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Original Article

Acute effects of medium-frequency electrical energy transfer (TECAR) and transcutaneous electrical nerve stimulation (TENS) on pain and flexibility in athletes with an acute hamstring injury: A randomized controlled trial

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ABSTRACT

This study compared the acute effects of electrical energy transfer (TECAR) and transcutaneous electrical stimulation (TENS) on pain and flexibility after a hamstring injury. Young athletes received either a 20 min TECAR ($n = 24$) or TENS ($n = 26$) session within 5 days following a hamstring injury, while the control (CON, $n = 25$) group was instructed to rest. Visual analogue scale (VAS), functional Assessment Scale for Acute Hamstring Injuries (FASH), straight leg raise test (SLR), and sit-and-reach scores (STR) were obtained prior to, immediately, 24, and 48 h after therapy. Group differences were detected after therapy in VAS and FASH scores ($p < 0.05$). Compared to pre-therapy measurements, VAS scores showed a greater decrease in the TECAR group (−38.75% to −63.33%) than in the TENS group (−16.67% to −25.00%) and both were greater than in the CON group (−2.81% to −9.81%) ($p < 0.05$). The TECAR group improved FASH scores (28.57%–48.21%) more than the TENS group (15.89%–27.79%) and both groups more than the CON group (0%–8.33%) ($p < 0.05$). The increase in SLR and STR was greater in the TECAR group (6.26%–13.96%) than in the TENS (1.72%–9.53%) and CON groups (0%–3.03%). These results suggest that in the acute phase of hamstring injury, the use of TECAR and, to a lesser extent, TENS may relieve pain symptoms and bring some improvements in flexibility more than instructing patients to rest.

1. Introduction

Hamstring injuries are very frequent in sports like soccer and track and field (sprinting events).[1] A characteristic of hamstring injuries is the considerable rate of re-injury, which can reach almost 20%.[2] This highlights the importance of appropriate management of athletes who sustain such an injury as a measure to reduce re-injury patterns.

Hamstring rehabilitation strategies include a variety of interventions, such as progressive running, eccentric, flexibility, or trunk stability exercises.[3,4] In any therapy, however, initiation of dynamic exercise tasks is subject to pain perception by the athlete.[3,4] Based on clinical practice guidelines, clinicians should consider therapeutic interventions to control pain and swelling early in the healing process.[4] However, further research into the role of such modalities is recommended.[4]

Transfer energy capacitive and resistive (TECAR) therapy is a relatively new method that is based on the generation of a medium-frequency current through radio frequencies delivered by an electrode to the deep tissues of the body.[5] TECAR therapy has been reported to have positive effects in various musculoskeletal conditions, by decreasing pain, improving flexibility, or decreasing stiffness.[6–8] The positive effects of medium-frequency currents are attributed to their capacity to induce hyperthermia,[9,10] to elicit changes in adipose-derived stem cells that lead to tissue repair and regeneration[11] and alter skin and muscle microcirculation.[5]

Although the application of TECAR has rapidly increased, evidence on its usefulness in sports is limited.[7] In particular, some studies[8,10,12,13] have found an increase in skin[13] and hamstring muscle temperature as well as blood circulation[14] after a TECAR session. Further, improvements

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in straight leg raising (SLR)[14] and sit-and-reach (STR)[12] scores were found. Finally, a TECAR therapy session improved range of motion and decreased hamstring stiffness in individuals with hamstring tightness.[8] The above results support the use of TECAR to improve hamstring muscle function. Nevertheless, such an intervention has not yet been used to relieve pain after an acute hamstring injury.

Transcutaneous electrical nerve stimulation (TENS) is a technique that is used to alleviate pain for the past 50 years.[15] Although there is a debate about its effectiveness, recent systematic reviews and meta-analyses have suggested that TENS therapy interventions are effective in reducing pain[15,16] while a recent systematic review and meta-analysis concluded that there is evidence that pain intensity is reduced during or immediately after a single TENS session compared with placebo.[17] To the best of our knowledge, the use of a TENS session in comparison to TECAR therapy for alleviating pain following an acute hamstring strain has not been previously examined.

Typical symptoms following a hamstring muscle injury include pain that is evident during stretching or activation, stiffness, bruising or hemorrhaging, and difficulty performing sports or daily activities.[4] If application of a TECAR or TENS therapy can help alleviate such symptoms, prior to or in parallel with the introduction of active (exercise) interventions, this could lead to a faster or better achievement of rehabilitation aims. This could give clinicians more therapeutic options for effectively treating acute hamstring injuries. The purpose of this study was to compare the acute effects of a TECAR therapy session with those of a TENS therapy session and no treatment on pain, flexibility, and functional capacity in individuals sustaining a hamstring injury. It was hypothesized that both therapies would improve pain immediately after the end of the session relative to the no-treatment condition. Since TECAR therapy causes thermal effect on deeper muscle tissues[14] whilst the TENS targets the pain nerve receptors,[15] we hypothesized that flexibility measures will improve in the TECAR group more than the TENS group, while both groups would show improvements relative to controls.

2. Methods

2.1. Study design

This was a parallel group randomized clinical trial that was completed within a three-year period. Therapy interventions were provided in an outpatient physiotherapy clinic. Athletes with acute hamstring strain were assigned to one of three groups: TECAR, TENS, or control (CON). Outcome measures were measured prior to (PRE), immediately after (PS), 24 (P24), and 48 (P48) h following a single intervention session.

The protocol was registered as a clinical trial (clinicaltrials.gov Nr: NCT05345015) and it was approved by the Aristotle University Ethics Committee (Sports and Physical Education-specific Department, ERC-007/2022) in accordance with the Helsinki Declaration. The study followed the recommendations of the Consolidated Standards of Reporting Trials (CONSORT) statement of 2010.[18] All participants gave their written consent to participate in this study.

2.2. Participants

Potential participants were sprinters or soccer players from clubs in the northeastern region of Greece. The clubs were contacted in the off-season period via personal contacts. Athletes and club trainers, therapists, and doctors were informed by personal meetings regarding the purpose of this study, and they were asked to contact one of the investigators immediately when they suspected of sustaining a hamstring injury. At this stage, only athletes who were older than 18 years of age and had not experienced a previous surgery within the past year were considered as potential participants.

During the three-year period, athletes who suspected that they sustained an injury contacted one of the investigators (A.K.), who examined whether they met the inclusion criteria, which included age above 18 years, amateur systematic soccer players or sprinters, suspicion of grade I or II hamstring injury, and cessation of training. Exclusion criteria included history of the same injury on the same leg in the last six months, other injury to the posterior thigh, other injuries or chronic pain in the trunk or lower limbs, and intake of non-steroidal anti-inflammatory drugs within three months prior to the injury. Those who met the criteria were examined by a medical orthopedist with a minimum of 10 years of experience. Clinical examination included pain upon palpation, impaired straight leg raise test (SLR) scores, the existence of pain during daily movements, and ultrasound examination. The injured muscle and the mechanism of injury were also recorded.

Using the research randomizer software (version 4)[19] administration staff who were blinded to the purpose of the study allocated random numbers to participants. Randomization was performed in groups of three, using a 1:1:1 ratio in each of the three groups, using gender as a stratification factor. Numbers were allocated in concealed envelopes. The allocation sequence was concealed from the therapists, using sequentially numbered, opaque, sealed, and stapled envelopes with a unique externally visible, identifiable code given to each participant. The participants were blinded to the purpose of this study. Two therapists of similar clinical experience applied the intervention procedures; they were blinded to participant membership, but they were aware of the study's purpose. Outcome measurements were obtained by one of the researchers (E.K.), who was blinded to participant membership. All outcome measurements were then collected by the administration staff, who updated each participant's record.

Based on previous studies, a minimum value of the difference in VAS of 2.00 is the minimum change needed to be considered clinically relevant.[20,21] The minimum number of participants was estimated using the Sample Size calculator,[22] for a two-sample model (CON group, excluded), a 5% type 1 error, an 80% power, a sample ratio of 1, and a minimum detectable change of 2. The calculation generated a sample size of at least 13 participants per group. This size increased by 20% to account for potential dropouts from the study, leading to a target sample size of 17 participants per group.

2.3. Interventions

Upon referral to the medical doctor, all participants were asked to rest and apply ice, compression, and elevate their leg every 2 h. Following their registration and confirmation of their eligibility, they were asked to have their therapy session between days 2 and 5 after injury. The participants were not in receipt of other therapy treatments or medication from the time they sustained injury until the final measurement session.

TECAR therapy was delivered using a Winback system (Winback, Villeneuve-Loubet, France) (Fig. 1). The system transfers medium frequency currents between two plates (electrodes): a rounded shape “active” (6 cm diameter) electrode and a rectangularly shaped “inactive” (20 cm × 15 cm) plate. The system was set to capacitive mode. The active plate has a high impedance; it is made of medical stainless steel with ceramic coating, and it is mainly applied to transfer energy at a radiofrequency of 500 kHz in superficial tissues, such as muscles or adipose tissues.[5] The participant was in the prone position. The active plate was positioned on the skin of the injured area (back thigh) and the inactive plate on the frontal thigh (opposite to the active plate). Conductive cream was applied to the active electrode to optimize application. During the session, the therapist shifted the active plate on the skin surface of the injured area using slow circular motions. Treatment intensity ranged between 40% and 60%, depending on the participant's tolerance to heat.

Transcutaneous nerve stimulation (TENS) was delivered using a Chattanooga Intellect Advanced Combo system (Chattanooga, Hixson, TN 37343, USA). Two electrodes (5 cm × 9 cm) were placed on the skin at a distance so that they cover the entire painful area (approximately 5–8 cm apart) (Fig. 1). The TENS asymmetric biphasic mode (phase 300 ms, frequency 80 Hz, continuous cycle) program was used. The intensity of the stimulation was set to the point at which a muscular contraction

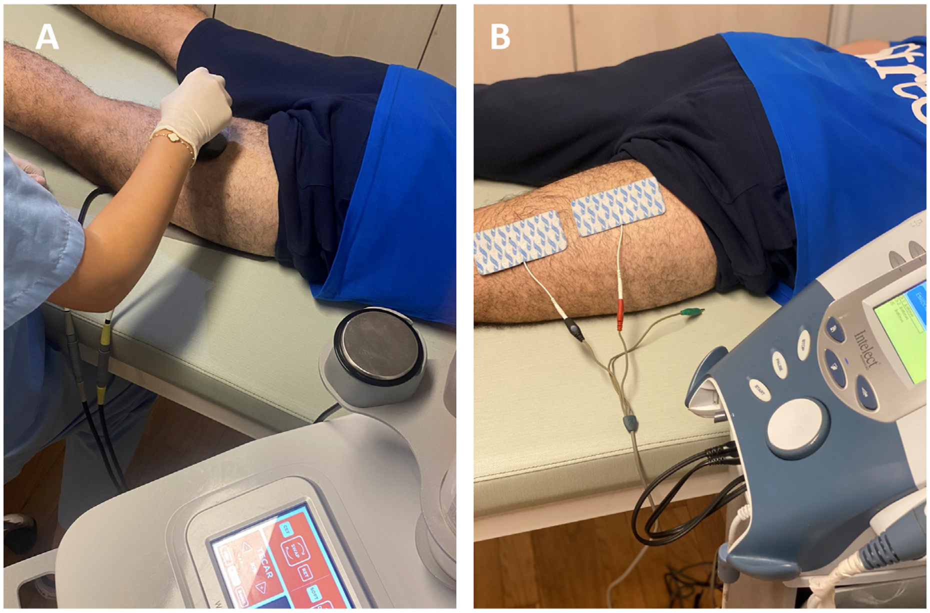

Fig. 1. Illustration of the application of the A. capacitive energy transfer (TECAR) and B. transcutaneous electrical stimulation (TENS) therapy on the injured area.

was produced and it was tolerated by the participant. The starting intensity varied across individuals between 15 and 35 mA. Since tolerance to the same intensity increases with time, intensity increased to a range of 22–41 mA after 10 min of application, and it then increased further to a range of 27–45 mA after 15 min of application.

A standardized form was used to monitor adverse effects, skin irritation or tenderness, pain, soreness, or any other discomfort.

Following injury registration, athletes in the control group were evaluated upon their first visit to the clinic, and they were then reassessed, 30 min, 24, and 48-h after their first measurements.

2.4. Outcome measurements

2.4.1. Pain intensity

Pain intensity was assessed by asking participants to rate their pain using a visual analogue scale (VAS), ranging from 0 (no pain) to 10 (maximum pain).

2.4.2. Functional Assessment Scale for Acute Hamstring Injuries (FASH)

All individuals completed the Functional Assessment Scale for Acute Hamstring Injuries (FASH), which is a validated questionnaire for the assessment of hamstring injury severity and its impact on the function of injured individuals.[23] The questionnaire consists of 10 items, each given a score from 0 to 10, where 10 represents a high level of physical ability and 0 represents complete disability. Item scores were then added, such that the lowest total score indicates more severe symptoms.

2.4.3. Sit and reach test

Participants sat on the floor, with their feet in contact with a customized wooden box and the trunk flexed (Fig. 2). From this position, they were asked to reach with their hands as far as possible, while keeping their legs fully extended. When they touched their toes, the score was equal to 26 cm. Score was measured in cm, such that a higher score indicates higher flexibility. They performed three efforts, and the best effort was further analyzed.

2.4.4. Straight leg raising test

The participants were in the supine position with the upper arms on their sides (Fig. 2). An Activforce 2 sensor (Activbody, San Diego, CA 92121, USA) was used to record range of motion (in degrees), and it was secured around the medial malleolus. In the starting position, the sensor was calibrated and zeroed. Then the examiner raised one leg (with the knee flexed about 10°–20° and the ankle in neutral position) until discomfort (pain, stretch, tingling) was reported. The pelvis and lumbar spine were not stabilized, as this rarely occurs in clinical daily practice.[24]

The reliability of STR and SLR measurements was examined in 15 healthy individuals who were tested on two separate occasions by the same examiner. For STR measurements, the intraclass correlation coefficient (*ICC*), calculated using the two-way random-effects model for single measures [*ICC*(2,1)], was 0.93 (95% confidence intervals [*CI*] ranged from 0.62 to 0.97) with a standard error of measurement (*SEM*) of 1.01 cm (3.01%). For the SLR tests, the *ICC* (2,1) was 0.87 (95% *CI* range from 0.80 to 0.97) and the *SEM* was 2.67° (2.44%).

2.5. Statistical analysis

Statistical analyses were performed using the JASP (v0.18.3, JASP Team, University of Amsterdam) open-access software. Data was checked for normality using the Kolmogorov-Smirnov test. A two-way repeated measures analysis of variance (ANOVA) was used to examine the effects of group (TECAR, TENS, and CON) and time (PRE, PS, P24, and P48) on VAS, SLR and STR and FASH scores using injury severity and day of examination after injury, as co-variates. Sphericity was checked using Mauchly's test, and if this condition was not satisfied, the Greenhouse-Geisser correction was applied to remove bias. Significant *F*-tests were followed by Tukey tests to analyze which pairwise mean differences were statistically significant. The eta squared value was also calculated as a measure of effect size. Eta squared (η^2) values of 0.01, 0.06, and 0.14 indicated a small, medium, and large effect size, respectively.[25]

2.5.1. Group differences in percentage change in scores

The percentage of change for each outcome measure at each time point relative to the initial measurement was also computed. Because these measurements were not normally distributed, group comparisons at each time point were performed using Kruskal-Wallis and, if significant, pair-wise comparisons were followed by Mann-Whitney *U* tests. Within each group, differences in percentage change were examined using Friedman tests and, if significant, they were followed by Wilcoxon signed-rank tests. The significance level was set at $p < 0.05$.

Fig. 2. Measurement of flexibility. A. To perform the sit-and-reach test, the participants had their feet in contact with a customized wooden box and the trunk flexed and from this position they reached with their hands as far as possible. B. To perform the straight leg raising test, a hand-held sensor was attached to the medial malleolus whilst the participants were in supine position. The examiner raised one leg until discomfort was reported.

3. Results

A total of 114 athletes were screened for a period of 25 months. After the initial registration phase, the sample included 78 males and females, who were initially assigned to three groups. Of these, 3 participants did not complete the study (2 were assigned to the TECAR group, and one participant was assigned to the CON group). Of these, two participants did not attend any scheduled therapy session (due to travel issues) while the third participant performed only the baseline measurements and then decided to exit the study. Therefore, there were 24 participants in the TECAR group, 26 in the TENS group, and 25 in the CON group. Their demographic characteristics at baseline are displayed in Table 1.

The statistical analyses indicated that gender did not have a significant effect on time by group comparisons on outcome variables. Hence, all data were pooled across genders.

The VAS and FASH scores are displayed in Table 2. The 2-way ANOVA showed significant interaction terms for VAS ($F_{[4.66,\ 163.27]} = 25.46$, $p < 0.000\,1$, $\eta^2 = 0.008$). Post-hoc Tukey comparisons indicated that group differences in VAS scores were not statistically significant in the PRE-session ($p > 0.05$). Both TECAR and TENS groups showed statistically significantly lower VAS scores compared to the CON group in each post-session time point ($p < 0.05$). Furthermore, the TECAR group showed statistically significantly lower VAS scores compared to the TENS group in each post-session time point ($p < 0.05$). For the TECAR group, VAS scores in PS, P24, and P48 were lower compared to PRE-scores ($p < 0.05$). In addition, P48 scores were lower than PS scores ($p < 0.05$). For the TENS group, VAS scores in P24 and P48 were significantly lower than PRE-scores ($p < 0.05$). Furthermore, the P48 score was greater than the PS score ($p < 0.05$). For the CON group, no differences between different time points were found ($p > 0.05$). Injury severity had a main effect on VAS scores ($F_{[1,\ 70]} = 37.67$, $p < 0.001$, $\eta^2 = 0.011$), as VAS scores were greater in athletes with Grade II injury (7.19 ± 0.95) compared to athletes with Grade I injury (6.13 ± 1.03). VAS scores did not differ between the days on which the first therapy session took place ($p > 0.05$).

Table 1

Mean (± standard deviation) demographic characteristics of the capacitive energy transfer (TECAR), transcutaneous electrical stimulation (TENS) and control (CON) groups (LH = biceps femoris short and long head; MH = semitendinosus and semimembranosus).

Variables	Groups		
	TECAR ($n = 24$)	TENS ($n = 26$)	CON ($n = 25$)
Males/Females	12/12	13/13	12/13
Age (years)	24.96 ± 8.73	23.23 ± 8.03	25.00 ± 6.30
Body Mass (kg)	67.92 ± 9.98	66.85 ± 11.65	65.80 ± 9.85
Height (cm)	173.25 ± 6.69	174.27 ± 7.81	172.12 ± 6.65
Injury location	LH = 14	LH = 12	LH = 15
	MH = 2	MH = 3	MH = 4
	Undefined: 7	Undefined: 6	Undefined: 5
Injury severity	Grade I = 11	Grade I = 12	Grade I = 12
	Grade II = 13	Grade II = 14	Grade II = 13
Day of examination (after injury)	Day 2 = 7	Day 2 = 4	Day 2 = 7
	Day 3 = 10	Day 3 = 12	Day 3 = 10
	Day 4 = 3	Day 4 = 7	Day 4 = 6
	Day 5 = 4	Day 5 = 3	Day 5 = 2

For FASH measurements (Table 2), the time × group interaction effect was statistically significant ($F_{[3.56,\ 124.52]} = 48.00$, $p < 0.001$, $\eta^2 = 0.003$]. FASH scores did not differ between groups in PRE and PS time points ($p > 0.05$). The TECAR group showed greater FASH scores than the CON group in P24 and P48 sessions ($p < 0.05$). In contrast, FASH scores were not different between the TENS and CON groups in any session ($p > 0.05$). No difference between TECAR and TENS groups in any measurement session was also detected ($p > 0.05$). For the TECAR group, FASH scores were greater in PS, P24, and P48 sessions compared to PRE-values ($p < 0.05$). In addition, P48 values were greater than PS values ($p < 0.05$). For the TENS group, PS, P24, and P48 values were greater than PRE-values ($p < 0.05$). P24 and P48 values were also greater than PS values ($p < 0.05$). Finally, for the CON group, no statistically significant differences between different time points were observed ($p > 0.05$). Injury severity had a main effect on FASH scores ($F_{[1,\ 70]} = 58.02$, $p < 0.001$, $\eta^2 = 0.38$), as FASH scores were lower in athletes with Grade II injury (21.91 ± 8.75) compared to athletes with Grade I injury (33.33 ± 9.09). FASH scores did not differ between the days on which the first therapy session took place ($p > 0.05$).

The SLR and STR scores are displayed in Table 3. The ANOVA showed a statistically significant time × group interaction effect on SLR ($F_{[3.76,\ 131.49]} = 13.31$, $p < 0.000\,1$, $\eta^2 = 0.001$) and STR ($F_{[4.64,\ 162.31]} = 14.68$, $p = 0.000\,1$, $\eta^2 = 0.002$) values. Post-hoc Tukey comparisons indicated no group differences in all measurement sessions ($p > 0.05$). Within each group, SLR and STR values in PS, P24, and P48 sessions were greater than the PRE-session for the TECAR and TENS groups ($p > 0.05$) but not for the CON group ($p > 0.05$). In addition, in the TECAR and TENS groups, PS SLR value was no different than P24 value ($p > 0.05$), but it was lower than the P48 value ($p < 0.05$). Injury severity and day of first therapy session did not affect flexibility measures ($p > 0.05$).

3.1. *Group differences in percentage change in scores*

The median and interquartile range values of percentage change of VAS and FASH scores are presented in Fig. 3. The TECAR group showed a statistically greater percentage decrease in VAS scores (ranging from −38.75% to −63.33%) compared to either the TENS (−16.67% to −25.00%) or the CON group (−2.81% to −9.81%, $p > 0.05$). Similarly, the TENS group showed a greater increase in VAS compared to the CON group ($p > 0.05$). The median percentage change in FASH score was greater for both TECAR (8.57%–48.21%) and TENS (15.89%–27.79%) groups compared to the CON (0%–8.33%) group and also in the TECAR group compared to the TENS group ($p < 0.05$).

SLR and STR percentage increase scores are presented in Fig. 4. The percentage increase in SLR was greater for the TECAR group (median value ranged from 6.26% to 8.76%) compared to the TENS (median value ranged from 1.72% to 4.89%) and CON (median value ranged from 0 to 1.89%) groups ($x^2 = 29.79$, $df = 2$, $p = 0.000\,01$) in each post-intervention point while there was no difference in percentage SLR increase between TENS and CON groups ($p > 0.05$). The percentage increase in STR was also greater in the TECAR (median value ranged from 9.60% to 13.96%) compared to the TENS (median value ranged from 3.85% to 9.53%) and CON (median value ranged from 0% to 3.03%) groups and it was also greater in the TENS compared to the CON group.

4. Discussion

This study investigated whether the acute effects of a TECAR therapy session on the pain and mobility of athletes with an acute hamstring injury differed compared to TENS therapy or a control group. The results indicated that a) there were significant improvements in all outcome scores for both treatment groups relative to the CON group, b) VAS scores showed a greater improvement in the TECAR group compared to the

Table 2

Mean (± standard deviation) of visual analogue pain scale (VAS) and Functional Assessment Scale for Acute Hamstring Injuries (FASH) values of the capacitive energy transfer (TECAR), transcutaneous electrical stimulation (TENS) and control (CON) groups before (PRE), immediately after (PS), 24 h after (P24) and 48 h after (P48) the initial session.

Testing Session	Groups		
	TECAR ($n = 24$)	TENS ($n = 26$)	CON ($n = 25$)
	VAS		
PRE	7.88 ± 1.23	8.03 ± 1.11	8.16 ± 1.07
PS	5.04 ± 1.00*#	6.77 ± 1.10*	7.96 ± 0.89
P24	4.75 ± 0.99*#	6.38 ± 1.10*	7.72 ± 0.68
P48	4.21 ± 1.59*#	6.04 ± 1.25*	7.36 ± 0.76
Time effects, $p < 0.05$	PS, P24, P48 < PRE P48 < PS	PS, P24, P48 < PRE P48 < PS	
	FASH		
PRE	23.17 ± 9.85	22.31 ± 9.32	23.52 ± 8.16
PS	30.17 ± 9.15	26.50 ± 9.14	23.80 ± 7.69
P24	33.38 ± 8.14*	28.15 ± 8.93	24.60 ± 7.46
P48	35.67 ± 7.82*	29.58 ± 9.26	25.92 ± 7.29
Time effects, $p < 0.05$	PS, P24, P48 > PRE P48 > PS	PRE > PS, P24,P48 P48, P24 > PS	

*Significantly different compared to CON group, $p < 0.\ 05$.
#Significantly different compared to TENS group, $p < 0.\ 05$.

Table 3

Mean (± standard deviation) values of straight leg raise (SLR) and sit and reach (STR) scores for the capacitive energy transfer (TECAR), transcutaneous electrical stimulation (TENS) and control (CON) groups before (PRE), immediately after (PS), 24 h after (P24) and 48 h after (P48) the initial session.

Testing Session	Groups		
	TECAR ($n = 24$)	TENS ($n = 26$)	CON ($n = 25$)
	SLR		
PRE	66.08 ± 6.76	67.12 ± 6.12	66.36 ± 5.86
PS	70.63 ± 7.71	68.54 ± 6.27	66.64 ± 6.34
P24	70.96 ± 7.72	69.04 ± 6.48	67.00 ± 6.02
P48	71.50 ± 8.15	70.35 ± 6.58	67.40 ± 6.09
Time effects, $p < 0.05$	PS, P24, P48 > PRE P48 > PS	PS, P24, P48 > PRE P48 > PS	
	STR		
PRE	29.17 ± 4.82	30.62 ± 3.40	30.24 ± 3.93
PS	32.25 ± 5.16	31.85 ± 4.13	30.28 ± 3.85
P24	33.29 ± 4.89	32.50 ± 4.02	30.84 ± 3.86
P48	33.79 ± 5.26	33.54 ± 4.24	31.04 ± 3.74
Time effects, $p < 0.05$	PS, P24, P48 > PRE P48 > PS	PS, P24, P48 > PRE P48 > PS	

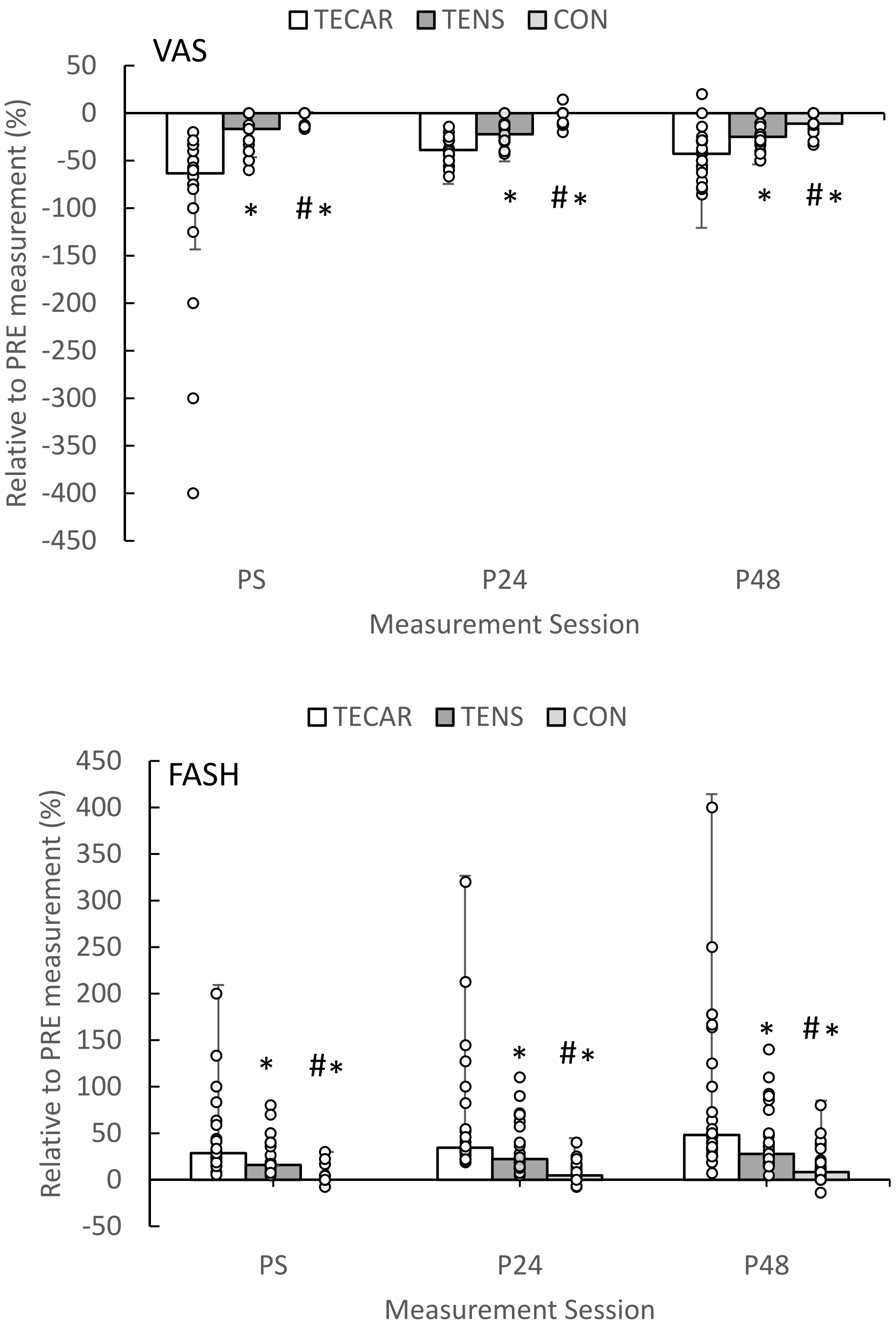

Fig. 3. Median (± interquartile range) percentage difference in visual analogue pain scale (VAS) and functional Assessment Scale for Acute Hamstring Injuries (FASH) scores relative to the values obtained prior to application of therapy for the capacitive energy transfer (TECAR), transcutaneous electrical stimulation (TENS) and control (CON) groups immediately after (PS), 24 h after (P24) and 48 h after (P48) the initial session (dots indicate individual values; error bars indicate interquartile range, * statistically significant difference compared to the TECAR group; # statistically significant difference compared to the TENS group, $p < 0.05$).

TENS group, c) FASH scores improved relative to pre-intervention measurements for TECAR and TENS groups, but they remained no different compared to the CON group, with the exception of P24 and P48 sessions where they increased for the TECAR group, only and, d) flexibility scores increased similarly for both intervention groups but they were no different in each time point compared to the CON group.

Both interventions showed an improvement in outcome variables (Tables 2 and 3). The mechanisms of pain reduction following the application of TECAR therapy may be related to the increase in temperature within the muscle. In particular, it has been shown that 8 min of TECAR therapy, in the capacitive mode, in healthy individuals, results the increased heat in underlying target tissues, without an excessive increase in skin temperature.[5,10,13,14] Further, application of 30 min TECAR therapy on paraspinal muscles increased haemoglobin saturation and tissue temperature, which was attributed to increases in the local release of inflammatory vasoactive compounds and suppression of the sympathetic nervous system.[26,27] Pain reduction following TENS therapy is in accordance with previous systematic reviews and meta-analyses articles, which showed that pain intensity in individuals suffering from acute pain is reduced during or immediately after a single TENS session compared with placebo.[16,17] These reviews, however, refer to the use of TENS for relieving acute pain for a variety of conditions, rarely following muscle injury, and, hence, their conclusions may not be directly comparable to the present results. Another systematic review concluded that TENS is no more effective than sham/placebo in reducing pain and promoting muscle recovery in untrained healthy individuals who experience exercise-induced delayed muscle soreness immediately, 24, 48, 72, and 96 h after the intervention.[28] According to the authors, quality issues may have influenced the results of this meta-analysis.[28] In addition, pain and functional deficits following exercise may differ compared

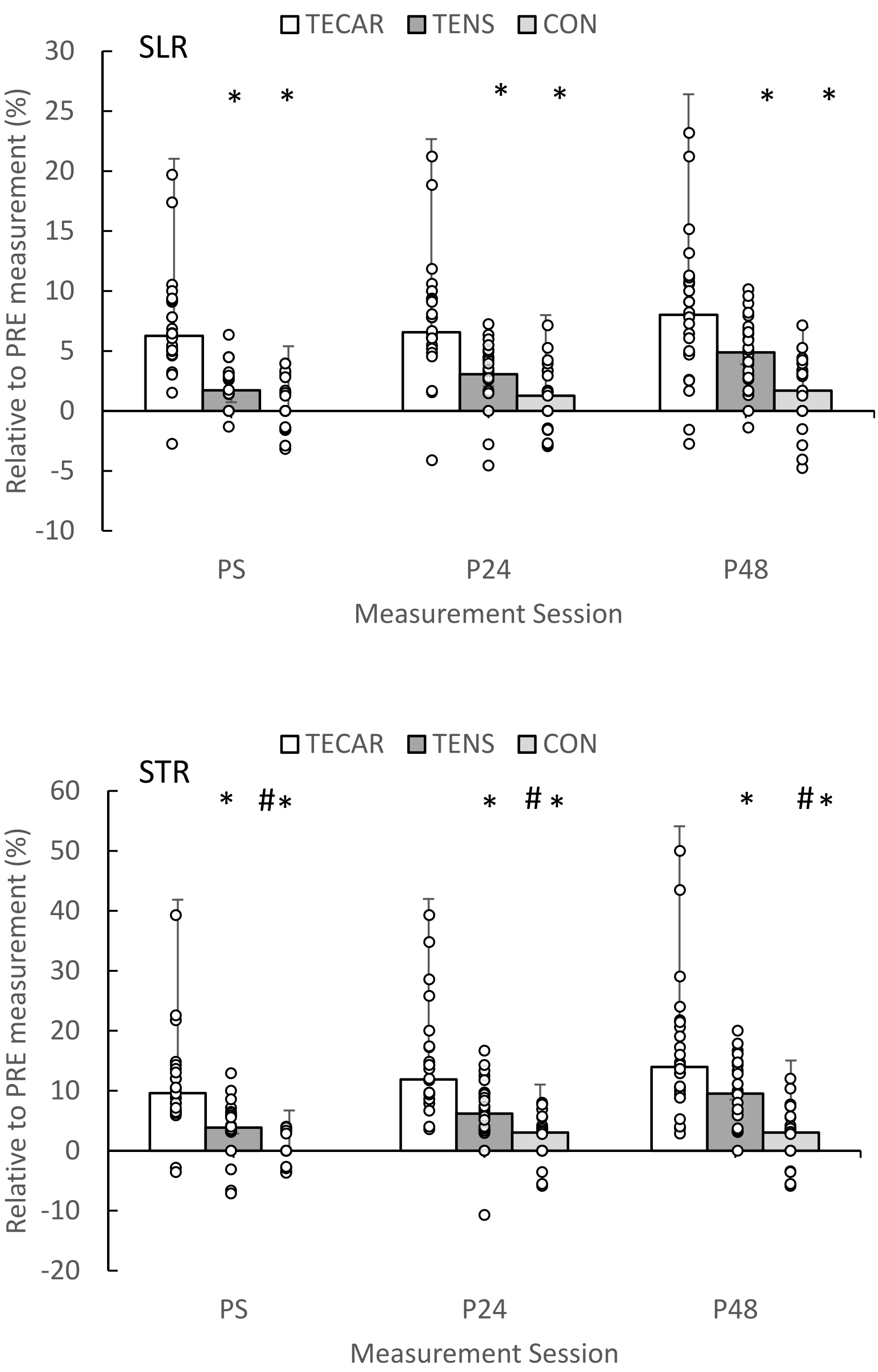

Fig. 4. Median (± interquartile range) percentage difference in straight leg raise (SLR) and sit and reach (STR) scores relative to the values obtained prior to application of therapy for the capacitive energy transfer (TECAR), transcutaneous electrical stimulation (TENS) and control (CON) groups immediately after (PS), 24 h after (P24) and 48 h after (P48) the initial session (dots indicate individual values; error bars indicate interquartile range, * statistically significant difference compared to the TECAR group; # statistically significant difference compared to the TENS group, $p < 0.05$).

to those experienced following a muscle injury. Nevertheless, a previous study has shown that the application of high-frequency TENS, as used in this study, reduces the pressure pain threshold.[29] The analgesic effects of TENS therapy have been attributed to a complex network of peripheral and central neural mechanisms, which result in activation of large-diameter afferent fibers and stimulation of descending pain inhibitory pathways.[30]

The TECAR group showed a greater increase in FASH scores compared to the TENS group (Table 2). FASH is mainly a tool that assesses the pain that an injured individual perceives when performing different movements.[23] FASH scores ranged from 21 to 28 for the injured athletes, which is within the range of previously reported values.[23] FASH scores improved in TECAR groups about 10–12 points (Table 3), which is above the minimum detectable change threshold, which has been reported by previous research.[31] Collectively, the FASH and VAS findings indicate that application of TECAR therapy provided a better short-term improvement in pain sensation than the TENS group.

The results showed a similar (but significant) improvement of SLR and STR scores immediately and up to 24 h following TECAR or TENS intervention (Table 3), which does not confirm the second hypothesis of the study. Previous studies on healthy hamstring muscles have shown that TECAR therapy reduced hamstring muscle stiffness and improved range of motion,[8,14] which are in line with the present findings. This improvement may be due to the decline in muscle stiffness[8] as well as the reduction in pain perception. Even though reduction of pain is not always associated with evident improvements in muscle function,[32,33] we can hypothesize that such a mechanism caused an improved performance in SLR and STR tests in the TENS group as well. It should be noted, however, that despite the acute improvements, flexibility scores remained non-statistically significantly different compared to the CON group (Fig. 3) which suggests that acute improvements that were observed following these therapy sessions, require additional therapy sessions (in conjunction with other modalities, such as exercise) to achieve long-term restoration of hamstring muscle function. Despite this, the short-term improvement in flexibility scores following either TENS or TECAR application relative to no-treatment conditions indicates that they can be useful tools to manage hamstring injury in the acute stage.

This study has some limitations. First, hamstring injuries of mild or moderate intensity were included in the sample, but they were randomly assigned to groups, without taking the injury location into consideration. Similarly, from a clinical point of view, we chose to include a control group and not a placebo group. Patients in the CON group completed the measurements upon their first visit to the clinic, and they were then given a date for their first therapy session within 48 h thereafter. The present results are applicable only to the specific settings of TECAR or TENS therapy (duration, frequency, type, and intensity). Similarly, the short-term acute effects of one therapy session do not permit any conclusions regarding the long-term effects of one or multiple sessions.

5. Conclusion

A 20 min application of capacitive TECAR therapy session in athletes who suffered a hamstring injury reduced VAS scores and improved flexibility more than the TENS and CON groups. Outcome parameters were also positively changed following TENS. In the acute stage, the application of TECAR and, to a lesser degree, of TENS therapy can alleviate pain symptoms and bring some improvements in flexibility, more than instructing the patients to rest.

CRediT authorship contribution statement

Anna Kelli: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Thomas Apostolou:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Conceptualization. **Paris Iakovidis:** Writing – review & editing, Supervision, Software, Methodology. **Georgios Koutras:** Writing – review & editing, Methodology. **Eleftherios Kellis:** Writing – review & editing, Project administration, Conceptualization.

Ethical approval statement

This study was approved by the Aristotle University Ethics Committee (Sports and physical Education-specific Department, ERC-007/2022) in accordance with Helsinki Declaration and its amendments from the 64th WMA General Assembly, Fortaleza, Brazil, October 2013.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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