the present study provides additional evidence supporting the superiority of technology-assisted rehabilitation. While both intervention protocols resulted in statistically significant improvements across all measured parameters, the experimental group, utilizing the BS4P and BBS, achieved complete restoration of inter-limb symmetry and superior neuromuscular recovery.

The findings clearly support the study hypothesis that rehabilitation programs integrating isokinetic and proprioceptive technologies are more effective than conventional exercise-based approaches. The absence of significant inter-limb differences at the final evaluation in the EG, combined with large effect sizes, confirms the capacity of the intervention to restore functional balance and joint stability. In contrast, the persistence of asymmetries in the CG indicates incomplete recovery and highlights the limitations of traditional rehabilitation methods in addressing complex neuromuscular deficits.

The superior outcomes observed in the EG can be attributed to the integration of objective, feedback-driven rehabilitation tools. Isokinetic training enables controlled resistance throughout the full ROM, promoting balanced activation of agonist and antagonist muscle groups while minimizing joint stress. Concurrently, proprioceptive training under unstable and sensory-deprived conditions enhances sensorimotor integration and neuromuscular coordination. Real-time feedback mechanisms likely accelerate motor relearning and contribute to the normalization of gait parameters, including symmetry and cadence.

From a clinical perspective, these findings highlight the importance of transitioning toward personalized, data-driven rehabilitation strategies. The use of objective assessment tools allows clinicians to identify deficits early and implement targeted interventions, ultimately improving rehabilitation efficiency and outcomes. This approach is particularly relevant in high-demand sports such as football, where optimal neuromuscular control is essential for performance and injury prevention.

The relatively small sample size (n = 22) and the per-protocol analysis approach may limit statistical power and reduce the generalizability of the findings. Therefore, the results should be interpreted with caution until confirmed by larger multicenter studies. Additionally, the inclusion of only male football players aged 17–20 years restricts the applicability of the findings to other populations. The high cost and limited accessibility of advanced rehabilitation technologies, such as the BBS, may also represent barriers to widespread implementation. Furthermore, the lack of a comprehensive assessment of additional neuromuscular and proprioceptive parameters limits the depth of mechanistic interpretation.

Future research should include larger and more diverse populations, as well as long-term follow-up, to evaluate the sustainability of these outcomes and their impact on recurrence rates.

5. Conclusions

The present randomized controlled trial demonstrates that both rehabilitation approaches, technology-assisted and conventional PT, lead to significant improvements in joint mobility, gait symmetry, cadence, and muscle strength in young football players with recurrent grade II AS. However, the technology-assisted protocol yielded superior outcomes.

Participants in the EG, who followed an individualized rehabilitation program based on isokinetic and proprioceptive assessment using the BS4P and Biodex Balance System, achieved complete restoration of inter-limb symmetry and neuromuscular balance. In contrast, the control group exhibited persistent functional asymmetries at the final evaluation, indicating incomplete recovery.

These findings confirm that rehabilitation protocols integrating objective, feedback-driven technologies are more effective in addressing the complex neuromuscular deficits associated with recurrent AS. The combination of controlled isokinetic loading and proprioceptive training under variable sensory conditions appears to play a critical role in restoring joint stability and optimizing functional recovery.

From a clinical perspective, the results support the implementation of individualized, technology-assisted rehabilitation strategies in sports medicine practice. Such approaches may enhance return-to-play readiness, reduce recurrence risk, and improve long-term functional outcomes, particularly in high-demand athletic populations.

Despite these promising results, the relatively small sample size and the homogeneous study population limit the generalizability of the findings. Future research should focus on larger and more diverse cohorts, as well as long-term follow-up, to validate the sustainability of these benefits and their impact on injury recurrence.

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