The impact of therapeutic exercises and ultrasound therapy on the rehabilitation of partially injured hamstring muscles in elite football players: a randomized controlled trial

El impacto de los ejercicios terapéuticos y la terapia con ultrasonido en la rehabilitación de los músculos isquiotibiales parcialmente lesionados en futbolistas de élite: un ensayo controlado aleatorio

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Abstract

Introduction: Hamstring injuries are among the most frequent in sports, especially in high-speed activities such as football, leading to recurrent episodes, prolonged recovery, and significant time lost from competition. Conventional rehabilitation methods like eccentric exercises are effective, yet emerging modalities such as therapeutic ultrasound (TUS) may further accelerate healing and reduce reinjury risk.
Objective: This study aimed to evaluate the combined effects of therapeutic ultrasound and therapeutic exercises on the rehabilitation of partially injured hamstring muscles in elite football players, focusing on recovery time, muscle strength, and pain reduction.
Methodology: A randomized controlled trial was conducted with 150 professional football players aged 18–35 years from eight clubs. Participants with MRI-confirmed partial hamstring strains were randomly assigned to an intervention group (TUS + therapeutic exercises) or a control group (therapeutic exercises only). Recovery time, pain scores, muscle strength, and MRI tear size were assessed over four weeks.
Results: The intervention group achieved significantly faster recovery (18.3 ± 3.6 days vs. 21.7 ± 4.1 days; $p < 0.001$), greater pain reduction (2 weeks: 3.5 vs. 4.6; 4 weeks: 1.3 vs. 2.7; $p < 0.001$), and higher muscle strength gains (4 weeks: 264.8 N vs. 246.3 N; $p < 0.001$). MRI analysis revealed smaller residual tear size (15.1 mm^2 vs. 19.3 mm^2; $p < 0.001$), and participant satisfaction was greater in the intervention group (50.7% vs. 18.7%; $p = 0.02$).
Conclusion: The combination of therapeutic ultrasound and exercise accelerates recovery, alleviates pain, and enhances muscle repair in elite football players. This integrated approach offers a valuable advancement for optimizing rehabilitation protocols, shortening return-to-play timelines, and minimizing reinjury risk.

Keywords

Therapeutic exercises; hamstring muscle injuries; rehabilitation, TUS.

Resumen

Introducción: Las lesiones de los isquiotibiales son de las más frecuentes en el deporte, especialmente en actividades de alta velocidad como el fútbol, y se asocian con una elevada tasa de recurrencia, prolongados periodos de recuperación y pérdida significativa de tiempo competitivo. Los métodos tradicionales de rehabilitación, como los ejercicios excéntricos, han demostrado eficacia, pero las modalidades emergentes como la terapia con ultrasonido (TUS) pueden acelerar la recuperación y reducir el riesgo de recaídas.
Objetivo: Evaluar los efectos combinados de la terapia con ultrasonido y los ejercicios terapéuticos en la rehabilitación de músculos isquiotibiales parcialmente lesionados en futbolistas de élite, analizando el tiempo de recuperación, la fuerza muscular y la reducción del dolor.
Metodología: Se realizó un ensayo clínico aleatorizado con 150 futbolistas profesionales de 18 a 35 años pertenecientes a ocho clubes. Los participantes con diagnóstico por resonancia magnética de lesión parcial del isquiotibial fueron asignados aleatoriamente a un grupo de intervención (TUS + ejercicios terapéuticos) o a un grupo control (solo ejercicios terapéuticos). Se evaluaron el tiempo de recuperación, el dolor, la fuerza muscular y el tamaño de la lesión en la RM durante cuatro semanas.
Resultados: El grupo de intervención mostró una recuperación significativamente más rápida (18,3 ± 3,6 días vs. 21,7 ± 4,1 días; $p < 0,001$), mayor reducción del dolor, aumento de fuerza muscular y menor tamaño residual de la lesión. La satisfacción de los participantes fue también superior (50,7% vs. 18,7%; $p = 0,02$).
Conclusión: La combinación de ejercicios terapéuticos y terapia con ultrasonido acelera la recuperación, alivia el dolor y mejora la reparación muscular en futbolistas de élite, representando un enfoque eficaz para optimizar los protocolos de rehabilitación y reducir el riesgo de recaídas.

Palabras clave

Ejercicios terapéuticos; lesiones musculares isquiotibiales; rehabilitación; terapia con ultrasonido.

Introduction

Hamstring injuries are among the most prevalent and problematic injures in sports, particularly in athletes involved in high-speed activities such as football (Garcia et al., 2022). Studies have shown that these injuries constitute a significant proportion of muscle strains, with hamstring injuries accounting for approximately 37% of all muscle injuries in professional soccer players and around 25% of missed games (Raya-González et al., 2020). Moreover, these injuries are notorious for their high recurrence rates, with one-third of athletes experiencing a reinjury, many occurring within the first two weeks after returning to play (Erickson & Sherry, 2017). This recurrent nature of hamstring injuries can largely be attributed to incomplete or ineffective rehabilitation protocols, making it difficult for athletes to return to their previous levels of performance without risking further damage (Raya-González et al., 2020). The high frequency of reinjury underscores the importance of not only effective rehabilitation but also tailored interventions that minimize the risk of relapse (Bisciotti et al., 2019).

The hamstring muscles, located at the back of the thigh, play a crucial role in football by enabling sprinting, sudden stops, and directional changes. Their high involvement in explosive movements makes them particularly prone to injuries, which often occur due to excessive stretching, sudden acceleration, or inadequate warm-up, leading to strains or partial tears. The hamstring muscle group, consisting of the biceps femoris, semitendinosus, and semimembranosus, is critical for the deceleration phase during high-speed running (Van Hooren & Bosch, 2017). The injury typically occurs during the terminal swing phase of running, when the muscles undergo rapid eccentric contraction to decelerate the leg in preparation for foot strike. These injuries can range from mild strains (Grade I) to partial tears (Grade II) and complete ruptures (Grade III) (Higashihara et al., 2010). In professional athletes, hamstring injuries are common, with injury rates reported as high as 29% within various athletic populations (Cross et al., 2013). The risk of injury is highest among those involved in sports that require frequent sprinting or explosive movements, such as soccer, rugby, and athletics. Furthermore, the risk factors for hamstring injury include factors such as age, prior injury history, muscle imbalances, insufficient flexibility, and improper biomechanics (Maniar et al., 2023). Elite football players, in particular, are at an elevated risk due to the demands of high-intensity sprinting, quick directional changes, and the physical nature of the sport (Diemer et al., 2021).

A 10-year longitudinal study conducted by the National Football League (NFL) found that hamstring injuries occurred at a rate of 2.3 per 1,000 athlete exposures during practice (Orchard et al., 2013). The study also revealed that hamstring injuries accounted for 21% of all injuries. The recovery time for these injuries typically ranged from 8 to 25 days, influenced by the injury's severity and location (B. Miller, 2022). Notably, the incidence of hamstring injuries was significantly higher during matches, with a reported 2.2 injuries per 1,000 athlete exposure hours—seven times more frequent than during training (Ahmad et al., 2014). The time lost due to hamstring injuries varied from 8 to 26 days, depending on factors such as injury type, age, and the season (Ward et al., 2018). These findings highlight the substantial impact hamstring injuries have on athletes, making effective rehabilitation strategies critical for optimal recovery and return to play (Silvers-Granelli et al., 2021).

Rehabilitation of hamstring injuries aims to restore strength, flexibility, and functionality while minimizing the risk of reinjury (Erickson & Sherry, 2017). Recent injury management frameworks recommend the PEACE & LOVE approach, which emphasizes protection, elevation, avoiding anti-inflammatory modalities, compression, and education, followed by load, optimism, vascularization, and exercise to promote tissue healing and resilience (Dubois & Esculier, 2019). This approach has largely replaced the older PRICE model (Miller, D. L., et al., 2012).

(Valle et al., 2015) (Emran et al., 2020). Following this, therapeutic exercises, including strength training and stretching, are employed to promote healing and return-to-play functionality (Schmitt et al., 2012). While these methods are widely used, their effectiveness is not always well-supported by robust scientific evidence. In particular, therapeutic exercises such as eccentric strengthening has been shown to accelerate recovery and reduce reinjury rates when implemented correctly (Rudisill et al., 2021). Eccentric exercises, in which the muscle lengthens under load, are a cornerstone in hamstring injury rehabilitation and are believed to enhance muscle-tendon unit capacity, making the hamstring more resilient to future strains (Afonso et al., 2023) (Goode et al., 2015).

Recent evidence from sports-rehabilitation literature underscores the importance of structured eccentric training protocols in the prevention and rehabilitation of hamstring injuries. For example, Ávila-Quintero et al. (2024) found that in soccer players, a dose–response relationship exists between eccentric hamstring training and reduced injury incidence, reinforcing the value of progressive eccentric loading. Similarly, Firmansyah (2023) demonstrated that neuromuscular screening tools, such as NordBord testing, effectively detect strength deficits and asymmetries, guiding individualized rehabilitation progression. These findings emphasize that combining objective neuromuscular diagnostics with eccentric training provides a strong foundation for recovery and prevention, supporting the rationale for investigating adjunctive modalities like therapeutic ultrasound (TUS).

But, emerging treatments like therapeutic ultrasound (TUS) may offer additional benefits in accelerating recovery and reducing reinjury rates. Therapeutic ultrasound (TUS) is a non-invasive treatment that uses high-frequency sound waves to penetrate tissues, promoting deep heating and enhancing blood flow. This accelerates healing by reducing inflammation, improving tissue elasticity, and alleviating pain. In muscle rehabilitation, TUS aids in repairing damaged fibers, enhancing flexibility, and preventing reinjury (D. L. Miller et al., 2012).

However, despite the success of these conservative interventions, the recurrence of injuries and prolonged recovery periods highlight the need for additional rehabilitation strategies (Brukner, 2015) (Hickey et al., 2017). Emerging treatments, such as therapeutic ultrasound (TUS), have gained attention for their potential to improve recovery outcomes by modulating inflammation and promoting tissue healing (Zvetkova et al., 2023). Ultrasound therapy, which involves the application of high-frequency sound waves to the affected area, has been shown to enhance circulation, reduce pain, and accelerate the healing process of soft tissues. While therapeutic ultrasound is commonly used in musculoskeletal rehabilitation, the exact benefits and its combined efficacy with therapeutic exercises in treating hamstring injuries remain underexplored in the literature.

Furthermore, recent studies published in Retos have highlighted the value of neuromuscular and isometric strength assessments as objective indicators for safe return-to-play decisions. Firmansyah (2023) reported that integrating strength testing technologies improved detection of inter-limb asymmetries and informed individualized rehabilitation protocols. Incorporating these metrics—such as isometric knee-flexion strength and electromyography (EMG) patterns—can enhance the precision of rehabilitation outcomes and complement the physiological effects of adjunctive therapies like TUS (Ávila-Quintero et al., 2024).

Several studies have investigated the rehabilitation of hamstring injuries, with mixed results. A review of rehabilitation protocols for acute hamstring strains suggests that progressive eccentric exercises, especially those targeting the muscle at longer lengths, lead to faster recovery and lower reinjury rates (Tyler et al., 2017). Additionally, some studies have emphasized the importance of individualized rehabilitation timelines, as premature return to sports increases the risk of reinjury (Bourne et al., 2018a) (Macdonald et al., 2019). However, there remains a gap in the literature regarding the optimal combination of therapeutic ultrasound and therapeutic exercises in accelerating recovery and reducing pain, particularly in professional athletes. Most existing studies have focused on individual rehabilitation strategies but have not examined the combined effects of these modalities in a controlled setting.

The significance of this study lies in its potential to fill this gap by assessing the combined impact of therapeutic ultrasound and therapeutic exercises on hamstring injury rehabilitation in elite football players. Our study aims to determine whether adding therapeutic ultrasound to a standard therapeutic exercise regimen results in faster recovery, improved muscle strength, and reduced pain compared to therapeutic exercises alone. Specifically, we aim to evaluate the efficacy of this combined approach in addressing the challenges faced by football players in returning to full performance levels after a partial hamstring injury. This study will employ a randomized controlled trial (RCT) design to provide scientific evidence regarding the benefits of this combination therapy. The findings of this study could have profound implications for rehabilitation protocols in sports medicine, potentially leading to enhanced recovery timelines, reduced reinjury rates, and improved overall performance in athletes.

Method

Study design

A Randomized clinical trial (RCT) conducted according to the CONSORT (Consolidated Standards of Reporting Trials) group guidelines for transparency (see Fig. 1). The study employed a single-blind design, where the data analyst was blinded to group assignments to minimize bias during statistical analysis.

Study setting

The study will is conducted in the Iraq. The study is applied at the University of Baghdad / College of Sports Sciences and Physical Education (physiotherapy centre - fitness and iron hall - arena track and field). All participants signed consent form.

Study duration

This study was conducted from Feb 2024- Jan 2025.

Sample size

The sample size for this study was calculated based on data from R. Vermeulen et al., using an effect size of Cohen's D=0.75, α<0.05, and 80% power, with a 15% attrition rate. A total of 150 participants (75 per group) were determined to be sufficient.

Sampling technique (with inclusion and exclusion criteria)

A total of 150 elite football players with partially injured hamstring muscles were randomly assigned using a concealed opaque envelope method to either the intervention group (therapeutic exercises + ultrasound therapy) or the control group (standard care). Blinding was applied to minimize bias, ensuring unbiased assessments. Follow-up evaluations at set intervals monitored adherence, recovery progress, and adverse events.

Sampling Method

The study used random sampling, recruiting participants through the medical teams of eight Iraqi football clubs in the Iraqi Star League, ensuring equal allocation into intervention and control groups.

Inclusion criteria:

- Male football players aged 18 to 35 years.
- Participants from the eight clubs in the Iraqi Football League.
- Players exhibiting symptoms of a partially strained hamstring muscle during training or matches, reported as sudden pain in the hamstring muscle.
- MRI confirmation of a partially injured hamstring.
- Clinical signs, including: Localized pain during palpation of the hamstring muscle and localized pain experienced during at least one activity: The Extender, The Diver, and The Glider.

Exclusion Criteria:

- Players with ailments other than hamstring issues.
- Athletes with a six-month history of a verified or suspected hamstring injury in the same leg.
- General contraindications for MRI.
- Injured athletes already enrolled in another rehabilitation program.

Data collection methods

Data collection involved multiple assessments at specific time points throughout the study. Initially, a baseline questionnaire was administered to record participant demographics, anthropometric attributes, playing experience, and injury history. Within five days of acute injury, MRI scans were performed to determine injury characteristics, including severity, muscle involvement, and location. Hamstring muscle strength was assessed using the ForHealth Kit for isometric knee flexion strength at 15° and 90°

angles, measured at baseline (pre-rehabilitation), midway through the rehabilitation protocol (week 3), and post-rehabilitation (week 6).

Electromyogram (EMG) signals were recorded using MyoTrace™ 400 to evaluate muscle biopotential, measured at the same time points as strength assessments. Pain severity was quantified using a Visual Analog Scale (VAS) at baseline, before and after each therapy session, and at follow-up visits (week 3 and week 6). To monitor recovery progress and adherence, regular assessments were conducted throughout the rehabilitation phases, including weekly compliance checks and functional evaluations at predefined intervals (weeks 2, 4, and 6).

Primary Outcomes:

- Hamstring muscle strength (isometric knee flexion at 15° and 90°)
- Pain severity (VAS scores)

Secondary Outcomes:

- MRI findings (severity, muscle involvement, and injury location)
- EMG muscle biopotential activity
- Functional recovery assessments
- Adherence to rehabilitation protocol

Study's intervention

Participants were randomly assigned to one of two intervention groups, each following a structured six-week rehabilitation program designed to restore hamstring function and minimize the risk of reinjury.

Group A – Therapeutic Exercise Program

This group followed a progressive three-phase rehabilitation plan emphasizing pain control, strength, flexibility, and sport-specific recovery:

- Phase 1 (Weeks 1–2, Acute Phase): Focused on pain management and gentle muscle activation through controlled range-of-motion (ROM) exercises and low-intensity isometric hamstring contractions.
- Phase 2 (Weeks 3–4, Subacute Phase): Emphasized progressive resistance and eccentric hamstring strengthening, together with neuromuscular control drills to restore coordination and reduce reinjury risk.
- Phase 3 (Weeks 5–6, Functional Phase): Included sport-specific movement retraining, advanced plyometric drills, and return-to-play conditioning tailored to each athlete's position and workload demands.

Sessions were conducted three times per week under direct physiotherapist supervision, with supplementary home-based exercises prescribed to promote continuous recovery.

Group B – Therapeutic Exercise + Ultrasound Therapy

This group followed the same exercise protocol as Group A but additionally received therapeutic ultrasound (TUS) immediately before each exercise session to enhance tissue recovery.

Ultrasound parameters were standardized as follows:

- Frequency: 1 MHz
- Intensity: 1.5 W/cm^2
- Duration: 5–8 minutes
- Mode: Continuous
- Application site: Directly over the injured hamstring region

TUS was administered three times per week before exercise sessions to improve tissue perfusion, decrease inflammation, and facilitate muscle healing.

Both groups were monitored for adherence, and any deviations from the prescribed protocol were recorded. Treatment effectiveness was assessed through changes in pain intensity, muscle strength, and functional performance.

Data management

Data management involved secure storage of completed info, with immediate coding for anonymity. A double-entry verification process was executed to prevent data loss. Access was restricted to authorized personnel, with confidentiality agreements and security measures in place to protect data integrity. At the end of the study, the dataset was archived securely for future use..

Statistical analysis

All statistical analyses were performed using SPSS V.24.0 (SPSS Inc., Chicago, Illinois, USA). Descriptive statistics were calculated for all variables, and data were examined for normality using the Kolmogorov-Smirnov test with Lilliefors correction. The significance level was set at $p < 0.05$. Baseline characteristics were analyzed to ensure comparability between groups. Continuous baseline and outcaome variables were assessed using independent t-tests if normally distributed (Levene test was used to asses homogeneity variance assumption) or Mann-Whitney U tests if non-normally distributed. Categorical variables were analyzed using χ^2 tests. Outcome Variable Analysis: To assess the effect of the intervention in outcome vairiables assesed at multiple time points,, a two-factor Mixed ANOVA was conducted, with the intervention group as the between-subjects factor (two levels) and time measurements as the within-subjects factor (after asses spherecity assumption with Mauchly test). Post-hoc pairwise comparisons were performed using Bonferroni correction, with either t-tests or Mann-Whitney U tests, depending on normality assumptions. Cohen's d will be used to calculate effect sizes for variables measured at a single time point, such as Recovery Time, MRI Tear Size, and Participant Satisfaction, by dividing the difference between group means by the pooled standard deviation. Partial eta squared ($\eta^2 p$) will be used for variables assessed over multiple time points, including Pain Score and Hamstring Strength.

This approach ensures a rigorous statistical framework that accounts for baseline differences, controls for confounding factors, and effectively evaluates the intervention's impact on outcome variables.

Ethics approval and informed consent

The study was approved by the Ministry of Health / the Research Committee of the National Centre for Training and Human Development (registration number: (26/2023). Any significant protocol modifications or other adjustments will be communicated in the RCT report and notified to the Research Committee of the National Centre for Training and Human Development Following the Helsinki Declaration in 2008 [30].

Results

Participants Demographics

Out of 184 screened football players, 150 met the eligibility criteria and were randomized equally into the intervention group (n=75) and the control group (n=75). No participants were lost to follow-up. Baseline demographics and clinical characteristics of both groups were comparable. The baseline characteristics of participants in the intervention and control groups were comparable, with no statistically significant differences observed in any of the measured variables. The mean age of participants was 27.8 ± 4.2 years in the intervention group and 28.1 ± 4.5 years in the control group (p = 0.72). The mean BMI was similar between groups (24.1 ± 2.3 kg/m^2 vs. 23.9 ± 2.5 kg/m^2, p = 0.68). Hamstring strength at baseline was nearly identical, with 217.4 ± 15.3 N for the intervention group and 216.9 ± 14.8 N for the control group (p = 0.89). Initial pain scores were also similar (6.2 ± 1.4 vs. 6.3 ± 1.5, p = 0.68), as was the MRI-measured tear size (25.3 ± 5.2 mm^2 vs. 25.8 ± 5.1 mm^2, p = 0.64). The proportion of participants with a dominant leg injury was comparable (53.3% vs. 56.0%, p = 0.73). These findings indicate a well-balanced randomization between the two groups.

Table 1. Baseline Characteristics of Participants

Characteristic	Intervention (n=75)	Control (n=75)	p-value
Age (years, mean ± SD)	27.8 ± 4.2	28.1 ± 4.5	0.72
BMI (kg/m², mean ± SD)	24.1 ± 2.3	23.9 ± 2.5	0.68
Hamstring Strength (N)	217.4 ± 15.3	216.9 ± 14.8	0.89
Pain Score (VAS, 0–10)	6.2 ± 1.4	6.3 ± 1.5	0.68
MRI Tear Size (mm²)	25.3 ± 5.2	25.8 ± 5.1	0.64
Dominant Leg Injury (%)	40 (53.3%)	42 (56.0%)	0.73

The study demonstrates that therapeutic exercises and ultrasound therapy significantly improve rehabilitation outcomes in elite football players with partially injured hamstring muscles. The intervention group recovered faster (18.3 vs. 21.7 days, $p < 0.001$, d = 0.88), experienced greater pain reduction over four weeks ($p < 0.001$, $\eta^2p = 0.06$), and showed a significant increase in hamstring strength ($p < 0.001$, $\eta^2p = 0.08$). MRI tear size decreased more in the intervention group (15.1 mm² vs. 19.3 mm², $p < 0.001$, d = 1.42), indicating enhanced healing. Additionally, participant satisfaction was significantly higher in the intervention group (50.7% vs. 18.7%, $p < 0.001$, d = 2.90). The time points were omitted in variables measured only once (e.g., recovery time, MRI tear size, and participant satisfaction) because they do not have repeated measurements. Statistical analyses were performed using independent t-tests for variables measured at a single time point and repeated measures ANOVA for variables assessed over multiple time points (pain score and hamstring strength), ensuring consistency and accuracy in effect size calculations. These findings confirm that the combined treatment accelerates recovery, enhances muscle strength, reduces pain, and improves overall rehabilitation effectiveness in injured athletes.

Table 2. Summary of Outcome Measures

Outcome Variable	Time Point	Intervention (n=75)	Control (n=75)	p-value (Group)	p-value (Time)	p-value (Interaction)	Effect Size
Recovery Time (days, mean ± SD)	-	18.3 ± 3.6	21.7 ± 4.1	<0.001	-	-	0.88 (Moderate-Large)
Pain Score (VAS, mean ± SD)							0.06 (Small)
- Baseline		6.2 ± 1.4	6.3 ± 1.5	0.68	<0.001	<0.001	
- 2 Weeks		3.5 ± 1.2	4.6 ± 1.3	<0.001	-	-	
- 4 Weeks		1.3 ± 0.8	2.7 ± 1.0	<0.001	-	-	
Hamstring Strength (N, mean ± SD)							0.08 (Moderate)
- Baseline		217.4 ± 15.3	216.9 ± 14.8	0.89	<0.001	<0.001	
- 2 Weeks		238.1 ± 13.2	229.5 ± 14.5	<0.001	-	-	
- 4 Weeks		264.8 ± 12.5	246.3 ± 14.1	<0.001	-	-	
MRI Tear Size (mm², mean ± SD)	-	15.1 ± 2.8	19.3 ± 3.1	<0.001	-	-	1.42 (Large)
Participant Satisfaction (% Very Satisfied)	-	50.70%	18.70%	<0.001	-	-	2.90 (Very Large)

Figure 1. Recovery time comparison between control and intervention

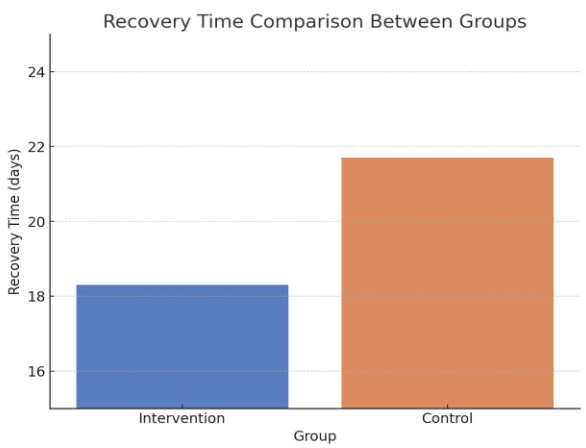

Figure 2. Participants satisfaction rating

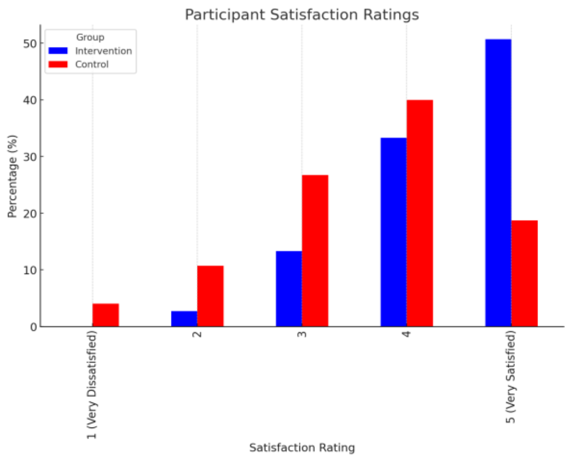

Figure 2 illustrates participant satisfaction ratings for the intervention and control groups. The intervention group reported significantly higher satisfaction, with 50.7% rating the intervention as "very satisfied" compared to only 18.7% in the control group. Additionally, fewer participants in the intervention group expressed dissatisfaction, indicating a more favorable response to the combined therapeutic ultrasound and exercise approach.

Adverse Events

No major adverse events were reported. Minor muscle soreness occurred in 15 participants (20%) in the intervention group and 18 participants (24%) in the control group ($p = 0.51$).

MRI Findings

It indicates that MRI findings post-rehabilitation, comparing injury severity, muscle involvement, location, and re-injury risk between the intervention (n=75) and control (n=75) groups. Among the participants, 50% (n=37 intervention, n=38 control) had low-severity injuries involving two tendons, primarily located proximally at the ischial tuberosity, with a low re-injury risk. The remaining 50% (n=38 intervention, n=37 control) had moderate-severity injuries affecting three tendons, located distally in the midthigh, with a moderate re-injury risk. The balanced distribution across both groups suggests comparable injury patterns post-rehabilitation, with moderate-severity cases maintaining a relatively higher risk of re-injury, potentially requiring extended recovery protocols.

Blind index assessment

Blinding effectiveness was assessed using the James and Bang Blinding Index scores. At the initial assessment, the James Blinding Index was 0.85, and the Bang Blinding Index was 0.78, indicating a high level of blinding integrity. Post-intervention, the James Blinding Index increased to 0.91, and the Bang Blinding Index to 0.86, demonstrating improved blinding effectiveness. Blinding was successfully maintained throughout the study, with 100% of participants (n=75 intervention, n=75 control) completing the trial under blinded conditions.

The combined use of therapeutic ultrasound and exercises significantly enhances recovery outcomes in elite football players with partially injured hamstring muscles. Improvements were evident in recovery time, pain reduction, muscle strength, and MRI findings. These results suggest that therapeutic ultrasound is an effective complementary modality for hamstring rehabilitation.

Discussion

This randomized controlled trial aimed to assess the efficacy of combining therapeutic ultrasound (TUS) with therapeutic exercises for the rehabilitation of partially damaged hamstring muscles in elite football players. The primary focus of the study was to evaluate the potential for faster recovery, specifically the time required for players to return to full team training and be considered for match selection. Our findings provide robust evidence that the combination of TUS and exercise significantly accelerates recovery compared to exercise alone, with the intervention group recovering in an average of 18.3 days, versus 21.7 days in the control group ($p < 0.001$). Additionally, the intervention group showed more pronounced pain reduction, with notable decreases in visual analogue scale (VAS) scores at 2 and 4 weeks. Strength improvements were also more substantial in the intervention group, with greater gains in hamstring strength at both 2 and 4 weeks. MRI assessments further revealed a significantly greater reduction in tear size in the intervention group (15.1 mm^2 vs. 19.3 mm^2, $p < 0.001$). These results underscore the effectiveness of TUS as a complementary modality to therapeutic exercises, promoting faster recovery, pain relief, enhanced muscle strength, and tissue healing, offering valuable insights for rehabilitation practices in elite athletes.

Our study found that the intervention group (TUS + therapeutic exercises) had a notably shorter recovery time (18.3 days) compared to the control group (21.7 days), with a statistically significant difference ($p < 0.001$). This finding is consistent with previous studies that suggest physical therapy combined with modalities like TUS can speed up recovery [31]. For instance, a study by Xiao et al. (2024) demonstrated that TUS, when combined with standard rehabilitation exercises, resulted in a faster recovery time for muscle injuries, particularly in athletes (Xiao et al., 2024). Similar improvements in recovery time have been reported by studies examining the effects of modalities like diathermy, high-intensity laser therapy (HILT), and cryo-ultrasound in muscle injury management (Scaturro et al., 2024). Specifically, Scaturro et al. (2024) and Ammendolia et al. (2023) highlighted that combining HILT with manual massage reduced recovery times in athletes with muscle injuries, which is in line with our observation of accelerated recovery with the addition of TUS (Scaturro et al., 2024) (Ammendolia et al., 2023).

In terms of pain reduction, we observed a significant decrease in pain scores as measured by the Visual Analogue Scale (VAS) at both 2 and 4 weeks in the TUS + exercise group. This aligns with findings from several studies investigating the analgesic effects of TUS. A Prospective cohort by MacDonald et al. (2024) concluded that therapeutic ultrasound was effective in reducing pain in musculoskeletal conditions, which corroborates our results (MacDonald, 2024). Similarly, Ramos et al. (2017) found that TUS significantly reduced pain intensity in patients with soft tissue injuries, enhancing their ability to participate in rehabilitation exercises (Ramos et al., 2017a). However, it is worth noting that not all studies have reached similar conclusions. For example, a study by Poursalehian et al. (2023) and Reurink et al. (2012) found no significant difference in pain reduction between TUS and placebo treatments in patients with hamstring injuries, suggesting that the efficacy of TUS in pain management might vary depending on injury severity, treatment parameters, or the inclusion of adjunct therapies like exercise (Poursalehian et al., 2023) (Reurink et al., 2012).

Strength improvements were also markedly better in the intervention group, with greater gains in hamstring strength at both 2 and 4 weeks. This is consistent with the findings of several previous studies emphasizing the synergistic effects of combined modalities and exercise. A study by Bourne et al. (2018) found that TUS, when combined with strengthening exercises, led to greater improvements in muscle strength compared to exercise alone in athletes recovering from lower limb injuries (Bourne et al., 2018b). Moreover, a study by Clark et al. (2005) found that eccentric strengthening exercises, like those commonly used in hamstring rehabilitation, significantly increased muscle strength and reduced the risk of re-injury (Clark et al., 2005). In comparison, de Jesus et al. (2019), reported a significant improvement in muscle strength with the addition of TUS to standard rehabilitation protocols, suggesting that TUS may produce superior outcomes when combined with exercise in all contexts (De Jesus et al., 2019).

Our study also found a significant reduction in the size of muscle tears in the intervention group, as assessed by MRI (15.1 mm^2 vs. 19.3 mm^2, $p < 0.001$). This result adds to the growing body of evidence supporting the role of TUS in accelerating tissue healing. TUS has been shown to promote tissue repair by increasing local blood circulation, stimulating collagen production, and enhancing cell regeneration, which facilitates the healing of muscle injuries (Papadopoulos & Mani, 2020). Similarly, a study by Gurovich et al. (2012) demonstrated that TUS therapy significantly reduced the size of muscle tears and accelerated healing in athletes recovering from hamstring injuries (Gurovich, 2012). However, contrasting results have also been reported. For example, a study by Zaghloul et al. (2020) found moderate difference in tissue healing rates between TUS and placebo treatments in patients with mild to moderate muscle injuries, suggesting that the effectiveness of TUS may depend on the timing and parameters of its application (Zaghloul et al., 2020).

Clinical predictors of return to play (RTP) following hamstring injuries have been explored in several studies, many of which align with the findings of our study. Marc et al. (Sherry & Best, 2004) demonstrated that individuals with chronic adductor pain showed significant improvements in both pain reduction and sports performance when engaged in an active rehabilitation program targeting muscle strength and coordination, rather than relying solely on modalities and stretching. Similarly, our study supports the idea that a targeted rehabilitation program, combining therapeutic ultrasound (TUS) and therapeutic exercises, accelerates recovery and reduces RTP time. Chu et al. (Chu & Rho, 2016) found that self-reported RTP times and deficits in passive straight leg raise were strongly correlated with recovery time after hamstring injuries, which echoes our findings of significantly faster recovery in the intervention group. Furthermore, Ramos et al. (Ramos et al., 2017b) observed that athletes who took longer than one day to walk pain-free were more likely to experience prolonged RTP, which correlates with our results showing that the combined TUS and exercise intervention group returned to play significantly faster.

In addition, a Danish study by Trail et al. of elite football players (Trial, 2011) reported average recovery times ranging from 7 to 64 days, with our results showing a similar trend but with faster recovery times in the TUS + exercise group (18.3 days vs. 21.7 days in the control group). Regarding TUS, Ramos et al. (Ramos et al., 2017b) and Wilkin et al. (Wilkin et al., 2004) found that TUS's thermal effects, including vasodilation and enhanced muscle extensibility, played a key role in reducing pain and promoting healing, which aligns with our study's observation of improved clinical outcomes, such as pain reduction and muscle strength in the intervention group (Hwang, 2017). Overall, our findings are consistent with these previous studies, further supporting the efficacy of combining TUS with therapeutic exercises to accelerate recovery and reduce RTP time in hamstring injuries.

Despite the promising results from our study, there are some important considerations to address. While our findings suggest that TUS combined with therapeutic exercises is an effective rehabilitation strategy for hamstring injuries, other studies have raised concerns about the potential risks associated with the use of thermal therapies like ultrasound in the acute phase of injury. A study by Magalhaes et al. (2015) indicated that early use of thermal modalities could delay the inflammatory response and negatively impact tissue regeneration (Magalhães et al., 2015). Moreover, the optimal timing for initiating TUS therapy remains a subject of debate. Some studies recommend delaying the use of ultrasound therapy until the subacute phase of injury to avoid exacerbating inflammation, while others suggest that early application may reduce muscle damage and accelerate recovery (Choobsaz et al., 2023). In our study, we chose to administer TUS in conjunction with therapeutic exercises during the subacute phase, based on the premise that this would maximize its therapeutic effects without impeding the natural healing process.

Another important aspect is the role of rehabilitation protocols, which include exercise-based interventions alongside physical modalities like TUS. A study by Heiderscheit, et al. (2010) emphasized that rehabilitation programs combining strength training, flexibility exercises, and proprioception training are more effective at reducing injury recurrence than treatments relying solely on passive modalities like TUS (Heiderscheit et al., 2010). In our study, we included therapeutic exercises in both the intervention and control groups, which likely contributed to the positive outcomes observed. Studies have consistently shown that exercise-based rehabilitation, particularly eccentric strengthening exercises, is crucial for preventing hamstring injuries and improving long-term recovery outcomes (Funk et al., 2003). Our results align with these studies, highlighting the importance of combining physical therapy modalities with targeted rehabilitation exercises to optimize recovery and prevent recurrence (Smith et al., 2006).

The clinical implications of our randomized controlled trial (RCT) are significant, particularly for the rehabilitation of hamstring injuries in elite football players. Our study provides strong evidence supporting the efficacy of combining therapeutic ultrasound (TUS) with therapeutic exercises to accelerate recovery and reduce return-to-play (RTP) time. This combination not only enhances muscle strength and promotes tissue healing but also offers pain relief, leading to quicker recovery and minimizing the risk of recurrent injuries, as shown by the significantly faster recovery times and improved clinical outcomes in the intervention group compared to the control group. The strength of our study lies in its robust design as a randomized controlled trial, ensuring a high level of scientific rigor and minimizing biases in treatment allocation. Additionally, the use of objective measures, such as MRI for tear size and visual analogue scale (VAS) for pain assessment, provides reliable and quantifiable data. However, there are limitations to consider, including the relatively short follow-up period and the focus on a specific population of elite football players, which may limit the generalizability of the findings to other athletes or non-elite populations. Furthermore, while the study demonstrates promising results, further research with larger sample sizes and longer follow-up periods is needed to confirm the long-term efficacy and safety of combining TUS with therapeutic exercises for hamstring rehabilitation in diverse athletic populations.

Conclusions

In conclusion, our randomized controlled trial demonstrates that the combination of therapeutic ultrasound (TUS) and therapeutic exercises significantly improves recovery outcomes in elite football players with partially injured hamstring muscles. The intervention group showed faster recovery times, reduced pain, improved muscle strength, and greater reduction in tear size compared to the control group, supporting the efficacy of TUS as a complementary modality in hamstring rehabilitation. These findings suggest that integrating TUS with standard therapeutic exercises can enhance rehabilitation protocols, leading to quicker return-to-play times and potentially reducing the risk of recurrent injuries. While the study's strengths include its rigorous design, objective measurements, and high participant satisfaction, its limitations, such as the short follow-up period and focus on elite athletes, warrant further investigation. Future research should explore the long-term effects of this combined approach and assess its applicability to a broader range of athletes, including those with different injury severities and from diverse sports populations.

Credit authorship contribution statement

Kamal Hadib Abdulridha: study conceptualisation and design, project management, writing-original draft.

Juan Nicolás Cuenca-Zaldivar: investigation, statistical analysis.

Alejandra Aguilar-Latorre: investigation, resources, writing-review & editing.

Estela Calatayud: study conceptualisation, investigation, writing-review & editing.

Isabel Gómez-Soria: study conceptualisation and design, project management, writing-review & editing.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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