Effects of deep heating modalities on the morphological and elastic properties of the non-insertional region of achilles tendon: a pilot study

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ABSTRACT

Background: Over the last 20 years, both diathermy and ultrasound have been popular choices for many clinicians in treating musculoskeletal disorders. However, there is a lack of clinical evidence of such deep heating modalities to treat tendon pathology. There is no study to investigate the effects of deep heating modalities on the non-insertional region of the Achilles tendon on able-bodied subjects.

Objective: The objective of the present study was to compare the effects of diathermy and ultrasound therapies on cross sectional area, transversal height percentage of the non-insertional region of the Achilles tendon after diathermy therapy in able-bodied subjects.

Methods: Thirty-two subjects were enrolled. Between-group comparisons showed a significant change on hardness percentage \( p = 0.004 \) after treatment in diathermy therapy group. Within-group comparison showed a significant improvement in tissue temperature \( p = 0.001 \) and hardness percentage \( p = 0.046 \) after two weeks of treatment.

Conclusion: This pilot study demonstrated larger effects on morphological and elastic properties of the non-insertional region of the Achilles tendon after diathermy than ultrasound therapy in normal tendons. Diathermy may be a useful deep heat modality for treating non-insertional Achilles tendinopathy.

Introduction

Treatment modalities for non-insertional Achilles tendinopathy vary and include non-operative and operative options. Nonoperative treatment modalities include physical therapy, extracorporeal shockwave therapy, injectable agents, and bracing and taping [1]. Based on a recent review, the initial option for patients with Achilles tendinopathy would be a non-operative physical therapy approach [1]. Basically, physical therapy modalities fall under four main categories: heat, cold, electricity, and manual therapy [2]. In the clinical setting, heating physical therapies are the most often used modalities for treating musculoskeletal disorders [3]. The gains are basically due to the hyperthermia effects of heat application which induces an increase in tissue temperature [4], cellular metabolism [5], nerve conduction velocity [6,7] and vasodilation [8]. By impacting functional impairments, such as stiffness and pain, the appropriate use of heat physical therapies by clinicians can speed up the recovery phase of treatment and prevent the onset of new injury or chronic dysfunction [9]. In theory, the correct use of an applied heating modality can directly impact both the rate and quality of return to function without limitation [2].

Commonly, therapeutic heating modalities are separated into two categories: superficial and deep applications. Over the last 20 years, both diathermy and ultrasound have been popular choices for many clinicians due their capacity to safely heat deeper structures; for instance, diathermy utilizes the properties of electromagnetic waves generated by highly conductive metal coils whereas ultrasound relies on acoustical energy [2]. A system for capacitive and resistive energy transfer diathermy, called ‘Tecar therapy’, has been used during clinical practice, however only few studies investigated its clinical efficacy reporting positive results in reducing pain and improving function musculoskeletal clinical impairments [10–12]. Tecar is a physical therapy modality promotes the natural physiological processes of tissue metabolism by...
transferring energy without introducing radiant energy from the exterior. Tecar which uses the physical principle of the condenser, consists of a device composed of 2 facing and separated elements by an insulating material, these elements are connected to a current generator (machine body) that produces a potential difference between the 2 plates. TECAR system enables the production of an endothermic effect that depends on the applied power and the impedance offered by the tissues upon passage of the current [11]. Ultrasound is a therapeutic agent commonly used to treat sports-related musculoskeletal conditions such as tendinopathy, bursitis, contracture, and fractures [13]. Despite the widespread popularity of both deep heating modalities to treat tendon pathology, there remains a lack of evidence for their efficacy from high-quality studies [3,14,15]. Up to our knowledge, only few studies to investigate the effects of such as physical modalities on morphological and elastic properties on the human tendons; furthermore these studies were conducted in non-living specimens [16–17].

The main aim of this pilot study was to compare the effects of diathermy and ultrasound therapies on cross sectional area, transversal height and hardness percentage of the non-insertional region of the Achilles tendon in healthy subjects after two treatment weeks. Our hypothesis was that we would observe a difference on morphological and elastic properties of the Achilles tendon after diathermy and ultrasound therapies.

Material and methods

Participants

This pilot study 42 included healthy adult (age greater than 18 years) volunteers. The enrollment period was from June 2017 to May 2019. Exclusion criteria were inclusion in other trials, painful conditions involving the lower limbs, contraindications to diathermy or ultrasound therapies: neoplasia or current/previous infections of the treatment area, a cardiac pacemaker, or pregnancy, epilepsy, angina pectoris, cardiovascular pathologies, breastfeeding, skin lesions, nervous system disorders, diabetes mellitus, thermal sensitivity dysfunction, drug or alcohol abuse, radiation therapy or chemotherapy in the past year and metallic implants.

After screening, the principal investigator (PI) randomly assigned eligible patients to the diathermy or the ultrasound groups group according to a simple software-generated randomization scheme. The PI was unaware of which group the subject would be allocated to (allocation was by sealed opaque envelopes). The randomization list was locked in a desk drawer accessible only to the PI.

All volunteers gave their informed, written consent to participate in the study, which was carried out according to the Declaration of Helsinki and approved by the local review board.

Treatment procedures

An expert physiotherapist performed all the treatment sessions. Subjects received a single 15-min treatment sessions once a day, 3 days a week, for 2 consecutive weeks (Mon-Wed-Thu). During treatment the subjects laid in the prone position with their feet off the table and a soft cushion beneath the ankle. The treated area was standardized using a reference system based on anatomical landmarks for non-insertional Achille tendinopathy and the application of the physical therapies was performed along its course, 2 to 6 cm proximally to the calcaneal insertion. The procedure region was defined with four strips of tape (Figure 1) [18], applied before each session.

Diathermy was delivered by means of an I-TECH.AR., device (I.A.C.E.R. srl, Martellago, Venice, Italy). During treatment a neutral plate coated with conductive cream, was positioned under the tibialis anterior muscle of the lower limb for the whole treatment period. This methodology was based on previous studies [19–20]. The diathermy treatment had two phases, capacitive (CAP) and resistive (RES), each lasted 7 min. The CAP phase electrode has a polyamide coating that acts as a dielectric medium, insulating its metallic body from the skin surface, thus forming a capacitor with the treated tissues. The RES electrode is uncoated and passes radiofrequency energy directly through the body and into the neutral plate. The power of energy in both phases was the same: 10–12 VA, equivalent to 0.42 J/cm², applied to an area of 28.2 cm² [20]. The CAP phase used a frequency of 600 kHz while the RES phase used a frequency of 450 kHz. A manufacturer-supplied conductive cream was employed as a coupling medium between the electrode and the skin surface.

The ultrasound therapy was administered using a DW 200 device (DW Elettronica Pagani s.r.l., Paderno Dugnano Milan, Italy) with a transducer which has 4 cm² application area, at 1.5 W/cm², 1 MHz frequency, continuous mode in the area for 15 min [21]. Aquasonic gel was used along with the full contact technique in rotational movements at a vertical angle to the skin.

Figure 1. Treatment setting and standardized reference frame for the application of diathermy on the Achilles tendon in one participant.
Evaluation procedures

All subjects were evaluated before (T0) and immediately after the last treatment session (T1). They underwent ultrasound evaluation using a MyLab 70 VXision system (Esaote SpA, Genoa, Italy) interfaced with a linear transducer (scanning frequency 13 MHz) and equipped with sonoelastography (ElaXto) software. They remained in the prone position with their legs outstretched. The Achilles tendon was examined 2 to 6 cm proximally to the calcaneal insertion, along its course. The probe was positioned perpendicular to the tendon surface in order to reduce any bias related to anisotropy [22]. The following tendon features were evaluated: thickness, cross-sectional area (CSA) and hardness percentage (%HRD). The antero-posterior tendon thickness and CSA were measured perpendicular to the greatest width of the Achilles tendon by means of conventional real-time B-Mode US. The %HRD was evaluated through sonoelastography, which was performed with the ElaXto software by applying light vertical rhythmic compression with the transducer over the non insertional region of the Achilles tendon (Figure 2). The optimal compression scale for measurement of the ElaXto software ensured exam quality [22].

Statistical analysis

Statistical analysis was carried out using the Statistical Package for Social Science for Macintosh, version 20.0 (IBM SPSS Inc, Armonk, NY, USA). Non-parametric tests were applied for inferential statistics because of the non-normal data distribution (Shapiro). The Mann-Whitney U-test was used to assess the homogeneity of the two groups at baseline and the effect of treatment between groups. For this purpose, we computed the differences in performance between T1 and T0 (T1-T0) for all outcome measures. Within-group comparisons (T1 vs. T0) were performed with the Wilcoxon signed-rank test for all outcomes. Descriptive analysis was used to evaluate the effect size measures between groups (Cohen’s d calculation) and the 95% confidence intervals. We estimated that a total of 32 subjects (16 patients per group) would provide 80% power to detect a difference of 0.3 cm² on the CSA between two measurements, assessing standard deviation (SD) = 0.4, correlation = 0.7, and alpha = 0.05 [23]. The alpha level for significance was set at $p < 0.05$

Results

Thirty-two healthy volunteers (15 males and 17 female; mean age $27.09 \pm 3.99$) were consecutively recruited at our Research Center. Nineteen patients were allocated to the Diathermy group and 13 persons were allocated to the Ultrasound group. There were no drop-outs and no adverse events occurred during the trial in any of the groups. The study diagram is illustrated in Figure 3. Information about the demographic and physical characteristics of our sample is detailed in Table 1.

Between-group comparison showed a significant change on the %HRD ($p = 0.004; Z: -1.992$) after treatment (Table 2). Within-group comparison showed a significant improvement in the %HRD for the diathermy ($p = 0.001; Z: -3.823$) and ultrasound ($p = 0.046; Z: -2.521$) after treatment. No significant changes were detected in both groups in the other outcome measures (Table 2).

Discussion

The main aim of this pilot study was to compare the effects of diathermy and therapeutic ultrasound on the morphological and elastic properties of Achilles tendon in healthy volunteers. Taking into account the numbers of healthy subjects involved in the present pilot study, our preliminary findings showed that tendon elasticity obtained a significantly greater improvement on %HRD in subjects who underwent diathermy than those treated by means of therapeutic ultrasound. This is in line with previous clinical studies, which demonstrated changing in tissue extensibility due to the higher depth efficiency of short-wave diathermy [3,24,25].

The clinical effects of diathermy are well documented, however there is a lack of clinical evidence from high-quality studies; Tecar therapy represents the technological evolution of diathermy [26–28]. Although Tecar has been widely used in physical therapy practise as a physical therapy agent for almost 20 years, there are only a few studies that have investigated its clinical efficacy [11,29]. Furthermore, there seems to be a substantial lack of knowledge on the physiologic responses induced by Tecar application [30].

To the best of our knowledge, this is the first study that investigates the effects of such as deep heat physical modalities on morphological and elastic properties on the Achilles tendon in able-bodied subjects. Järvinen et al. mentioned that tendinopathy as being among the most common clinical diagnoses of Achilles disorders (55–65%) [31] and the nonoperative care, e.g. physical therapy, extracorporeal shockwave therapy, injectable agents, and bracing and taping, is initial option for patients with Achilles non-insertional tendinopathy [1]. Despite the popularity of diathermy as Tecar therapy, there is a lack of clinical evidence on Achilles tendinopathy.

Currently, both diathermy and ultrasound therapies have been popular choices for many clinicians in treating musculoskeletal disorders; in practice, understanding when and how to use therapeutic modalities to aid in healing and the recovery of function can often be unclear [2].

In our preliminary study, we found out a significant change on the %HRD after diathermy therapy compared to therapeutic ultrasound. This difference can be mainly explained as the results of the deeper heat application induced by the diathermy therapy and basically, two possible factors could contribute to detect this difference.

The first factor is that the thermal property of diathermy induces a superficial and deep hyperthermia. As temperature increases, the tissue viscosity is modified by the improvement of the collagen extensibility and the reduction connective, subsequently, the extensibility of soft tissues is increased [2,32]. Basically, diathermy therapy promotes the natural physiological processes of tissue metabolism by transferring...
Figure 2. Sonoelastography image of an Achilles tendon.

Figure 3. CONSORT Flow diagram of the study.
energy without introducing radiant energy from the exterior rather by using the physical principle of the condenser. This enables the production of an endothermic effect that depends on the applied power and the impedance offered by the tissues upon passage of the current [33,34]. Indeed the effect of the capacitive system is due to the increase in cell membrane potential, due to the kinetic effect of the ions in both intracellular and intermediate fluid and due to the subsequent increase in internal temperature [35].

The underlying key mechanisms of Tecar are CAP and RET techniques: the first works in tissue containing a high content of electrolytes such as muscles, while the second works in tissues with higher resistance such as bones, tendons, and joints. In our study we decided to use both techniques in the diathermy group. Therefore, we hypothesized that the application of diathermy on the Achilles tendon area warms up the superficial and deep tissues and the passage of current itself induces an electromagnetic field and these effects could increases the extensibility of the connective tissue. Researchers have studied the effects of diathermy modalities on increasing the extensibility of soft tissues and often these studies incorporate a stretching protocol following the application of heat [36,37]. Moreover, there has been conflicting evidence with studies suggesting either positive [2] or no effects [9] on tissue extensibility. Our pilot study is line with similar studies [19,37,38]. Yokota and collaborators suggested that capacitive and resistive electric transfer by means of high radiofrequency device, is an effective intervention to improve muscle flexibility [37]. However, no direct assessments on morphological and elastic properties of the tendon were performed. We also observed that in the ultrasound group significant changes were detected on %HRD tissue hardness of the Achilles tendon. Ultrasound may induce thermal and non-thermal physical effects in tissues; however, it has been suggested that the non-thermal effects of ultrasound, including cavitation and acoustic micro-streaming, are more important in the treatment of soft tissue lesions than the thermal physical effects [39]. Most clinicians remain convinced that ultrasound is useful in the treatment of musculoskeletal impairments. Despite this, there is little clinical research documenting the efficacy of ultrasound in treating tendinopathy or promoting tendon healing [14,40] and these studies presented contradictory results. As suggested by Magalhães FE and collaborators, the application of ultrasound has no therapeutic effects on connective tissues and muscular extensibility [41]. However, further research should be performed since Lounsberry NL presented the contradictory results that therapeutic ultrasound treatment applied to the hamstrings can increase muscular extensibility [38]. The absence of clearly evidence for benefit for ultrasound in soft tissue extensibility may be due to a true lack of effect, but poor study design or technical factors may play a role.

The second factor is the increase of local hyperemia induced by the diathermy which allows vasodilatation with an increase of local blood circulation in the tissues [11,42] contributing to the re-supply of oxygen and nutritional substances as well as the removal of catabolites [27]. These effects could lead to an improvement of the extensibility of the collagenous and a decrease of viscosity. Therefore, we infer that these improvements are supported by our preliminary results where the %HRD was reduced.

Temperature and blood flow changes secondary to radio-frequency exposure are largely thermophysiological responses [4]. While the literature suggests that a small rise in tissue temperature of about 1 °C will help to relieve mild inflammation, many of the clinical benefits of heating such as increasing tissue extensibility occur when temperatures are raised by 2–4 °C [43,44]. Therapeutically, an increase of 3–4 °C of skin temperature can produce changes in tissue extensibility and improves the contractile performance of muscle, as it increases ATPase activity and changes the mechanical properties of collagen in tendons [45]. Diathermy applications could reach a peak skin temperature of 35 °C [44]. Despite a direct assessment of blood flow was not performed, our study is line with others that demonstrated that local hyperemia induced by deep heating application, increases the tissue extensibility more than superficial heating or no heating [3,44].

This pilot study had some limitations. First, the small sample size of the current study calls for caution in the interpretation of results and no power analysis was conducted. Second, a limitation of the present study is a possible placebo effect of diathermy therapy that can influence perceptions and performance [19]. A sham diathermy therapy group rather than a control group would eliminate any chance for psychologically-induced effects of a subject’s

Table 1. Demographic and physical features of subjects.

| Age (years) | Diathermy Group | Ultrasound Group |
|-------------|-----------------|-----------------|
| n = 19 mean (SD) | n = 13 mean (SD) |
| 26.42 ± 4.19 | 28.58 ± 3.59 |
| Sex (m. male/female) | | |
| 7(12) | 8(5) |
| Height (cm) | 169.84 ± 6.72 | 171.54 ± 9.73 |
| Weight (kg) | 64.15 ± 10.92 | 71.60 ± 13.28 |

n: number; SD: standard deviation.

Table 2. Comparison of treatment effects within and between groups in outcome measures.

| Outcome variables | Group | Pretreatment mean (SD) | Post-treatment mean (SD) | Comparisons | Mann-Whitney test between-group differences |
|-------------------|-------|------------------------|--------------------------|-------------|------------------------------------------|
| CSA (mm²) | Diathermy Group | 52.89 ± 12.56 | 53.63 ± 9.31 | 0.431 (−0.788) | 0.623 (−0.520) |
| TH (mm) | Diathermy Group | 4.15 ± 0.62 | 4.16 ± 0.49 | 0.864 (−0.172) | 0.677 (−0.444) |
| HRD (%) | Diathermy Group | 79.89 ± 18.92 | 57.79 ± 20.47 | 0.001 (−3.823) | 0.004 (−2.559) |

CSA: Cross Sectional Area; TH: Transversal Height; HRD: hardness percentage measurement; SD: standard deviation; *p < 0.05.
belief. Third, we did not include any clinical and functional evaluations and instrumental assessment related to blood flow or temperature to detect the direct effects of the physical therapies on local vasodilation (e.g., Doppler ultrasound) and thermal effects. Fourth, the study was conducted considering a short-term application on healthy volunteers and we cannot prove the effectiveness of both physical therapies for treating non-insertional Achilles tendinopathy; therefore, it should be emphasized that the strength of our speculations and conclusions is limited. Fifth, in line with the pilot nature of this pilot study, assessment bias and selection bias have to be considered.

Our findings provide evidence that diathermy therapy leads greater improvement on HRD of the Achilles tendon than ultrasound therapy due to the higher depth efficiency of short-wave diathermy. Diathermy may be a useful deep heat modality for treating non-insertional Achilles tendinopathy.

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