Journal of Back and Musculoskeletal Rehabilitation -1 (2023) 1–10 1
DOI 10.3233/BMR-230265
IOS Press

Effectiveness of cryo plus ultrasound therapy versus diathermy in combination with high-intensity laser therapy for pain relief in footballers with muscle injuries: A prospective study

Dalila Scaturro[a], Alessandro de Sire[b,c,*], Fabio Vitagliani[d], Davide Lo Nardo[d], Sofia Tomasello[e], Antonio Ammendolia[b,c] and Giulia Letizia Mauro[a]

[a]*Department of Surgical, Oncological and Stomatological Disciplines, University of Palermo, Palermo, Italy*
[b]*Department of Medical and Surgical Sciences, University of Catanzaro "Magna Graecia", Catanzaro, Italy*
[c]*Research Center on Musculoskeletal Health, MusculoSkeletalHealth@UMG, University of Catanzaro "Magna Graecia", Catanzaro, Italy*
[d]*Department of Biomedical and Biotechnological Sciences, University of Catania, Catania, Italy*
[e]*Faculty of Medicine and Surgery, University of Palermo, Palermo, Italy*

Received 17 August 2023
Accepted 15 November 2023

Abstract.
BACKGROUND: Muscle injuries are common traumatic events in the clinical practice of the rehabilitation field. There is still a gap in the scientific literature on the effectiveness of physical agent modalities in the management of muscle injuries in athletes.
OBJECTIVE: The aim of this study was to assess the effectiveness of cryo plus ultrasound therapy com-pared to diathermy in combination with high-intensity laser therapy (HILT) for pain relief in professional footballers with muscle injuries.
METHODS: A case-control study was conducted on 31 professional footballers with a muscle injury of the lower limbs. Of these, 17 patients, assigned to a Group A (AG), were treated with HILT and cryoultrasound therapy; the remaining 14 patients, assigned to a Group B (BG), underwent HILT and diathermy. We assessed the extent of the pain, the size of the muscle injury, frequency of recurrence and number of days to recovery, at the time of recruitment, at the end of the rehabilitation and 3 months after the injury.
RESULTS: Group A athletes had a greater benefit on pain (4.65 $\pm$ 0.61 vs 3.24 $\pm$ 0.63; $p < 0.05$) and muscle injury recurrence. The return to play in the athletes of group A took place 4.73 days earlier.
CONCLUSION: HILT and cryo plus ultrasound therapy, in combination with therapeutic exercise, rep-resent a valid strategy in the treatment of muscle injuries in professional footballers.

Keywords: Athletic injuries, physical therapies, rehabilitation, muscle performance, football

1. Introduction

Muscle injuries are common traumatic events in clinical practice, as they occur in daily life, during work and during sports practice. In sports, their incidence varies from 10% to 55% of total injuries, depending

*Corresponding author: Alessandro de Sire, Physical and Rehabilitative Medicine, Department of Medical and Surgical Sciences, University of Catanzaro "Magna Graecia", Viale Europa, 88100, Catanzaro, Italy. Tel.: +39 961369768; E-mail: alessandro.desire@unicz.it.

on the practiced sport [1]. These injuries occur more frequently in contact sports such as football, basketball, and rugby. In professional football, they account for 25% of the total number of days absent from training and competition. There appears to be no gender differences in the incidence of these injuries. Generally, injuries from direct trauma recover faster than those from indirect trauma.

A recent systematic review analysed the incidence of injuries in professional footballers: the results showed a higher incidence of injuries during competitions than during training in both young and adult players, with a higher incidence in young athletes during training [2].

Another recent systematic review summarised the current literature describing the activities performed around the time of injury in football (soccer). Running and kicking were the pre-dominant activities leading to thigh and hamstring injuries. Changing direction and kicking were the predominant activities leading to hip and groin injuries, duels were the predominant activities leading to ankle injuries [3].

According to Mueller Wohlfart's classification, muscle injuries are classified into direct trauma injuries (contusion-laceration) and indirect trauma injuries, subdivided in turn into non-structural (grade I and II) and structural injuries [4–6]. Structural injuries are further subdivided into partial muscle injury (grade III): 3 A, minor partial injury, i.e., injury of one or more primary bundles with a secondary bundle; 3 B, moderate partial injury, i.e., injury of at least one secondary bundle and with a rupture area $< 50\%$ of the muscle surface; and (sub)total muscle injury (grade IV) [7].

Muscle injury often occurs in the dominant limb. The muscle groups most commonly involved in direct injuries are the quadriceps femoris (especially the vastus lateralis and vastus intermedius) and the gastrocnemii (especially the lateralis); in indirect injuries, however, are the biarticular ones such as the biceps brachii in the upper limb and the hamstrings for the lower limb, as the injury often occurs while the two joints are performing opposite movements [8]. In football, the greatest number of indirect muscle injuries affect the hamstrings, quadriceps femoris, adductors and soleus-gastrocnemius muscle complex [9].

There is still heterogeneity across studies and lack of consensus in regards to classification, diagnosis, treatment and prevention. Muscle injuries compromise athlete's performance with time loss due to injury, shortens their highest-level career longevity with higher risk of reinjury rates, and is a defying problem for clubs to balance financial losses due to having their players off the pitch [10].

Following a muscle injury, the player may generally report sudden onset of pain and functional impotence, the presence of haematomas or ecchymosis, oedemas, gaps, muscle retractions, changes in muscle profile, stiffness, hyposthenia, and painful contractures [11]. If the pathology is underestimated or not properly treated, they can force the athlete to interrupt sports activity for long periods with a high risk of recurrence [12]. The diagnosis is confirmed by imaging techniques: ultrasound is the first level exam that will assess the presence of a hypoechogenicity pattern caused by the interruption of the common myofibrillar pattern; as a second level investigation magnetic resonance imaging is used, which better identify the muscle fibre and possible tendon and ligament problems.

In the acute phase, the current management of muscle injuries is essentially based on the PRICE protocol (protection, rest, ice, compression, elevation), although there are still no randomized controlled trials in the literature that demonstrate its real efficacy [13,14]. Subsequently, the player undertakes rehabilitation with exercise and therapy aimed at solving the oedema, repairing the injury, strengthening the muscles, and restoring athletic movements.

Physical agent modalities are widely used in clinical practice for their analgesic and anti-inflammatory action, not only in muscle injuries, but in all disorders of the musculoskeletal system [15–18]. The type of physical agent modality as well as the specific treatment for muscle injuries are discordant in the scientific literature [19].

High intensity laser therapy (HILT) is a particular pulsed Nd Yttrium Alluminium Garnet (YAG) laser which uses specific wavelength of light within the infrared (1064 nm). HILT delivers high-intensity light energy to deep tissue in short pulses (120–200 μs). In addition to possessing anti-inflammatory, analgesic, and anti-edema effects. HILT also has photothermal properties, resulting from the transformation of high-energy light into heat in tissues. The heat induces vasodilation which causes an increase in blood flow, vascular permeability, and cellular metabolism, accelerating tissue healing [20].

In this context, cryoultrasuond therapy involves a combination of vasoconstriction (cryotherapy) and vasodilatation (ultrasound) with a biostimulating action on the injured muscle fibre [21,22]. Diathermy, also known as TECAR (Capacitive and Resistive Energy Transfer) activates reparative and anti-inflammatory mechanisms in biological tissues by reducing the repairing time of muscle injuries [23]. Physical therapy is always combined with therapeutic exercise in order to achieve remodelling of the repair tissue as close as possible to physiology and strengthening of the injured muscle [24]. Training programs incorporating general and sport-specific exercises that involve the use of postural and core muscles show an improvement of body balance, back muscle strength, and endurance [25].

To the best of our knowledge, there is still a gap in the scientific literature on the effectiveness of physical agent modalities in the management of muscle injuries in athletes. Numerous authors have observed positive results with the use of physical therapy on muscle injuries, recommending its use in athletes especially in terms of pain reduction [23,26]. On the contrary, other authors do not agree with this, stating that there is insufficient evidence demonstrating improved muscle regeneration after injury following treatment with physical therapies [27,28]. Therefore, aim of the present study was to assess the effectiveness of cryoultrasound therapy compared to diathermy in combination with high-intensity laser therapy for pain relief in male professional footballers with muscle injuries.

2. Materials and methods

2.1. Study design

In this prospective study we included male professional football players affected by subacute lower limb muscle injury. Data collection, using hospital database, included professional footballers who underwent a rehabilitation treatment following a lower limb muscle injury between September 2022 and March 2023 in the U.O.C. of Recovery and Functional Rehabilitation of the A.O.U.P. "Paolo Giaccone" of Palermo.

The study received approval from the local ethical committee "Palermo 1" (approval n° 11/2022) of the A.O.U.P. Paolo Giaccone of Palermo and was conducted in accordance with the declaration of Helsinki. The processing of information and data has been carried out according to the guidelines of Good Clinical Practice (GCP).

2.2. Participants

The following inclusion criteria were used: age 18–21 years; professional footballer in a competitive club; presence of a grade III A lower limb muscle lesion, according to the Mueller-Wohlfart classification, confirmed by ultrasound examination and occurring during sports activity at least 5 days before inclusion in the present study; no previous muscle injuries in the last 6 months; signature of the written informed consent for participating in the study.

Exclusion criteria were: previous muscle injuries or bone fractures of the lower limbs in the last 6 months; knee instability due to previous rupture of knee ligaments; instability or previous sprain of the ankle; active neoplastic or infectious diseases; and congenital anomalies of the lower limbs.

2.3. Intervention

We included 26 professional soccer players, depending on the treatment 14 patients were assigned to Group A (AG) and 12 to Group B (BG). Group A received a combined rehabilitation treatment of HILT and cryoultrasound therapy, group B received a combined rehabilitation treatment of HILT and diathermy. Physical therapy was held daily for a total of 10 sessions lasting 30 minutes each. At the end of physical therapy sessions, patients of both group underwent rehabilitation program lasting further 60 minutes. Physical therapy and rehabilitation program were held by the same experienced sports physiotherapist.

2.3.1. Physical agent modalities

HILT (BTL, Milan, Italy) was used for 15 minutes per session with a total delivered energy of 1300 joules at an average power of 3W. This treatment was received by both groups [20].

Patients of Group A underwent cryoultrasound therapy (Medical Cold Therapy, Catania, Italy) for 15 minutes per session with temperature of −2 degrees, frequency of 1 Mhz and dose between 1 and 1.3 Wcm2 depending on the patient's tolerance [22]. Patients of Group B underwent diathermy (BTL, Milan, Italy) for 15 minutes per session in a 10–13 W capacitive system, it exploits a well-known mechanism: diathermy. It is an effective and widely used therapy in the treatment of muscle, joint and tendon pathologies in sportsmen [29].

Energy density delivered can be calculated for each individual patient with the following formula compared to the above parameters: DE (J/cm2) = Treatment surface (total area/head area) /((Time (seconds) x Power Density (W X % pulsed)).

2.3.2. Rehabilitation program

All patients received a rehabilitation protocol of 5 weekly sessions lastingapproximately 60 minutes, for approximately 3 weeks. During the early post-injury phases the protocol included isometric exercises to strengthen core stability. These exercises were each performed for 3 sets of 30 seconds, although the number of sets and repetitions can be varied depending on the athlete's response. The exercises proposed were: plank, static lateral bridge, and dynamic lateral bridge with hip raises, crunches, squats, static superman and dynamic superman, spiderman, extensors, glute bridge, and lunges. When the athlete does not feel pain she can also start a slow run (with a speed of approximately 7 km/h) without changing direction, generally performing 3 blocks of 10 minutes each. Isotonic exercises based on concentric contraction are introduced with progressively increasing intensity, so the athlete begins to no longer feel pain in the injured muscle. In the second phase of our protocol, eccentric exercise is introduced, which is very useful for preventing muscle relapses. Our protocol used Copenhagen and Nordic hamstring exercises depending on the type of muscle injury. All isotonic exercises were initially performed using 70% maximum strength and exploiting different knee flexion angles (0°–30°–60°–90°). At the beginning these exercises were performed without resistance and subsequently a progressively increasing load was introduced, avoiding stressful loads in the initial phases. When the athlete is ready, the reathleticization protocol continues on the playing field with teamwork in which the athletic trainer also participates, always under close observation of the doctor. Finally, the program was concluded with plyometric, ballistic, and isoinertial exercises, to repeatedly perform sport-specific movements, including the one that caused the injury; and with stretching exercises (static, dynamic, PNF) to improve hip and knee ROM and muscle lengthening.

2.4. *Outcome measures*

Through patients' medical records we collected information regarding: age, gender, body mass index (BMI), dominant foot, side of the muscle lesion, location of the muscle lesion and location of the muscle involved. The entity of the pain was evaluated through the administration of the Numeric Rating Scale (NRS). With the aid of an ultrasound probe, the same blinded radiologist, with many years of experience in the musculoskeletal field, defined the size of the muscle lesion by measuring it in centimeters. All these information were collected at the time of recruitment (T0) and at the end of the rehabilitation program (T1). Finally, we also evaluated the number of days required to return to play and the frequency of muscle injury recurrence 3 months after the injury (T2). Primary outcome was the evaluation of pain, secondary outcome were the size of the muscle tear, the frequency of relapses and the number of days needed to return to play.

2.5. *Statistical analysis*

The data collected was indexed on Excel. We first calculated the sample size of the study according to the below formula:

$$n = \frac{Z^2_{\alpha/2}\sigma^2}{\varepsilon^2} \rightarrow \boxed{n = \frac{z^2_{\alpha/2}\cdot\pi(1-\pi)}{\varepsilon^2}}$$

The aim of detecting a mean difference in NRS (0–10) between the two groups. A power analysis was conducted with the type I error set at 0.05 and the type II error at 0.15 (85% power). The estimated sample size was 15 patients from each group to detect the minimal clinically significant difference in NRS of 2.1 units. The follow-up loss was estimated to be 20%. For this reason, the number of 14 patients for Group A and 12 patients for Group B was considered sufficient to prove our thesis.

Through the use of the Shapiro-Wilk test, the normality of our collected data was verified. In the text and in the tables we have reported continuous variables, expressed as means and standard deviations, and categorical variables, expressed as absolute numbers and percentages.

For the statistical analysis of the data, we used the t-test, for the comparison of the means between the quantitative variables, while the Mood's median test was used for the comparison of the medians between the categorical variables. Finally, to evaluate the statistically significant difference of the NRS and lesion diameter variables examined between the two groups, a repeated measures ANOVA was used. R statistical software (R Core Team, 2021) was used to analyze the collected data. A priori results showing $P < 0.05$ were considered statistically significant.

3. Results

In the course of this study, 26 professional soccer players fulfilled the inclusion and exclusion criteria and were included in the study and allocated into the two groups: 14 athletes belonging to group A and 12 athletes belonging to group B.

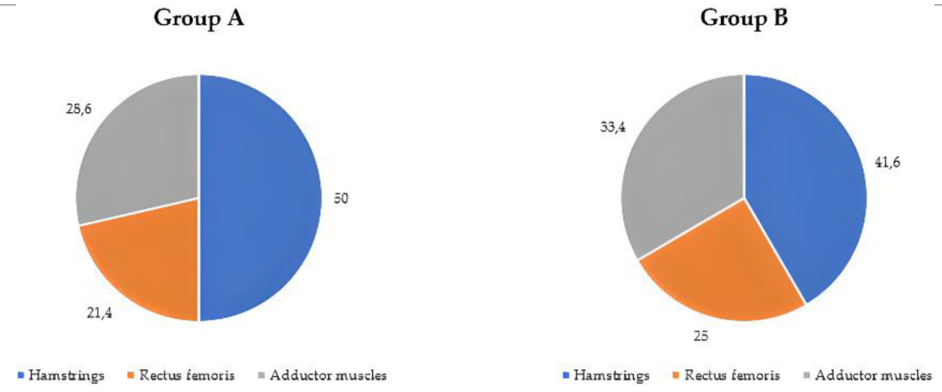

Fig. 1. Locations of muscle injuries in group A (a) and group B (b).

The included athletes had a mean age of 19.3 ± 1.37 years and were all male, with a mean BMI of 19.4 ± 1.9 Kg/m2. Seventeen patients (56.6%) had the right foot as dominant and the remaining 9 (43.4%) the left. The side of the muscle injury was right in 16 patients (61.5%) and left in 10 patients (38.5%). The muscle injury occurred during training sessions in 19 players (73.1%), and in the remaining 7 (26.9%) during a match. The most frequent injury sites were the hamstrings (38.4%), followed by the adductor muscles (34.7%) and rectus femoris (26.9%) (Fig. 1). The mean perceived pain was 6.85 ± 1.01 points according to the NRS scale, while the mean diameter of the muscle injury was 1.84 ± 1.81 cm. No statistically significant difference was present at baseline between the two groups examined (Table 1).

Table 2 shows, at T1, the results of the two different rehabilitation treatments on the outcomes considered. Regarding pain, we observed a statistically significant improvement in both group A (NRS: 7.1 ± 0.84 vs 2.32 ± 0.71; $p < 0.05$) and group B (6.6 ± 1.05 vs 3.3 ± 0.8; $p < 0.05$) (Table 2). When comparing the changes in NRS score between the two groups, however, we observed a greater benefit in athletes belonging to group A (4.78 ± 0.59 vs 3.3 ± 0.64; $p < 0.05$). With regard the reduction of the diameter of the muscle lesion, a statistically significant improvement was observed in both group A (1.89 ± 1.76 vs 0.15 ± 0.24; $p < 0.05$) and group B (1.71 ± 1.78 vs 0.25 ± 0.22; $p < 0.05$) (Table 2). No statistically significant difference was observed between changes in mean diameter between the two groups (1.74 ± 2.01 vs 1.46 ± 2.13; $p = 0.72$) (Table 2). Concerning return to play, it occurred 21.34 days after the injury in Group A patients, and 27.5 days in Group B. This difference showed to be statistically significant (21.34 ± 3.2 vs 27.5 ± 4.1; $p < 0.05$). Group A patients returned to play 6.16 days earlier than Group B, a percentage difference of 28.8%.

Finally, 1 athlete in group A and 2 athletes in group B had a recurrence of muscle injury after treatment, with a percentage difference between the two groups of 66.6%. No adverse events to the different treatments were reported in the two groups. All patients completed the rehabilitation protocol.

4. Discussion

Muscle injuries of the lower limbs are one of the most feared injuries by athletes, particularly footballers, due to the many days away from sporting activity [1,30,31]. Many authors have focused on the role of physical therapies in the management of muscle injuries, although conflicting data exist on the reduction of recovery times and the incidence of relapses [32,33]. Evidence has demonstrated the effectiveness of rehabilitation protocols in the treatment of muscle injuries, in particular Szabo et al., in a systematic review, demonstrated the effectiveness of combined treatment diathermy + HILT with manual massage [23]. During this study, we tested the effectiveness of two combined physical therapy protocols, HILT + diathermy, and HILT + cryoultrasound, on footballers' muscle injuries. Our study demonstrated that the HILT + diathermy protocol as well as HILT + cryoultrasound, in combination with kinesitherapy, are effective treatments in the management and recovery of muscle injuries, according to previous systematic reviews. From our data, the HILT + cryoultrasound combination has been shown to achieve greater pain relief and an earlier return to play than the other protocol. This may be caused by the fact that the combination of ultrasound and cryotherapy results in a mutual enhancement of their biological and therapeu-

Table 1
General characteristics of the 26 athletes included

Characteristics	Total ($n = 26$)	Group A ($n = 14$)	Group B ($n = 12$)	p-value
Age, mean ± SD	19.3 ± 1.37	19.5 ± 1.66	19.1 ± 1.12	0.76
Sex, mean ± SD				
Male	30 (100)	14 (100)	12 (100)	0.99
Female	0 (0)	0 (0)	0 (0)	
BMI, mean ± SD	19.4 ± 1.9	19.1 ± 1,6	19.3 ± 1.6	0.82
Foot Dominant, n°(%)				
Right	17 (56.6)	9 (64.2)	8 (66.6)	0.41
Left	9 (43.4)	5 (35.8)	4 (33.4)	
Wound side, n°(%)				
Right	16 (61.5)	9 (64.3)	7 (58.3)	0.52
Left	10 (38.5)	5 (35.7)	5 (41.7)	
Accident place, n°(%)				
Training	19 (73.1)	10 (71.4)	9 (75)	0.18
Match	7 (26.9)	4 (28.6)	3 (25)	
Lesion site, n°(%)				
Rectus Femoris	7 (26.9)	3 (21.4)	3 (25)	0.22
Hamstrings	10 (38.4)	7 (50)	5 (41.6)	
Adductor muscles	9 (34.7)	4 (28.6)	4 (33.4)	
NRS, mean ± SD	6.85 ± 1.01	7.1 ± 0.84	6.6 ± 1.05	0.17
Lesion diameter, mean ± SD	1.84 ± 1.81	1.89 ± 1.76	1.71 ± 1.78	0.72

Table 2
Primary and secondary outcomes in the two groups at T1

Characteristics	Group A	Group B	p-value
NRS, mean ± SD			
T0	7.1 ± 0.84	6.6 ± 1.05	0.17
T1	2.32 ± 0.71	3.3 ± 0.8	< 0.05
p-value	< 0.05	< 0.05	
Diameter, mean ± SD			
T0	1.89 ± 1.76	1.71 ± 1.78	0.72
T1	0.15 ± 0.24	0.25 ± 0.22	0.28
p-value	< 0.05	< 0.05	
Return to play, mean ± SD	21.34 ± 3.2	27.5 ± 4.1	< 0.05

tic effect. HILT has a greater penetration force deep into the tissues and through its photochemical effects, increases mitochondrial oxidation and facilitates the formation of adenosine triphosphate (ATP), as well as inducing an increase in metabolism and blood circulation, with rapid absorption of edema and elimination of exudates [20]. HILT also has an important biological action by causing muscle relaxation and inhibition of free nerve endings resulting in immediate pain reduction [23]. Cryoultrasound therapy is generally used for its anti-inflammatory, pain-relieving, and anti-edema effects, exploiting the alternation of vasoconstriction, produced by the cold, and superficial and deep vasodilation, induced by ultrasound. This alternation generates important benefits, especially in cases of edema, bruises, and tissue lesions. The synergy between these two approaches allows you to obtain all the typical benefits of ultrasound, attenuating the so-called thermal effect and related complications; furthermore, low temperatures improve the transmission capacity of ultrasound [22]. The final effect will therefore be the reduction of acute inflammation and edema with consequent reduction of pain [34]. In this scenario, it has recently been shown that the application of low temperatures immediately after a muscle injury can delay muscle regeneration and induce collagen deposits, reducing the expression of growth factors involved in muscle regeneration [35]. In contrast, Singh et al. [36] highlight how the use of low temperatures decreases or delays the infiltration of inflammatory cells and the expression of proangiogenic factors. After muscle injuries, returning to play is the main goal of the recovery process for athletes. Nowadays, scientific evidence on the timing of a return to play is still limited. Ekstrand et al. evaluated the return to the field after the most frequent injuries in professional footballers over 13 years. Moderate injuries resulted in absence from the field of play for 7 to 28 days; although serious injuries had an average RTP (return to play) > 28 days [37], these data are very similar to the results of our study.

Finally, recurrences of muscle injuries represent the most feared complication not only by athletes but also by rehabilitators. In our study, we found a rate of approximately 10% within 6 months of the first injury. In this scenario, it appears fundamentally important to implement a gradual rehabilitation program that aims to strengthen the affected muscles and reduce relapses. Core-stability exercises are used by 100% of elite soccer teams [38], although the literature evidence of their effect is not unanimous [39]. These exercises are aimed at reducing weakness of the iliopsoas muscle and gluteus maximus during running or kicking the ball, which is the main cause of injuries of the rectus femoris or hamstring muscles [39]. The use of isotonic concentric exercises is important. During an isotonic concentric contraction, the muscle belly shortens by the sliding of the myofilaments with a constant force proportional to the external load. In this way the repair area is not stressed in traction and a diastasis mechanism of the stumps during the remodeling/repair phase is avoided. Studies have shown that the Nordic hamstring, performed during the warm-up, reduces hamstring injuries by 50% [40,41]; the Copenhagen exercise, on the other hand, leads to an increase in the strength of the adductor muscles by 8% and prevents relapses [42]. Bisciotti et al. evaluated the risk of recurrence of muscle injuries in athletes obtained according to our results. They showed that the risk of relapse is greatest in the first two months after returning to play; approximately 25% of them occur between 2 and 12 months after the primary lesion; after a hamstring injury, the risk of recurrence does not normalize before 22 weeks [43].

Our study presents some limitations: first of all, the low number of patients recruited does not allow us to completely generalize the results obtained. The second limitation is that of not having considered pharmacological treatment as an adjuvant in the management of muscle injuries. In this context, a review carried out by our group highlighted the role of pharmacological treatment on athletes' pain caused by musculoskeletal injuries, concluding that the optimal strategy for the management of sports-related injuries should include not only pharmacological interventions, but also tailored prescription, load management and rehabilitation [44]. Mackey et al. analyzed the use of NSAIDs following a muscle injury, underlining that they have an important effect on pain in the days following the injury, but highlighting some doubts about their long-term use [45]. In contrast, the administration of COX inhibitors inhibits biological processes of muscle regeneration, causing long-term impairment of muscle function [46–48].

Finally, a further limitation of our study is that it focused only on the effectiveness of these physical therapies and less on the dosage parameters most suitable for the treatment of muscle injuries in athletes. This aspect appears to be rather lacking in the literature, in fact, and to date it is not possible to establish recommendations on the appropriate dosage to use in various musculoskeletal pathologies.

5. Conclusions

Muscle injuries are the main cause of absence from training and competition for professional footballer. Physical agent modalities and rehabilitation are commonly used in the treatment of muscle injuries, although evidence on their effectiveness is conflicting in the literature. The rehabilitation protocols we have analysed for muscle injuries in professional footballers have proven to be valid and functional. The rehabilitation protocol consisting of HILT and cryoultrasound therapy in combination with therapeutic exercise showed to be an effective treatment for pain relief in professional footballers with muscle injuries in sub-acute phase. Further studies are warranted to confirm these data in order to provide stronger evidence on the role of a patient-tailored rehabilitation plan for functioning in athletes with muscle lesions.

Author contributions

Conceptualization, D.S. and F.V.; methodology, A.d.S; software, D.L.N.; validation, A.A. and G.L.M.; formal analysis, F.V.; investigation, D.L.N.; resources, F.V. and D.L.N.; data curation, D.S.; writing – original draft preparation, D.S. and A.d.S.; writing – review and editing, A.A. and G.L.M.; visualization, F.V., D.L.N., and S.T.; supervision, A.d.S. and G.L.M. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Ethics statement

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Local Ethics Committee "Palermo 1" (protocol code 11/2022).

Informed consent

Written informed consent has been obtained from the patients to publish this paper.

Data availability statement

Data used to support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

None to report.

Conflict of interest

The authors declare no conflict of interest.

References

[1] Järvinen TA, Järvinen TL, Kääriäinen M, Kalimo H, Järvinen M. Muscle injuries: biology and treatment. Am J Sports Med. 2005 May; 33(5): 745-64. doi: 10.1177/0363546505274714. PMID: 15851777.

[2] Pfirrmann D, Herbst M, Ingelfinger P, Simon P, Tug S. Analysis of injury incidences in male professional adult and elite youth soccer players: A systematic review. J Athl Train. 2016 May; 51(5): 410-24. doi: 10.4085/1062-6050-51.6.03. Epub 2016 May 31. PMID: 27244125; PMCID: PMC5013706.

[3] Aiello F, Impellizzeri FM, Brown SJ, Serner A, McCall A. Injury-inciting activities in male and female football players: A systematic review. Sports Med. 2023 Jan; 53(1): 151-176. doi: 10.1007/s40279-022-01753-5. Epub 2022 Oct 31. PMID: 36315396; PMCID: PMC9807506.

[4] Counsel P, Breidahl W. Muscle injuries of the lower leg. Semin Musculoskelet Radiol. 2010 Jun; 14(2): 162-75. doi: 10.1055/s-0030-1253158. Epub 2010 May 18. PMID: 20486025.

[5] Pollock N, James SL, Lee JC, Chakraverty R. British athletics muscle injury classification: a new grading system. Br J Sports Med. 2014 Sep; 48(18): 1347-51. doi: 10.1136/bjsports-2013-093302. Epub 2014 Jul 16. PMID: 25031367.

[6] Maffulli N, Oliva F, Frizziero A, Nanni G, Barazzuol M, Via AG, Ramponi C, Brancaccio P, Lisitano G, Rizzo D, Freschi M, Galletti S, Melegati G, Pasta G, Testa V, Valent A, Del Buono A. ISMuLT Guidelines for muscle injuries. Muscles Ligaments Tendons J. 2014 Feb 24; 3(4): 241-9. PMID: 24596685; PMCID: PMC3940495.

[7] Mueller-Wohlfahrt HW, Haensel L, Mithoefer K, Ekstrand J, English B, McNally S, Orchard J, van Dijk CN, Kerkhoffs GM, Schamasch P, Blottner D, Swaerd L, Goedhart E, Ueblacker P. Terminology and classification of muscle injuries in sport: the Munich consensus statement. Br J Sports Med. 2013 Apr; 47(6): 342-50. doi: 10.1136/bjsports-2012-091448. Epub 2012 Oct 18. PMID: 23080315; PMCID: PMC3607100.

[8] Schache AG, Wrigley TV, Baker R, Pandy MG. Biomechanical response to hamstring muscle strain injury. Gait Posture. 2009 Feb; 29(2): 332-8. doi: 10.1016/j.gaitpost.2008.10.054. Epub 2008 Nov 26. PMID: 19038549.

[9] Morgan BE, Oberlander MA. An examination of injuries in major league soccer. The inaugural season. Am J Sports Med. 2001 Jul-Aug; 29(4): 426-30. doi: 10.1177/ 03635465010290040701. PMID: 11476380.

[10] Garcia AG, Andrade R, Afonso J, Runco JL, Maestro A, Espregueira-Mendes J. Hamstrings injuries in football. J Orthop. 2022 Apr 11; 31: 72-77. doi: 10.1016/j.jor.2022.04.003. PMID: 35464813; PMCID: PMC9026901.

[11] Noonan TJ, Garrett WE Jr. Muscle strain injury: diagnosis and treatment. J Am Acad Orthop Surg. 1999 Jul-Aug; 7(4): 262-9. doi: 10.5435/00124635-199907000-00006. PMID: 10434080.

[12] Wangensteen A, Tol JL, Witvrouw E, Van Linschoten R, Almusa E, Hamilton B, Bahr R. Hamstring reinjuries occur at the same location and early after return to sport: A descriptive study of MRI-confirmed reinjuries. Am J Sports Med. 2016 Aug; 44(8): 2112-21. doi: 10.1177/0363546516646086. Epub 2016 May 16. PMID: 27184543.

[13] Orchard JW, Best TM, Mueller-Wohlfahrt HW, Hunter G, Hamilton BH, Webborn N, Jaques R, Kenneally D, Budgett R, Phillips N, Becker C, Glasgow P. The early management of muscle strains in the elite athlete: best practice in a world with a limited evidence basis. Br J Sports Med. 2008 Mar; 42(3): 158-9. doi: 10.1136/bjsm.2008.046722. Erratum in: Br J Sports Med. 2009 Oct 1; 43(10): 764. Erratum in: Br J Sports Med. 2010 Oct; 44(13): e1. PMID: 18334622.

[14] Ueblacker P, Haensel L, Mueller-Wohlfahrt HW. Treatment of muscle injuries in football. J Sports Sci. 2016 Dec; 34(24): 2329-2337. doi: 10.1080/02640414.2016.1252849. Epub 2016 Nov 16. PMID: 27849130.

[15] Letizia Mauro G, Scaturro D, Gimigliano F, Paoletta M, Liguori S, Toro G, Iolascon G, Moretti A. Physical Agent Modalities in Early Osteoarthritis: A Scoping Review. Medicina (Kaunas). 2021 Oct 26; 57(11): 1165. doi: 10.3390/medicina57111165. PMID: 34833383; PMCID: PMC8619194.

[16] Marotta N, de Sire A, Ammendolia A. Role of physiotherapy and physical agent modalities for musculoskeletal disorders: Present and future. Applied Sciences. 2023; 13(11): 6461. doi: 10.3390/app13116461.

[17] de Sire A. Sports-related musculoskeletal injuries: From diagnostics to rehabilitation. J Back Muscu-loskelet Rehabil. 2022; 35(4): 687-689. doi: 10.3233/BMR-225002. PMID: 35662105.

[18] Demeco A, de Sire A, Marotta N, Spanò R, Lippi L, Palumbo A, Iona T, Gramigna V, Palermi S, Leigheb M, Invernizzi M, Ammendolia A. Match analysis, physical training, risk of injury and reha-bilitation in padel: Overview of the literature. Int J Environ Res Public Health. 2022 Mar 31; 19(7): 4153. doi: 10.3390/ijerph19074153. PMID: 35409836; PMCID: PMC8998509.

[19] Valle, Xavier. Clinical practice guide for muscular injuries: Epidemiology, diagnosis, treatment and prevention. BRIT J SPORT MED. 2011; 45. doi: 10.1136/bjsm.2010.081570.20.

[20] Zielińska P, Soroko M, Godlewska M, Śniegucka K, Dudek K, Howell K. Photothermal effects of high-intensity laser therapy on the superficial digital flexor tendon area in clinically healthy racehorses. Animals (Basel). 2022 May 12; 12(10): 1253. doi: 10.3390/ani12101253. PMID: 35625098; PMCID: PMC9137476.

[21] Bleakley C, McDonough S, Gardner E, Baxter GD, Hopkins JT, Davison GW. Cold-water immersion (cryotherapy) for preventing and treating muscle soreness after exercise. Cochrane

Database Syst Rev. 2012 Feb 15; 2012(2): CD008262. doi: 10.1002/14651858.CD008262.pub2. PMID: 22336838; PMCID: PMC6492480.

[22] Ammendolia A, de Sire A, Lippi L, Ammendolia V, Spanò R, Reggiani A, Invernizzi M, Marotta N. Cryo plus ultrasound therapy, a novel rehabilitative approach for football players with acute lateral ankle injury sprain: A pilot randomized controlled trial. Sports (Basel). 2023 Sep 9; 11(9): 180. doi: 10.3390/sports11090180. PMID: 37755857.

[23] Szabo DA, Neagu N, Teodorescu S, Predescu C, Sopa IS, Panait L. TECAR therapy associated with high-intensity laser therapy (Hilt) and manual therapy in the treatment of muscle disorders: A lit-erature review on the theorised effects supporting their use. J Clin Med. 2022 Oct 19; 11(20): 6149. doi: 10.3390/jcm11206149. PMID: 36294470; PMCID: PMC9604865.

[24] Tyler TF, Schmitt BM, Nicholas SJ, McHugh MP. Rehabilitation after hamstring-strain injury em-phasizing eccentric strengthening at long muscle lengths: Results of long-term follow-up. J Sport Rehabil. 2017 Apr; 26(2): 131-140. doi: 10.1123/jsr.2015-0099. Epub 2016 Aug 24. PMID: 27632842.

[25] Zemková E, Zapletalová L. The role of neuromuscular control of postural and core stability in functional movement and athlete performance. Front Physiol. 2022 Feb 24; 13: 796097. doi: 10.3389/fphys.2022.796097. PMID: 35283763; PMCID: PMC8909639.

[26] Clijsen R, Leoni D, Schneebeli A, Cescon C, Soldini E, Li L, Barbero M. Does the application of tecar therapy affect temperature and perfusion of skin and muscle microcirculation? A pilot feasibility study on healthy subjects. J Altern Complement Med. 2020 Feb; 26(2): 147-153. doi: 10.1089/acm.2019.0165. Epub 2019 Oct 3. PMID: 31580698; PMCID: PMC7044785.

[27] Ramos GA, Arliani GG, Astur DC, Pochini AC, Ejnisman B, Cohen M. Rehabilitation of hamstring muscle injuries: a literature review. Rev Bras Ortop. 2016 Dec 15; 52(1): 11-16. doi: 10.1016/j.rboe.2016.12.002. PMID: 28194375; PMCID: PMC5290083.

[28] Medeiros DM, Aimi M, Vaz MA, Baroni BM. Effects of low-level laser therapy on hamstring strain injury rehabilitation: A randomized controlled trial. Phys Ther Sport. 2020 Mar; 42: 124-130. doi: 10.1016/j.ptsp.2020.01.006. Epub 2020 Jan 10. PMID: 31991284.

[29] Rodríguez-Sanz J, López-de-Celis C, Hidalgo-García C, González-Rueda V, Ragazzi P, Bueno-Gracia E, Llurda-Almuzara L, Pérez-Bellmunt A. Is tecar therapy effective on biceps femoris and quadriceps rehabilitation? A cadaveric study. J Sport Rehabil. 2022 Apr 1; 31(6): 756-763. doi: 10.1123/jsr.2021-0458. PMID: 35365590.

[30] Brooks JH, Fuller CW, Kemp SP, Reddin DB. Epidemiology of injuries in English professional rugby union: part 1 match injuries. Br J Sports Med. 2005 Oct; 39(10): 757-66. doi: 10.1136/bjsm.2005.018135. PMID: 16183774; PMCID: PMC1725032.

[31] Gescheit DT, Cormack SJ, Duffield R, Kovalchik S, Wood TO, Omizzolo M, Reid M. Injury epidemi-ology of tennis players at the 2011–2016 Australian open grand slam. Br J Sports Med. 2017 Sep; 51(17): 1289-1294. doi: 10.1136/bjsports-2016-097283. Epub 2017 Jul 7. PMID: 28687543.

[32] Siqueira AF, Vieira A, Bottaro M, Ferreira-Júnior JB, Nóbrega OT, de Souza VC, Marqueti RC, Babault N, Durigan JLQ. Multiple cold-water immersions attenuate muscle damage but not alter systemic in-flammation and muscle function recovery: A parallel randomized controlled trial. Sci Rep. 2018 Jul 19; 8(1): 10961. doi: 10.1038/s41598-018-28942-5. PMID: 30026562; PMCID: PMC6053395.

[33] Sánchez-Ureña B, Rojas-Valverde D, Gutiérrez-Vargas R. Effectiveness of two cold water immersion protocols on neuromuscular function recovery: A tensiomyography study. Front Physiol. 2018 Jun 26; 9: 766. doi: 10.3389/fphys.2018.00766. PMID: 29997522; PMCID: PMC6028616.

[34] Sakamoto M. Effects of Physical Agents on Muscle Healing with a Focus on Animal Model Research. Phys Ther Res. 2021 Feb 24; 24(1): 1-8. doi: 10.1298/ptr.R0011. PMID: 33981522; PMCID: PMC8111410.

[35] Takagi R, Fujita N, Arakawa T, Kawada S, Ishii N, Miki A. Influence of icing on muscle regeneration after crush injury to skeletal muscles in rats. J Appl Physiol (1985). 2011 Feb; 110(2): 382-8. doi: 10.1152/japplphysiol.01187.2010. Epub 2010 Dec 16. PMID: 21164157.

[36] Singh DP, Barani Lonbani Z, Woodruff MA, Parker TJ, Steck R, Peake JM. Effects of topical icing on inflammation, angiogenesis, revascularization, and myofiber regeneration in skeletal muscle following contusion injury. Front Physiol. 2017 Mar 7; 8: 93. doi: 10.3389/fphys.2017.00093. PMID: 28326040; PMCID: PMC5339266.

[37] Ekstrand J, Krutsch W, Spreco A, et al. Time before return to play for the most common injuries in professional football: A 16-year follow-up of the UEFA elite club injury stud. British Journal of Sports Medicine. 2020; 54: 421-426.

[38] McCall A, Davison M, Andersen TE, Beasley I, Bizzini M, Dupont G, Duffield R, Carling C, Dvorak J. Injury prevention strategies at the FIFA 2014 World Cup: perceptions and practices of the physicians from the 32 participating national teams. Br J Sports Med. 2015 May; 49(9): 603-8. doi: 10.1136/bjsports-2015-094747. PMID: 25878078; PMCID: PMC4413740.

[39] Goode AP, Reiman MP, Harris L, DeLisa L, Kauffman A, Beltramo D, Poole C, Ledbetter L, Taylor AB. Eccentric training for prevention of hamstring injuries may depend on intervention compliance: A sys-tematic review and meta-analysis. Br J Sports Med. 2015 Mar; 49(6): 349-56. doi: 10.1136/bjsports-2014-093466. Epub 2014 Sep 16. PMID: 25227125.

[40] Schuermans J, Danneels L, Van Tiggelen D, Palmans T, Witvrouw E. Proximal neuromuscular control protects against hamstring injuries in male soccer players: A prospective study with electromyography time-series analysis during maximal sprinting. Am J Sports Med. 2017 May; 45(6): 1315-1325. doi: 10.1177/0363546516687750. Epub 2017 Mar 1. PMID: 28263670.

[41] Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. Am J Sports Med. 2011 Nov; 39(11): 2296-303. doi: 10.1177/0363546511419277. Epub 2011 Aug 8. PMID: 21825112.

[42] Bourne MN, Duhig SJ, Timmins RG, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: impli-cations for injury prevention. Br J Sports Med. 2017 Mar; 51(5): 469-477. doi: 10.1136/bjsports-2016-096130. Epub 2016 Sep 22. Erratum in: Br J Sports Med. 2019 Mar; 53(6): e2. PMID: 27660368.

[43] Harøy J, Clarsen B, Wiger EG, Øyen MG, Serner A, Thorborg K, Hölmich P, Andersen TE, Bahr R. The Adductor Strengthening Programme prevents groin problems among male football players: a clus-ter-randomised controlled trial. Br J Sports Med. 2019 Feb; 53(3): 150-157. doi: 10.1136/bjsports-2017-098937. Epub 2018 Jun 10. PMID: 29891614.

[44] van der Horst N, Backx F, Goedhart EA, Huisstede BM; HIPS-Delphi Group. Return to play after hamstring injuries in football (soccer): A worldwide Delphi procedure regarding definition, medical criteria and decision-making. Br J Sports Med. 2017 Nov; 51(22): 1583-1591. doi: 10.1136/bjsports-2016-097206. Epub 2017 Mar 30. PMID: 28360143.

[45] de Sire A, Marotta N, Lippi L, Scaturro D, Farì G, Liccardi A, Moggio L, Letizia Mauro G, Ammendolia A, Invernizzi M. Pharmacological treatment for acute traumatic musculoskeletal pain in athletes. Me-dicina (Kaunas). 2021 Nov 5; 57(11): 1208. doi: 10.3390/medicina57111208. PMID: 34833426; PMCID: PMC8618079.

[46] Mackey AL, Mikkelsen UR, Magnusson SP, Kjaer M. Rehabilitation of muscle after injury – the role of anti-inflammatory drugs. Scand J Med Sci Sports. 2012 Aug; 22(4): e8-14. doi: 10.1111/j.1600-0838.2012.01463.x. Epub 2012 Mar 26. PMID: 22449131.

[47] Delaney K, Kasprzycka P, Ciemerych MA, Zimowska M. The role of TGF-β1 during skeletal muscle regeneration. Cell Biol Int. 2017 Jul; 41(7): 706-715. doi: 10.1002/cbin.10725. Epub 2017 Jan 19. PMID: 28035727.

[48] Duchesne E, Dufresne SS, Dumont NA. Impact of inflammation and anti-inflammatory modalities on skeletal muscle healing: From fundamental research to the clinic. Phys Ther. 2017 Aug 1; 97(8): 807-817. doi: 10.1093/ptj/pzx056. PMID: 28789470.