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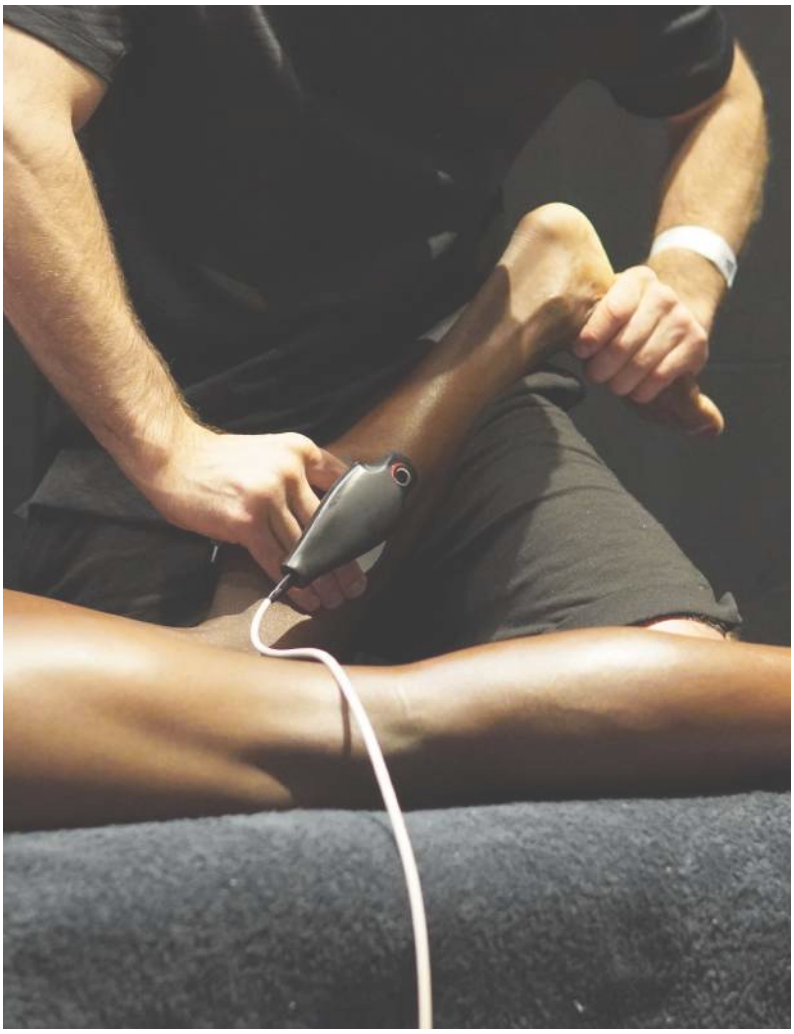

Ricerca scientifica Tecar T Plus

SM HEALTHCARE medical equipment

T Plus rappresenta lo stato dell'arte della tecnologia Tecar in termini di Performance.

E possibile gestire reazioni Thermal e Non Thermal in parti del corpo attentamente mirate, agendo sulla perfusione sanguigna e se necessario, è possibile aggiungere incrementi di temperatura e vasodilatazione.

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- Nel 2021 sempre sulla stessa rivista è stata inserita nelle 10 migliori soluzioni a livello Europeo per la gestione del dolore
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  I valori forniti dal dispositivo si riferiscono sempre all'energia effettivamente assorbita dai tessuti e non semplicemente quella erogata
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- Dispositivo Medico Classificazione II, Certificato CE Medicale
- Potenza – Tensione CAP 450 VA – 600 V, Potenza – Tensione RES 300 W – 150 V
  Peso 6,8 kg, Dimensione 50cm x 27cm x 19cm

Indice

Un laboratorio Universitario completamente dedicato alla ricerca scientifica per validare gli effetti di T Plus

'Universitat Internacional de Catalunya (UIC Barcellona) e Wintecare

Un accordo di collaborazione per approfondire la ricerca su nuove terapie per migliorare la qualità della vita e la riabilitazione di anziani e atleti.

L'obiettivo principale della ricerca è scoprire in che misura la terapia di trasferimento elettrico capacitivo-resistivo (CRET) viene utilizzata nel corpo umano.

Does the Application of Tecar Therapy Affect Temperature and Perfusion of Skin and Muscle Microcirculation?
A Pilot Feasibility Study on Healthy Subjects

Ron Clijsen, PhD,[1,2,3] Diego Leoni, MSc,[4] Alessandro Schneebeli, MSc,[4] Corrado Cescon, PhD,[4] Emiliano Soldini, MSc,[4,5] Lihui Li, PhD,[4] and Marco Barbero, PhD[4]

Abstract

Background: Tecar therapy (TT) is an endogenous thermotherapy used to generate warming up of superficial and deep tissues. TT capability to affect the blood flow is commonly considered to be the primary mechanism to promote tissue healing processes. Despite some preliminary evidence about its clinical efficacy, knowledge on the physiologic responses induced by TT is lacking.

Objective: The aim of this quantitative randomized pilot study was to determinate if TT, delivered in two modes (resistive and capacitive), affects the perfusion of the skin microcirculation (PSMC) and intramuscular blood flow (IMBF).

Design: A randomized controlled pilot feasibility study.

Subjects: Ten healthy volunteers (n = 4 females, n = 6 males; mean age 35.9 –10.7 years) from a university population were recruited and completed the study.

Intervention: All subjects received three different TT applications (resistive, capacitive, and placebo) for a period of 8 min.

Outcome measures: PSMC, IMBF, and the skin temperature (ST) were measured pre- and post-TT application using power Doppler sonography, laser speckle contrast imaging (LSCI), and infrared thermography.

Results: Compared with placebo application, statistically significant differences in PSMC resulted after both the resistive (p=0.0001) and the capacitive (p=0.0001) TT applications, while only the resistive modality compared with the placebo was capable to induce a significant change of IMBF (p = 0.013) and ST (p = 0.0001).

Conclusions: The use of power Doppler sonography and LSCI enabled us to evaluate differences in PSMC and IMBF induced by TT application.

Thermal and non-thermal effects off capacitive-resistive electric transfer application on the Achilles tendon and musculotendinous junction of the gastrocnemius muscle: a cadaveric study

Carlos López-de-Celis[1,2†], César Hidalgo-García[3,4†], Albert Pérez-Bellmunt[1], Pablo Fanlo-Mazas[3,4], Vanessa González-Rueda[1,2], José Miguel Tricás-

Abstract

Background: Calf muscle strain and Achilles tendon injuries are common in many sports. For the treatment of muscular and tendinous injuries, one of the newer approaches in sports medicine is capacitive-resistive electric transfer therapy. Our objective was to analyze this in vitro, using invasive temperature measurements in cadaveric specimens.

Methods: A cross-sectional study designed with five fresh frozen cadavers (10 legs) were included in this study. Four interventions (capacitive and resistive modes; low- and high-power) was performed for 5 min each by a diathermy "T-Plus" device. Achilles tendon, musculotendinous junction and superficial temperatures were recorded at 1-min intervals and 5 min after treatment.

Results: With the low-power capacitive protocol, at 5 min, there was a 25.21% increase in superficial temperature, a 17.50% increase in Achilles tendon temperature and an 11.27% increase in musculotendinous junction temperature, with a current flow of 0.039 A ± 0.02.
With the low-power resistive protocol, there was a 1.14% increase in superficial temperature, a 28.13% increase in Achilles tendon temperature and an 11.67% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.063 A ± 0.02. With the high-power capacitive protocol there was an 88.52% increase in superficial temperature, a 53.35% increase in Achilles tendon temperature and a 39.30% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.095 A ± 0.03. With the high-power resistive protocol, there was a 21.34% increase in superficial temperature, a 109.70% increase in Achilles tendon temperature and an 81.49% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.120 A ± 0.03.

Conclusion: The low-power protocols resulted in only a very slight thermal effect at the Achilles tendon and musculotendinous junction, but current flow was observed. The high-power protocols resulted in a greater temperature increase at the Achilles tendon and musculotendinous junction and a greater current flow than the low-power protocols. The high-power resistive protocol gave the greatest increase in Achilles tendon and musculotendinous junction temperature. Capacitive treatments (low- and high-power) achieved a greater increase in superficial temperature.

Thermal and non-thermal effects of capacitive–resistive electric transfer application on different structures of the knee: a cadaveric study

Jacobo Rodríguez-Sanz[1,2,6], Albert Pérez-Bellmunt[1,2,6*], Carlos López-de-Celis[1,2,3,6], Orosia María Lucha-López[4,5*], Vanessa González-Rueda[1,2,3], José Miguel Tricás-Moreno[4,5*], Mathias Simon[1,2] & César Hidalgo-García[4,5,6]

Capacitive–resistive electric transfer therapy is used in physical rehabilitation and sports medicine to treat muscle, bone, ligament and tendon injuries. The purpose is to analyze the temperature change and transmission of electric current in superficial and deep knee tissues when applying different protocols of capacitive–resistive electric transfer therapy. Five fresh frozen cadavers (10 legs) were included in this study. Four interventions (high/low power) were performed for 5 min by a physiotherapist with experience. Dynamic movements were performed to the posterior region of the knee. Capsular, intra-articular and superficial temperature were recorded at 1-min intervals and 5 min after the treatment, using thermocouples placed with ultrasound guidance. The low-power protocols had only slight capsular and intra-capsular thermal effects, but electric current flow was observed. The high-power protocols achieved a greater increase in capsular and intra-articular temperature and a greater current flow than the low-power protocols. The information obtained in this in vitro study could serve as basic science data to hypothesize capsular and intra-articular knee recovery in living subjects. The current flow without increasing the temperature in inflammatory processes and increasing the temperature of the tissues in chronic processes with capacitive–resistive electric transfer therapy could be useful for real patients.

Thermal and Current Flow Effects of a Capacitive–Resistive Electric Transfer Application Protocol on Chronic Elbow Tendinopathy. A Cadaveric Study

Carlos López-de-Celis [1,2,3,†] Simón A. Cedeño-Bermúdez [1] , Jacobo Rodríguez-Sanz [1,2,†] , César Hidalgo-García [4] , Daniel Zegarra-Chávez [1] , Pablo Fanlo-Mazas [4] and Albert Pérez-Bellmunt [1,2,]

Abstract:

Lateral elbow tendinopathy, or "tennis elbow," is a pathology that affects around 1.3% of the general population. Capacitive–resistive electric transfer therapy aims to provoke temperature and current flow changes in superficial and deep tissues. The aim of this in vitro study was to analyze the thermal behavior and transmission of electric current on the superficial and deep tissues of the elbow during the application of different modalities of a capacitive–resistive electric transfer treatment protocol for chronic elbow tendinopathy. A cross-sectional study was designed; five fresh cryopreserved cadavers (10 elbows) were included in this study. A 30 min intervention was performed based on a protocol commonly used in clinics for the treatment of chronic lateral elbow tendinopathy by diathermy using the "T-Plus." Common extensor tendon, radiohumeral capsule, and superficial temperatures were registered after each application for the duration of the 30 min treatment protocol. During all applications, we observed a current flow of over 0.03 A. The protocol showed a statistically significant increase in superficial temperature by 24% (5.02°) ($p < 0.005$), the common extensor tendon by 19.7% (4.36°) ($p < 0.007$), and the radiohumeral joint capsule by 17.5% (3.41°) ($p < 0.005$) at the end of the 30 min protocol compared with the baseline temperature. The different applications of the protocol showed specific effects on the temperature and current flow in the common extensor tendon and radiohumeral capsule. All applications of the protocol produced a current flow that is associated with the generation of cell proliferation. These results strengthen the hypothesis of cell proliferation and thermal changes in deep and distal structures. More studies are needed to confirm these results..

Temperature and current flow effects of different electrode placement in shoulder capacitive-resistive electric transfer applications: a cadaveric study

Jacobo Rodríguez-Sanz[1†], Carlos López-de-Celis[1,2†], César Hidalgo-García[3*], Max Canet-Vintró[1], Pablo Fanlo-Mazas[3] and Albert Pérez-Bellmunt[1]

Abstract

Background: Impingement syndrome is currently estimated to represent 60% of all shoulder pain disorders. Capacitive-Resistive electric transfer therapy is aimed to provoke temperature and current flow changes in superficial and deep tissues. This in vitro study has evaluated the variation of temperature and current flow in the shoulder tissues during two different areas of application of the movable capacitive-resistive electric transfer electrode.

Methods: A cross-sectional study designed, five fresh cryopreserved cadavers (10 shoulders) were included in this study. Four interventions (capacitive and resistive modes; low- and high-power) were performed for 5 min each by a diathermy "T-Plus" device in two shoulder regions: postero-superior and antero-lateral. Supraspinatus tendon, glenohumeral capsule and superficial temperatures were recorded at 1-min intervals and 5 min after treatment.

Results: A statistically significant difference was found only for the superficial area and time interaction, with high power-resistive application at the postero-superior shoulder area ($P < 0.035$). All the applications showed a 5 min after treatment temperature increase compared with the basal data, in all the application points.

Superficial temperature in the high power-resistive application showed the greatest percent increase (42.93% ± 22.58), followed by the temperature in the tendon area with the same high power-resistive application (22.97% ± 14.70). The high power-resistive application showed the greatest percent of temperature increase in the applications, reaching 65.9% ± 22.96 at 5-min at the superficial level, and 32% ± 24.25 at 4-min at the level of the supraspinatus tendon. At the capsule level, high power-resistive was also the application that showed the greatest percent of increase, with 21.52% ± 16.16. The application with the lowest percent of temperature increase was the low power- capacitive, with a mean value of 4.86% at supraspinatus tendon level and 7.47% at capsular level.

Conclusion: The shoulder postero-superior or antero-lateral areas of application of capacitive-resistive electric transfer did not cause statistically significant differences in the temperature changes in either supraspinatus tendon or glenohumeral capsule tissues in cadaveric samples. The high power-resistive application in the postero-superior area significantly increased superficial temperature compared with the same application in the antero-lateral position area.

Is Tecar Therapy Effective on Biceps Femoris and Quadriceps Rehabilitation? A Cadaveric Study

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Background: Capacitive-resistive electric transfer therapy is an interesting rehabilitation treatment to use in musculoskeletal injuries. The purpose is to analyze the temperature change and current flow in superficial and deep biceps femoris and quadriceps tissues when applying different protocols of capacitive-resistive electric transfer therapy. Methods: Five cryopreserved cadavers (10 legs) were included in this study. Four interventions (high/low power) were performed for 5 minutes. Dynamic movements were performed to the biceps femoris and quadriceps. Superficial, middle, and deep temperature were recorded at 1-minute intervals and 5 minutes after the treatment using invasive temperature meters placed with ultrasound guidance.

Results: Low- power applications have generated a very low thermal effect and an important current flow. The high-power capacitive application achieves a greater increase in superficial temperature compared with low power ($P < .001$). The high-power resistive application recorded a greater increase in superficial, middle, and deep temperatures with a greater current flow compared with the other applications ($P < .001$). Conclusion: This study could serve as basic science data to justify the acceleration of the processes of muscle recovery, improving cell proliferation without increasing the temperature in acute muscle injuries and increasing the temperature and viscoelasticity of the tissues in chronic processes with this therapy.

Comparison of resistive capacitive energy transfer therapy on cadaveric molars and incisors with and without implants

Albert Pérez-Bellmunt[1,2,7], Jordi Caballé-Serrano[3,4,7], Jacobo Rodríguez-Sanz[1,2*], César Hidalgo-García[5], Vanessa González-Rueda[1,2,6], Sergi Gassó-Villarejo[1,2], Daniel Zegarra-Chávez[1,2] & Carlos López-de-Celis[1,2,6]

Capacitive–resistive energy transfer therapy (CRet) is used to improve the rehabilitation of different injuries. This study aimed to evaluate and compare the changes in temperature and current flow during different CRet applications on upper and lower molars and incisors, with and without implants, on ten cryopreserved corpses. Temperatures were taken on molars and incisors with invasive devices and skin temperature was taken with a digital thermometer at the beginning and after treatments. Four interventions: 15 VA capacitive hypothermic (CAPH), 8 watts resistive (RES8), 20 watts resistive (RES20) and 75 VA capacitive (CAP75) were performed for 5 min each.

All treatments in this study generated current flow (more than 0.00005 A/m^2) and did not generate a significant temperature increase ($p > 0.05$). However, RES20 application slightly increased surface temperature on incisors without implants ($p = 0.010$), and molar with ($p = 0.001$) and without implant ($p = 0.008$). Also, CAP75 application increased surface temperature on molars with implant ($p = 0.002$) and upper incisor with implant ($p = 0.001$). In conclusion, RES8 and CAPH applications seem to be the best options to achieve current flow without an increase in temperature on molars and incisors with and without implants.

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Does the Application of Tecar Therapy Affect Temperature and Perfusion of Skin and Muscle Microcirculation? A Pilot Feasibility Study on Healthy Subjects

Ron Clijsen, PhD,[1,2,3] Diego Leoni, MSc,[4] Alessandro Schneebeli, MSc,[4] Corrado Cescon, PhD,[4] Emiliano Soldini, MSc,[4,5] Lihui Li, PhD,[4] and Marco Barbero, PhD[4]

Abstract

Background: Tecar therapy (TT) is an endogenous thermotherapy used to generate warming up of superficial and deep tissues. TT capability to affect the blood flow is commonly considered to be the primary mechanism to promote tissue healing processes. Despite some preliminary evidence about its clinical efficacy, knowledge on the physiologic responses induced by TT is lacking.

Objective: The aim of this quantitative randomized pilot study was to determinate if TT, delivered in two modes (resistive and capacitive), affects the perfusion of the skin microcirculation (PSMC) and intramuscular blood flow (IMBF).

Design: A randomized controlled pilot feasibility study.

Subjects: Ten healthy volunteers ($n=4$ females, $n=6$ males; mean age 35.9 ± 10.7 years) from a university population were recruited and completed the study.

Intervention: All subjects received three different TT applications (resistive, capacitive, and placebo) for a period of 8 min.

Outcome measures: PSMC, IMBF, and the skin temperature (ST) were measured pre- and post-TT application using power Doppler sonography, laser speckle contrast imaging (LSCI), and infrared thermography.

Results: Compared with placebo application, statistically significant differences in PSMC resulted after both the resistive ($p=0.0001$) and the capacitive ($p=0.0001$) TT applications, while only the resistive modality compared with the placebo was capable to induce a significant change of IMBF ($p=0.013$) and ST ($p=0.0001$).

Conclusions: The use of power Doppler sonography and LSCI enabled us to evaluate differences in PSMC and IMBF induced by TT application.

Keywords: diathermy, physical therapy modality, perfusion imaging, regional blood flow, laser speckle contrast imaging, skin temperature

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Introduction

The Tecar (capacitive and resistive energetic transfer) is an endogenous thermotherapy that uses electrical currents, induced by a 448 kHz capacitive/resistive monopolar radiofrequency, to generate warming up of deep tissues.[1,2] Its use in clinical practice has been relatively common for nearly 20 years, but only a few recent studies investigated its clinical efficacy. Most of them reported encouraging results in decreasing pain and improving function in different musculoskeletal clinical conditions as low back pain,[1,3,4] insertional tendinopathies of the Achilles, the patellar, and the wrist extensor common tendons.[5] Its capability to affect the blood flow, as a consequence of its thermotherapeutic effect, is commonly considered one way in which TT supports the healing processes of injured/dysfunctional tissues.[6] Nevertheless, a substantial lack of knowledge exists on the question: does TT affect blood flow in superficial tissue layers?

The Tecar device provides two different treatment modes: capacitive (CAP) and resistive (RES). These modes are normally delivered with different probes (electrodes), made of medical stainless steel. According to Tecar's developers, the two treatment modes induce different tissue responses depending on the resistance of the treated tissue. When the active electrode is provided with an insulating ceramic layer, acting as a dielectric medium, (CAP) the energetic transmission generates only heat in superficial tissue layers, with a selective action on low-impedance (water rich) soft tissues, for example, adipose tissue, muscle, cartilage, and lymphatic system. If the active electrode has no insulating layer, (RES) the radiofrequency energy passes directly through the body in the direction of the inactive electrode, generating heat in the deeper more resistant (low water content) tissue layers, for example, bone, muscular facia, capsules, and tendons. A recent study on healthy volunteers concluded that the delivery of the TT in a mixed mode (described as a ''capacitive/resistive'') enhances blood flow volume in muscle tissue.[2] To the best of knowledge, this pilot project is the first experimental study evaluating the effect of TT (CAP and RES separately) on the perfusion of skin microcirculation (PSMC) and intramuscular blood flow (IMBF) using laser speckle contrast imaging (LSCI) and power Doppler sonography. The aim of this quantitative pilot study is to determine if TT, administered in two modes, affects the IMBF, PSMC, and skin temperature (ST) in healthy subjects. Furthermore, the authors want to estimate variability to determine the sample size for future clinical trials evaluating the physiologic responses of TT.

Materials and Methods

A sample of 10 healthy subjects ($n = 4$ females, $n = 6$ males; mean age 35.9 ± 10.7 years, mean height 175.7 ± 9.3 cm, mean weight 72.8 ± 12.6 kg) was recruited from a university population. The first 10 volunteers meeting the inclusion criteria were admitted to the study. The inclusion criteria were nonpainful full active range of motion for the right shoulder, elbow, wrist, hand, and cervicothoracic spine. Exclusion criteria were lack of consent in receiving TT, use of pacemaker, epilepsy, angina pectoris, cardiovascular pathologies, pregnancy or breastfeeding, skin lesions, current or recent neck or upper extremity pain (at least 3 consecutive days in the past 6 months), nervous system disorders, diabetes mellitus, thermal sensitivity dysfunction, upper extremities, breast or cervical spine surgery, drug or alcohol abuse, tumors, radiation therapy or chemotherapy in the past year, metallic implants, and internal infection with encapsulated abscess.

All experimental sessions were performed between April 9, 2018 and May 15, 2018, in the Rehabilitation Research Laboratory of the Department of Business Economics, Health and Social Care, University of Applied Sciences and Arts of Southern Switzerland (Manno, Switzerland). Ethical approval was granted by the Ethics Committee of Canton Ticino (2018-00271/CE3327), and the procedures were conducted according to the Declaration of Helsinki. All subjects signed written informed consent before the study. The proposed methodology was developed according to the Consolidated Standards of Reporting Trials statement (2010) containing an extension for a pilot and feasibility trial.[7]

A Tecar device (T-Plus; Wintecare SA, Chiasso, Switzerland) was used to administer the treatment. LSCI (moorFLPI-2; Moor Instruments Ltd., Devon, United Kingdom) and a power Doppler (MyLab Class C; Esaote S.p.a, Genoa, Italy) with a linear probe (LA 533) were used to assess PSMC and IMBF, respectively, according to previous studies investigating similar outcome variables.[2,8–10]

Heart rate (HR), blood pressure (BP), and ST were measured, respectively, with a digital sphygmomanometer (BM 85, Breuer, Ulm, D) and an infrared thermography device (Infrared IR 500-8S, Voltcraft, Hirschau, D). A digital hygrometer and thermometer (Multimeter Voltcraft MT51, Voltcraft, Hirschau, D) were used to measure room temperature and room humidity. A wooden frame for the right upper arm was used to standardize the position during all the experimental procedures.

Three experimental sessions were planned for each participant to test the three different Tecar modes separately: RES, CAP, and placebo (PLAC) separately. To prevent carryover effects, a wash-out period of 1 week between the treatment sessions was considered to be more than sufficient. The order of treatment modality was randomized by asking each participant to choose between three sealed envelopes at the beginning of session I and II. All Tecar applications were performed by the same Tecar-certified physiotherapist.

TT was administered in the RES modality using a round-shaped low-impedance electrode made of medical stainless steel, while the CAP modality TT was delivered using a high-impedance electrode made of medical stainless steel with ceramic coating. In the PLAC modality, TT was delivered by alternating between the high- and low-impedance electrodes with the device switched off. The PLAC application was included to test the potential variation of the blood flow related to the mechanical effect of the probe manipulation and not to the physiologic effect of the TT itself.

TT was applied to the same region of the right forearm during each of the three sessions. The area was standardized using a reference system based on anatomical landmarks and defined with four strips of tape (Fig. 1), applied during the acclimatization phase at the beginning of each session. The same reference system was used to standardize the position of all the measurement devices. Two pen marks on the lateral strip of tape helped to standardize the position of the power Doppler's probe. In addition, a picture of that frame was

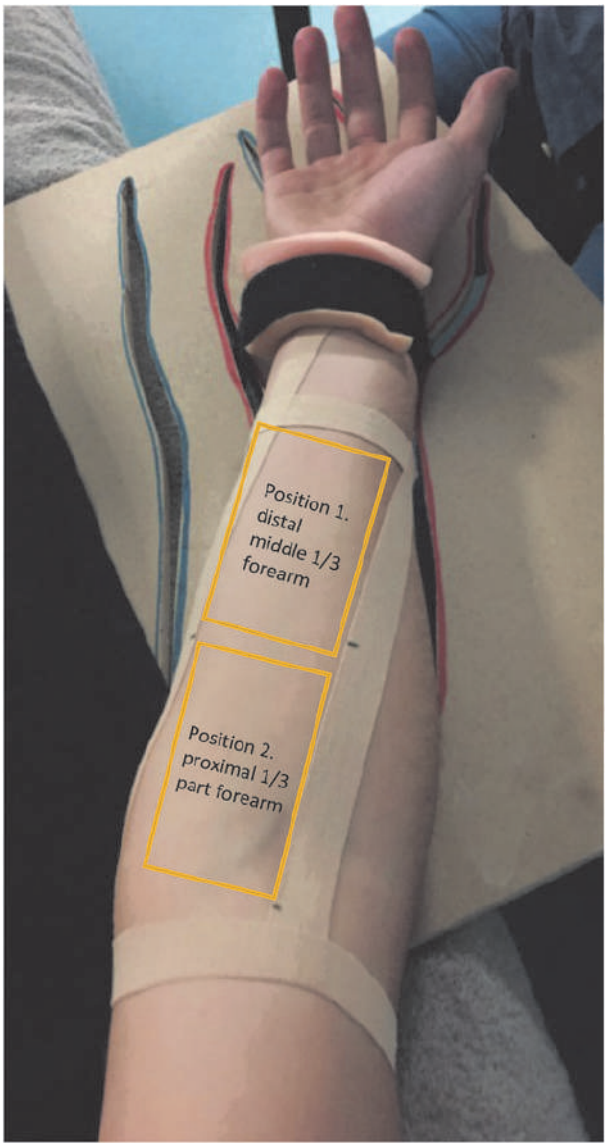

FIG. 1. Standardized reference frame for the application of Tecar therapy.

taken in session I to have a standardized reference for the following sessions II and III.

The Tecar's plate electrode (inactive electrode), coated with conductive cream, was positioned under the right scapular region before the subjects were placed in a supine position. Following the completion of all premeasurements, a sufficient amount of conductive cream was applied to the skin of the volar forearm to facilitate optimal gliding of the Tecar's probe, and an 8-min TT application was administered. The round-shaped probe was handled with a roto-translatory movement. Each movement cycle lasted 1 sec. A metronome was used to ensure a precise handling of the probe.

The intensity of each mode was set according to a previous pilot testing to ensure the highest possible tolerable treatment intensity. In detail: RES (70%), CAP (40%), and PLAC (0%). In the event that the heat generated by the TT was no longer tolerable, the intensity was decreased as follows: RES (35%) and CAP (20%). After each application, the conductive cream was gently removed from the skin using a cotton towel.

A standard explanation of the experimental procedure was given to the subjects. They were instructed to communicate the heat intensity during the TT application. Subjects were in a supine position with legs straight and both upper arms beside the body. A soft pillow was positioned under the head to avoid discomfort. The right upper arm was positioned at 20° of shoulder abduction, the elbow in full extension, and the forearm was held in full supination by fixing the wrist to the wooden positioning frame with a Velcro strap. Subjects were asked not to move their hand and fingers, to avoid interference with the effect of the Tecar application, respectively, to impair the accuracy of the LSCI and Doppler measurements.

According to similar previous studies,[2,10] before the measurements all subjects respected a 20-min acclimatization period before any experimental procedure was started. During this time, the subjects rested for 20 min in a supine position in a quiet and darkened room to guarantee stable HR and BP values and the stability of these parameters for the duration of the measurements.

All measurements were performed under standardized laboratory conditions. To compare the effect of TT, pre- and postmeasurements of PSMC, IMBF, HR, BP, and ST were conducted immediately after the TT application (post 1), at time interval 2 min (post 2), and after 10 min (post 3).

The power Doppler images were assessed in two different positions on the volar forearm and arm: Position 1: between the distal and the middle 1/3 of the volar forearm and Position 2: proximal third part of the volar forearm (Fig. 1). In both positions, the probe of the power Doppler was positioned transversally to the longitudinal axis of the forearm, to detect the blood vessels of the transverse section of the wrist flexor muscles at a maximum depth of 3–4 cm.

Two B-mode images, one in each position, were taken before assessing the power Doppler clips. Six power Doppler clips (5 sec long), three in each position, were taken before and immediately after the Tecar application (post 1). The same procedure was repeated at time interval post 2 (2 min) and post 3 (10 min) post-TT application.

The LDCI measurements were performed with a wavelength of 750 nm in a supine position. One day before the measurements, the LDCI system was successfully calibrated. To minimize the risk of confounding factors, daylight and other sources of light were diminished as well as movements of the system during the measurements. The subjects were instructed to breathe normally and not to talk or move during the measurements. The laser aiming function of the device was used to obtain the optimal distance between the measured skin area and the LSCI-system. An *a priori* specified region of interest (ROI) was marked on the volar forearm to obtain standardized values. High-resolution LSCI images (752×580 pixels), at a frame rate of 25 Hz (1 sec/frame with an interval of 5 sec), were recorded. The LSCI device uses arbitrary units that reflect the mean flux of an area of interest. The flux is related to the concentration of moving red blood cells in the tissue sample volume, where the level of flux is scaled from blue (low perfusion) to red (high perfusion). LSCI is a relatively new valid method to assess blood flow in the microcirculation of the skin. Compared with laser

Doppler flowmetry and laser Doppler imaging, LSCI has some potential advantages. The macroscopic noncontact measurements, with a high spatial and temporal resolution, allow large full-field imaging of the skin microcirculation in real time due to a faster signaling processing.[11,12] Especially in experimental settings where surface contact is undesirable and microcirculatory perfusion measurements of large skin areas are required, the reproducibility of cutaneous blood flow seems to be superior when measured with LSCI.[13,14]

The Shapiro–Wilks test revealed a non-normal distribution, and thus, data were described using median and interquartile range. The Friedman test was used to analyze the data for statistically significant median differences between pre- and postmeasurements within the three Tecar modes. Bonferroni correction for multiple comparisons was applied. Averages, medians, and standard deviations of all parameters were calculated to describe pre- and postmeasurements as well as their difference.

All statistical analyses were executed using the SPSS statistical package software (IBM SPSS Statistics version 24; SPSS, Inc., Chicago, IL). The significance level was set to $p < 0.05$.

Clips from the power Doppler were analyzed to extract three parameters: (1) area of blood vessels, (2) number of identified vessels, and (3) median power intensity of blood flow. The procedure for the extraction of these three parameters is described in the following paragraphs. The clips from power Doppler were recorded at 11 fps and were 10 sec long, to include at least three systolic and three diastolic movements. Each frame consisted of an image with two superimposed layers: b-mode and blue shade power Doppler image. The pixels with blue shades referred to an arbitrary scale ranging from 0 to 255 according to the ratio between blue and red color intensity in the RGB color code. An arbitrary threshold was set to 100 to avoid measuring background noise that was always present in the images.

The number of pixels with a blue color intensity above 100 was computed for each frame. Since the pixel area curve was increasing during systole and decreasing during diastole, the authors used that curve to identify the systolic and diastolic cycles. The frame indexes corresponding to three systolic and three diastolic movements were identified from the curve of the blood vessels' area and those frames were used to extract the variables of interest. The area of blood vessels was evaluated as described above. To estimate the number of vessels from the images, the individual areas with at least 10 pixels not connected to each other were counted. A threshold of 10 pixels was set to avoid the measurement of background noise.

An example of this procedure of noise filtering and calculating the area is presented in Figure 2, where Figure 2A represents the power Doppler acquisition with background noise and Figure 2B the filtered image for the calculation of the blood flow area. The final parameter evaluated was the median power intensity of blood flow. This value was derived from the histogram of blue color intensity computed in the area extracted (Fig. 2C) ranging from 0 to 255 on an arbitrary color scale.

Due to fluctuations in the values between the two BP phases, it was decided to analyze only those images taken during the diastole. Using the statistical function from the moorFLPI Review V5.0 analysis software, the mean perfusion values of the ROI from the five recorded frames for every measurement interval (pre- and post-TT) were calculated (Fig. 3).

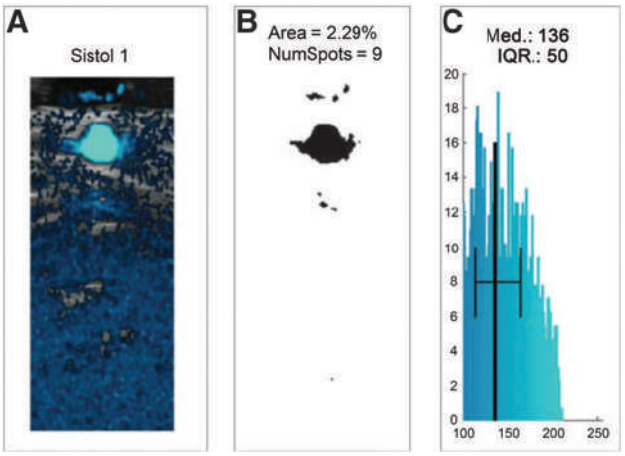

FIG. 2. **(A)** Example of a power Doppler image with background noise. **(B)** Example of a filtered power Doppler image for the calculation of the blood flow area. **(C)** Histogram of blue color intensity computed in the extracted area.

For the following variables, PSMC, IMBF (proximal and distal), HR, and mean arterial pressure (MAP), the median difference between pre- and postintervention measurements was calculated and reported as a percentage. The MAP was calculated from systolic BP (SBP) and diastolic BP (DBP), using the formula as follows: $MAP = (SBP + 2 \times DBP)/3$.

Results

All 10 volunteers successfully completed the three experimental sessions. The experimental procedure and the subjects' position were described as tolerable and comfortable, and none of them reported any adverse effects. Room temperature and room humidity values (mean 24.1°C ± 2.1 and 36.9°C° ± 2.0, respectively) measured immediately before and after the Tecar application were stable enough to assume that any potential difference between pre- and postmeasurements was not influenced by them. Statistically significant differences ($p < 0.05$) of the median difference between each pre- and postintervention measurement were found for PSMC (PLAC—CAP, and CAP—RES), IMBF distal (PLAC-post 1—RES-post 3, CAP-post 2—RES-post 3), and ST (PLAC—RES). For both the control variables, HR and MAP, no statistically significant differences were found (Table 1). Pre- and postabsolute values are reported in Supplementary Table S1.

Discussion

Although TT 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.[1,3] There seems to be a substantial lack of knowledge on the physiologic responses induced by TT application. A better understanding of the physiologic effects of TT would help in defining the mechanisms underlying its

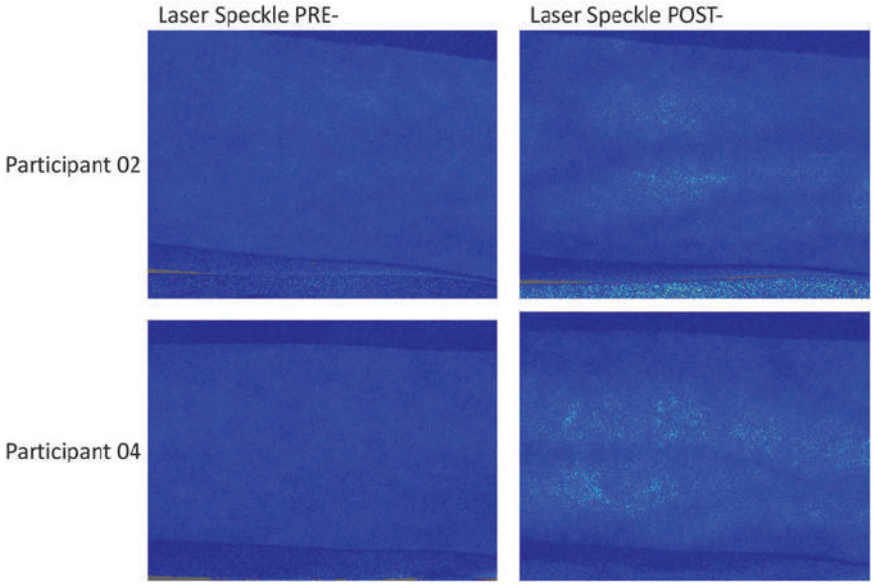

FIG. 3. Laser speckle contrast images before and after resistive Tecar application. The *brighter dots* in the postimages represent an increase of skin perfusion.

clinical efficacy. From the perspective of evidence-based practice, it would be ideal to base the optimal dosage and choice of mode of a TT application on sound physiologic knowledge. This pilot study on healthy volunteers was, to knowledge, the first attempt to estimate the effect of the TT on blood flow when delivered in two distinct modes: RES and CAP. Ten healthy volunteers were recruited and completed the study. All subjects received three different TT applications (RES, CAP, and PLAC) for a period of 8 min, with an interval of 1 week between applications. PSMC, IMBF, and the ST were measured pre- and postintervention. To minimize the risk of bias, standardization of the procedures (definition of the treatment area, Tecar delivery modes, and measurement acquisition) was planned carefully. Compared with the PLAC application, both the RES and CAP modes were found to be effective in inducing a change in the PSMC. Unexpectedly, the CAP mode induced a slight decrease, while the RES mode, as expected, induced a moderate increase in the PSMC. Regarding the change in IMBF, a significant increase was found for the RES mode at the proximal third of the forearm. In comparison with placebo, no significant changes in IMBF were found for either the CAP or for the RES mode in the measurement at the distal middle third of the forearm.

It should be noted that the significant difference in IMBF, for the RES mode, was only found proximally (position 2: at the proximal third of the forearm), and 10 min after the TT application. A possible explanation for this could be the larger cross-sectional area and consequently vascularization of the forearm (at the site of the proximal measurements) in

Table 1. Pre- and Postdifferences of the Selected Outcome Measurements

Outcomes	*Placebo*	*Capacitive*	*Resistive*
IMBF, proximal (%)			
Pre- and post 1-difference	0.01 (0.7)[a]	0.36 (4.4)	0.53 (1.04)
Pre- and post 2-difference	0.17 (1.6)	0.79 (3.3)[b]	2.2 (1.95)
Pre- and post 3-difference	0.05 (1.1)	–0.09 (1.9)	2.06 (3.3)[a,b]
IMBF, distal (%)			
Pre- and post 1-difference	–0.2 (1.1)	1.4 (4.06)	1.4 (3.02)
Pre- and post 2-difference	0.5 (1.9)	0.5 (5.2)	1.12 (3.95)
Pre- and post 3-difference	0.1 (2.1)	0.65 (1.13)	1.5 (3.69)
Skin perfusion (%) PSMC			
Pre- and postdifference	–24.8 (16.8)[c,d]	–3.97 (22.01)[c]	23.1 (56.4)[d]
Heart rate (bpm)			
Pre- and postdifference	–1 (7)	1.5 (9)	0.5 (10)
Mean arterial pressure (mmHg)			
Pre- and postdifference	–4.2 (6)	–2.8 (6.3)	0.65 (5)
Skin temperature (°)			
Pre- and postdifference	–2.3 (1.5)[e]	0.9 (1.3)	2.8 (2)[e]

All values are reported as median and IQR.
[a–e]Indicate significant differences ($p < 0.05$) between groups.
IMBF, intramuscular blood flow; IQR, interquartile range; PSMC, perfusion of the skin microcirculation.

comparison with the position 1 region (where distal measurements were taken). The onset of change in IMBF needs further investigation. Changes in PSMC and IMBF seem not to be related to any systemic cardiovascular responses, since both HR and MAP did not vary between pre- and postmeasurements, suggesting that TT affects blood flow only at a local level. Interestingly, the difference between pre- and postvalues of ST was only significant when comparing the RES mode with the PLAC mode, with an increase and a decrease of $\sim 2°C$, respectively. These results are in line with Kumaran and Watson[2] stating that TT has the capability to induce a response in the deep tissue without an excessive increase of ST, a remarkable feature for any intervention with a thermotherapeutic effect.[2] A limitation that might have influenced the decrease in ST between the RES mode and PLAC mode is the use of a ''cold'' (room temperature) steel electrode and conductive paste during the application in the PLAC mode. This might have influenced the ST and could have caused a vasoconstrictive effect on the PSMC. The use of thermotherapy is still quite common among physiotherapists, and also of interest to researchers to evaluate the forms of thermotherapy in the management of a variety of musculoskeletal disorders.[15–18]

The ability to induce a thermotherapeutic effect in the deep target tissue (deep muscle layers, joints, and tendons) without generating an excessive increase of the superficial (skin) temperature makes TT highly tolerable for the patients and suitable for the treatment of a variety of musculoskeletal disorders. Therefore, TT applications could be a treatment option especially in conditions where a dysfunction in blood flow plays an important role in generation and persistence of pain and dysfunction (i.e., osteoarthrosis, tendinopathies, and myofascial pain syndrome).[1,3–5,15–22] Although tendons are poorly vascularized and tendon nutrition is more reliant on synovial fluid diffusion than vascular perfusion, the role of changed vascularization during healing of tendon healing is still not clear.[23] It remains questionable if TT can affect blood flow in other anatomical structures such as tendons and joint capsules. A previous published study of Kumaran and Watson[2] suggested that TT application can affect the volume and velocity of IMBF. Compared with this research, some methodological differences can be pointed out. The main difference was in the way in which TT was applied. Kumaran and Watson[2] delivered TT combining 10 min of the RES mode immediately followed by 5 min in the CAP mode, for a total treatment period of 15 min,[2] although this option is more similar to commonly used clinical treatment sessions. Combining the two modes does not allow researchers to discriminate if the changes in blood flow differ or depend on the mode delivered. Furthermore, the intensity of the treatment was not standardized for all subjects but was set depending on the perceived local thermal sensation that can be potentially different for every participant. Defining the treatment intensity this way implies a risk of increasing the heterogeneity of the blood flow variations, as it is likely that increasing the treatment intensity might also affect the response size.

Concerning the use of pulsed wave Doppler for blood flow measurement, some differences between the two studies exist, particularly concerning the probe placement. In each participant, Kumaran and Watson used the most prominently identifiable pulsatile (arterial) flow, then following this, the probe was placed parallel to the longitudinal axis of that arteria, to detect its longitudinal section.[2] Conversely, in the present study, the probe was placed perpendicularly to the forearm to detect the transverse section of regional vessels. This method allowed us to detect blood flow changes occurring not only in one large vessel but also in the smaller ones. This could be considered to a more accurate and suitable method to detect changes in blood flow within the muscle tissue.[8,24]

Despite all the methodological differences, it is encouraging that both the present pilot study and the study of Kumaran and Watson[2] reported similar results concerning the potency of the TT to affect IMBF. Although the operator's efforts to utilize the same amount of pressure when placing the Tecar's probe on the treated area, no precise measurement of the pressure applied on the skin was carried out during the TT application.

This limitation might have partially affected the variations in blood flow during the three application modes. Other limitations could be the chosen measurement intervals after the TT intervention and the fact that the authors could only measure PSMC before and directly after TT application. The present study found a significant increase of IMBF for the RES mode, which provides support for mechanism of action. It should be stated that this does not necessarily mean that this difference is clinically important or meaningful to patients. Future studies investigating the effect of TT on IMBF and PSMC postintervention measurement should be evaluated in 1-min intervals to get more precise information on the onset of microcirculation blood flow changes.

Conclusions

In conclusion, these results indicate that TT applications in RES and CAP mode significantly effect PSMC in comparison with a TT PLAC application. A significant change in IMBF and ST was found only for the TT RES mode in comparison with the PLAC application. As the changes in PSMC and IMBF were not related to any systemic cardiovascular responses, TT seems to affect blood flow only at a local level. The applied method using LSCI and the power Doppler technique enabled us to estimate the change in PSMC and IMBF. To improve the clinical efficacy of TT, future studies should focus on physiologic differences between the different TT treatment modes.

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Author Disclosure Statement

No competing financial interests exist.

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Supplementary Material

Supplementary Table S1

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Thermal and non-thermal effects off capacitive-resistive electric transfer application on the Achilles tendon and musculotendinous junction of the gastrocnemius muscle: a cadaveric study

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Abstract

Background: Calf muscle strain and Achilles tendon injuries are common in many sports. For the treatment of muscular and tendinous injuries, one of the newer approaches in sports medicine is capacitive-resistive electric transfer therapy. Our objective was to analyze this in vitro, using invasive temperature measurements in cadaveric specimens.

Methods: A cross-sectional study designed with five fresh frozen cadavers (10 legs) were included in this study. Four interventions (capacitive and resistive modes; low- and high-power) was performed for 5 min each by a diathermy "T-Plus" device. Achilles tendon, musculotendinous junction and superficial temperatures were recorded at 1-min intervals and 5 min after treatment.

Results: With the low-power capacitive protocol, at 5 min, there was a 25.21% increase in superficial temperature, a 17.50% increase in Achilles tendon temperature and an 11.27% increase in musculotendinous junction temperature, with a current flow of 0.039 A ± 0.02.
With the low-power resistive protocol, there was a 1.14% increase in superficial temperature, a 28.13% increase in Achilles tendon temperature and an 11.67% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.063 A ± 0.02. With the high-power capacitive protocol there was an 88.52% increase in superficial temperature, a 53.35% increase in Achilles tendon temperature and a 39.30% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.095 A ± 0.03. With the high-power resistive protocol, there was a 21.34% increase in superficial temperature, a 109.70% increase in Achilles tendon temperature and an 81.49% increase in musculotendinous junction temperature at 5 min, with a current flow of 0.120 A ± 0.03.

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Conclusion: The low-power protocols resulted in only a very slight thermal effect at the Achilles tendon and musculotendinous junction, but current flow was observed. The high-power protocols resulted in a greater temperature increase at the Achilles tendon and musculotendinous junction and a greater current flow than the low-power protocols. The high-power resistive protocol gave the greatest increase in Achilles tendon and musculotendinous junction temperature. Capacitive treatments (low- and high-power) achieved a greater increase in superficial temperature.

Keywords: Achilles tendon, Cadaver, CRet, Musculotendinous junction, Physical therapy

Background

Calf muscle strain injuries are common in different activities and sports [1–3].

In different imaging studies there appears to be an injury predominance of the medial head of the gastrocnemius (58 to 65%), the fascial intersection of the medial gastrocnemius and soleus as they merge with the proximal Achilles tendon (66%) [4] and the distal part of the Achilles tendon [5].

Vascular supply has an important effect on tendon tissue repair [6]. Studies in rabbits have shown that when the blood supply in the Achilles tendon is interrupted the tendon fascicles and the tenocytes lost their normal properties, becoming shortened and degenerated and the strands of collagen become acellular and fragmented. Moreover, changes observed in chronic degenerative tendon disorders were shown to be the same as those that occur when the blood supply to the rabbit's Achilles tendon is disturbed [7, 8]. This demonstrates that vascular supply is one of the key factors in treating tendon tissue.

Capacitive-resistive electric transfer (CRet) therapy is used to treat musculoskeletal injuries [9–12]. CRet is a non-invasive electrothermal therapy classified as deep thermotherapy. It is based on the application of electric currents within the radio frequency range of 300 kHz – 1.2 MHz. This current can generate warming of deep muscle tissues and in turn improve hemoglobin saturation, an increase in deep and superficial blood flow, vasodilation, increase in temperature, elimination of excess fluid and increase in cellular proliferation [13, 14]. Responses such as the increased blood perfusion seem clearly associated with the temperature increase, which is generated due to a physical reaction generated by the flow of current (Joule effect) [15]. The increase in cellular proliferation, however, appears to be associated mainly with the flow of current rather than the temperature increase [16].

CRet therapy provides two different treatment modes: capacitive and resistive. Both treatment modes induce different tissue responses depending on the resistance of the treated tissue. Capacitive mode is provided with an insulating ceramic layer and the energetic transmission generates heat in superficial tissue layers, with a selective action in tissues with low-impedance (water rich). Resistive mode has no insulating ceramic layer, the radiofrequency energy passes directly through the body in the direction of the inactive electrode, generating heat in the deeper and more resistant tissues (with less water content) [17].

The use of deep heating modalities has long been used in the treatment of overuse tendinopathies [18]. It has been reported that the application of heat leads to improved blood flow and oxygen saturation in the Achilles tendon [19, 20]. Thus, thermal agents may be an effective method of treating tendon disorders.

Currently, treatments are based on empirical experience, and the levels of energy and current that must be transferred to produce the desired effects are unknown [9, 11, 13, 21]. There is an article on CRet in Achilles tendinopathies found improved blood circulation of the Achilles tendon but was not able to measure the increase in tendon temperature [22]. Another article studied the changes in temperature with non-invasive devices to monitor deep tissue temperature rather than invasive devices. This was one of the main limitations that the authors themselves commented on in their article [13].

Therefore, conducting a study on cadavers with invasive measurements would help to know the current flow and temperature that deep structures reach in an ethical manner.

Our hypothesis is that the resistive mode is able to have a deeper effect on current flow and generate higher temperature rise in deep structures. The capacitive mode increases more the temperature in superficial structures.

Methods

Aim

Our objective was to analyze the thermal behavior and transmission of electric current in the Achilles tendon and the musculotendinous junction of the gastrocnemius muscle with different CRet protocols, using non-living specimens and invasive temperature measurements.

Study design

This was a cross-sectional study designed to assess the effect of resistive energy/electrical capacitive transfer with the T-Plus Wintecare device on the temperature in the Achilles tendon, musculotendinous junction and superficial region of the calf in cadaveric specimens. The

body donor program of the Faculty of Medicine and Health Science of *Universitat Internacional de Catalunya* provided all specimens. The study was conducted in July 2019. The Ethics Committee "Comitè d'Ètica de Recerca (CER) from the Universitat Internacional de Catalunya" approved the study with CBAS201907 reference number.

Cadaveric specimens

The study material included 5 fresh frozen cadavers: 4 male and 1 female (10 legs). The age range at the time of death was 60–80 years (mean 69.80 ± 6.04). The bodies were stored at 3 °C and brought to room temperature a day before the test to make it stable. The basal superficial, Achilles tendon and musculotendinous junction temperatures were measured prior to any intervention to ensure the same starting values. None of the cadaveric specimens used for this study had evidence of traumatic injuries or surgical scars on the lower limbs.

Intervention

To better understand the temperature behavior and passage of current in conditions similar to rehabilitative treatments, we applied a power limit similar to that typically applied with a T-Plus device during real-life treatments. This was based on the power level, which is easily identifiable and controllable by the therapist during therapy, and the watts (absorbed power) shown by the device during the therapy.

The power range of a very large T-Plus device ranges from 1 to 300 watts in resistive and from 1 to 450 Volt-Ampere (VA) in capacitive mode.

Two thresholds were identified: *high power* and *low power,* based on the real powers that the therapist typically applies when she/he wants to generate a thermal or non-thermal reaction. On this basis, *high-power* thresholds were set at 90VA in capacitive mode (HPC) and 60 watts in resistive mode (HPR), while low-power thresholds were set at 20VA in capacitive mode (LPC) and 10 watts in resistive mode (LPR). In real-life use, on average, thresholds of 10 watts and 20 VA respect the limit of 0.3 A, while applications at 60 watts and 90 VA are widely-used for a thermal effect.

The 4 interventions (capacitive and resistive mode; low- and high-power) were performed for 5 min each, by a physiotherapist with experience in the use of T-Plus. Dynamic movements similar to those used with real patients were performed with constant pressure to the posterior region of the heel (Fig. 1).

Experimental procedures

Cadavers were placed in the prone position. Hips were placed in neutral rotation, with the knee in 30° of flexion, and a thermoplastic splint maintained the ankle joint position. The skin was cleaned with chlorhexidine-isopropyl alcohol [23].

The order of the 4 treatment protocols and the specimen (leg side) were both randomized generating a prelisting through Random.org. by one of the researchers not involved in the recruitment. The temperature generated in the specimen was allowed to return to normal before the next application.

All instrumentation received a calibration certificate prior to the study. Thermocouples *"Hart Scientific PT25 5628-15"* were used to measure the musculotendinous junction and Achilles tendon temperature, and a digital thermometer *"Thermocomed"* was used to measure the superficial temperature of the calf (Fig. 2a). Thermocouples were placed under ultrasound guidance *"US Aloka Prosound C3 15.4"*, with a high-frequency linear transducer (USTTL01, 12 L5), by a researcher expert in the use of the instrument (Fig. 2b). One thermocouple was placed in the middle of the Achilles tendon and the other in the musculotendinous junction (Fig. 2c).

The return electrode of the T-Plus was placed on the abdomen of the specimen and the treatment was carried out with the movable electrode of the T-Plus on the heel for 5 min. The initial superficial, Achilles tendon and musculotendinous junction temperatures were measured. These measurements were recorded at 1-min intervals for 5 min and at 5 min after the end of each treatment. Prior to treatment, impedance was always measured (*Multimeter Fluke 8846A)* to ensure that the values marked by the T-Plus Wintecare device were correct. In addition, the current flow of each application was calculated. Using the average voltage divided by the initial impedance.

Statistical analysis

Analyses were performed using SPSS Statistics version 22.0. Normality of distribution was analyzed using the Shapiro-Wilk test ($p > 0.05$). Mean and standard deviation were calculated for the superficial, Achilles tendon and musculotendinous junction temperatures. The percentages of temperature change respect to baseline temperature were calculated.

For intra-protocol differences, the Friedman test and Wilcoxon signed-rank test were used. Inter-protocol comparisons were performed using the Kruskal-Wallis test and Mann-Whitney U test. A p value < 0.05 was considered statistically significant.

Results

Temperature was recorded at the specified time points during the different protocols. Descriptive outcomes of superficial, Achilles tendon and musculotendinous junction temperature are shown in Table 1. The starting temperature values in the different protocols did not

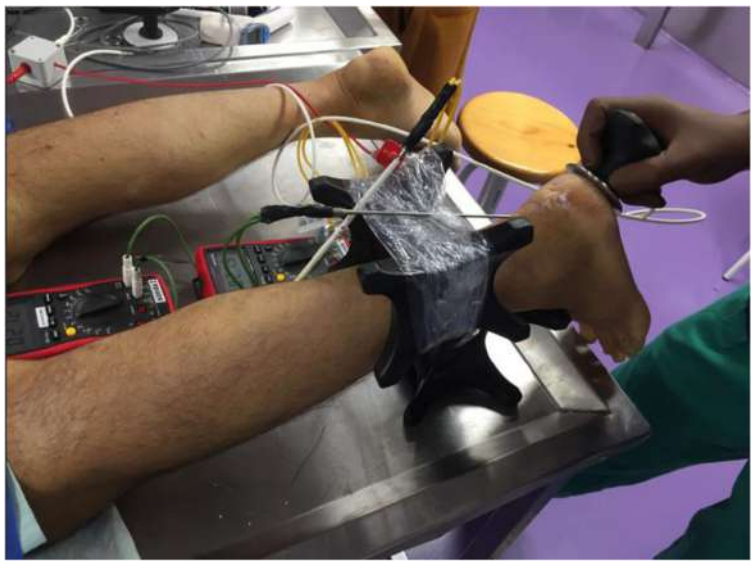

Fig. 1 Intervention with T-Plus Wintecare

show a statistically significant difference at any of the positions (superficial, $P < 0.299$; Achilles tendon, $P < 0.396$; musculotendinous junction, $P < 0.871$). The current flow in these protocols was stable, with averages of 0.095 A ± 0.03 (HPC); 0.039 A ± 0.02 (LPC); 0.120 A ± 0.03 (HPR) and 0.063 A ± 0.02 (LPR).

All protocols showed a progressive increase in temperature at all depths, and a decrease in temperature at 5 min post-application ($P < 0.001$, Friedman test).

The biggest increase in superficial temperature was found at the end of application in the HPC protocol, at 39.63 °C, which represented an 88.5% increase from the starting temperature. However, this temperature decreased in the 5 min post-application to 28.8 °C, representing a 36.9% increase from baseline. The other protocols showed similar values, at around a 26% increase, except for the LPR protocol, which showed almost imperceptible increases of between 1

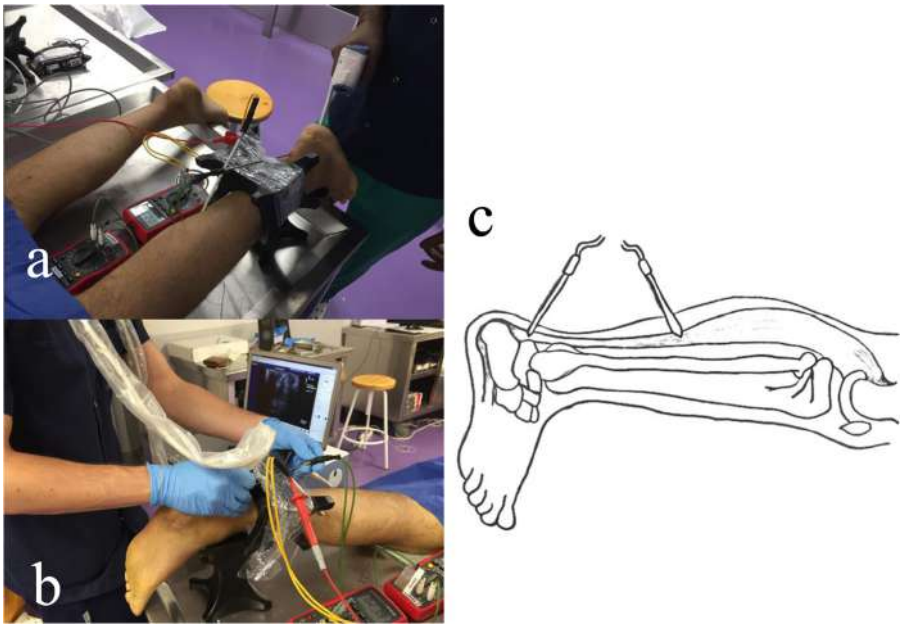

Fig. 2 a Temperature measurement with digital thermometer; b Thermocouple placement under ultrasound guidance; c Thermocouple position

Table 1 Descriptive outcomes: temperature

		Baseline	1 min	2 min	3 min	4 min	5 min	5 min post-application
Superficial	HPC	21.08 ± 0.68	30.13 ± 4.67	33.69 ± 4.91	35.27 ± 3.62	39.52 ± 4.02	39.63 ± 5.08	28.80 ± 3.02
	LPC	21.38 ± 1.18	24.32 ± 0.93	25.46 ± 1.22	25.72 ± 1.20	26.28 ± 1.26	26.70 ± 0.72	22.30 ± 0.61
	HPR	20.71 ± 1.14	23.63 ± 1.52	24.20 ± 1.10	25.37 ± 1.25	25.02 ± 1.64	26.14 ± 1.90	23.68 ± 0.93
	LPR	21.66 ± 1.25	21.90 ± 1.25	21.97 ± 1.10	21.86 ± 1.20	22.12 ± 1.39	21.88 ± 0.87	20.83 ± 1.00
Achilles tendon	HPC	23.99 ± 1.81	35.45 ± 7.00	35.30 ± 6.40	35.60 ± 6.80	36.33 ± 8.50	36.56 ± 7.79	26.37 ± 1.42
	LPC	23.47 ± 1.67	26.13 ± 2.08	26.52 ± 2.55	26.70 ± 2.55	26.98 ± 2.08	27.58 ± 2.73	25.34 ± 0.88
	HPR	23.97 ± 0.85	47.33 ± 6.65	47.86 ± 5.20	48.57 ± 6.24	49.18 ± 6.32	50.27 ± 6.95	28.11 ± 1.41
	LPR	23.21 ± 1.52	28.33 ± 1.87	28.78 ± 1.79	29.32 ± 1.98	29.60 ± 1.82	29.68 ± 1.87	25.08 ± 0.56
Musculotendinous junction	HPC	19.62 ± 1.98	24.04 ± 4.32	25.45 ± 3.96	25.97 ± 4.19	26.80 ± 4.69	27.33 ± 4.78	22.06 ± 2.33
	LPC	20.03 ± 1.36	21.59 ± 1.85	21.81 ± 1.91	21.99 ± 1.94	22.11 ± 1.91	22.29 ± 1.99	21.06 ± 1.19
	HPR	19.51 ± 1.58	30.30 ± 5.80	32.19 ± 6.09	33.06 ± 6.33	35.29 ± 7.19	35.15 ± 7.24	23.91 ± 2.01
	LPR	20.33 ± 2.62	21.19 ± 1.66	21.57 ± 1.74	21.80 ± 1.76	22.14 ± 1.87	22.42 ± 1.95	20.81 ± 0.93

HPC high-power capacitive, *LPC* low-power capacitive, *HPR* high-power resistive, *LPR* low-power resistive.

and 2.3%, registering a 3.8% decrease at 5 min post-application.

All protocols showed a decrease in temperature at 5 min post-application: the most pronounced decrease was with HPC (Table 1), but this protocol also generated the highest temperature increase (Fig. 3).

Differences between protocols were statistically significant for the difference between baseline and 5 min of intervention and between baseline and 5 min post-application, except for the difference between LPC and LPR for baseline vs 5 min post-application ($P < 0.853$).

In the Achilles tendon, the HPR protocol produced the biggest temperature increase at 5 min of application, at 50.27 °C, which represented a 109.7% increase from baseline. This value decreased 23.98 °C at the 5-min post-application measurement, representing a 17.4% increase from baseline. In the other protocols, there was less temperature increase, the second highest being 10.3% in the HPC protocol (Fig. 4).

Differences between protocols were statistically significant for between baseline and 5 min of application ($P < 0.003$) except HPC and LPR ($P < 0.165$). Between baseline and 5 min post-application, a statistically significant difference was found between HPR and HPC ($P < 0.019$), LPC and HPR ($P < 0.002$), HPR and LPH ($P < 0.002$). In the other protocols, no statistically significant difference was reached for baseline vs 5 min of application ($P > 0.353$).

Temperatures at the musculotendinous junction reached their highest values at 5 min of the HPR protocol, at 35.15 °C, which represented an 81.5% increase from the starting temperature. The protocol that caused the second-highest temperature increase (by 39.3%) was the HPC protocol, while the rest caused an increase of around 11.5%. However, at 5 min post-application of HPR, temperature decreased to 23.91 °C, which represented a 23.2% increase from baseline, but the HPC increased further, by 1.47 °C, reaching a final temperature of 28.8 °C, representing a 12.6% increase

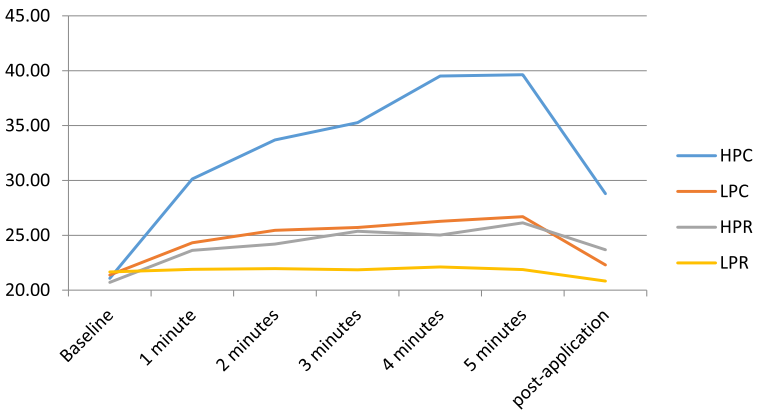

Fig. 3 Superficial temperature. HPC: high-power capacitive; LPC: low-power capacitive; HPR: high-power resistive; LPR: low-power resistive

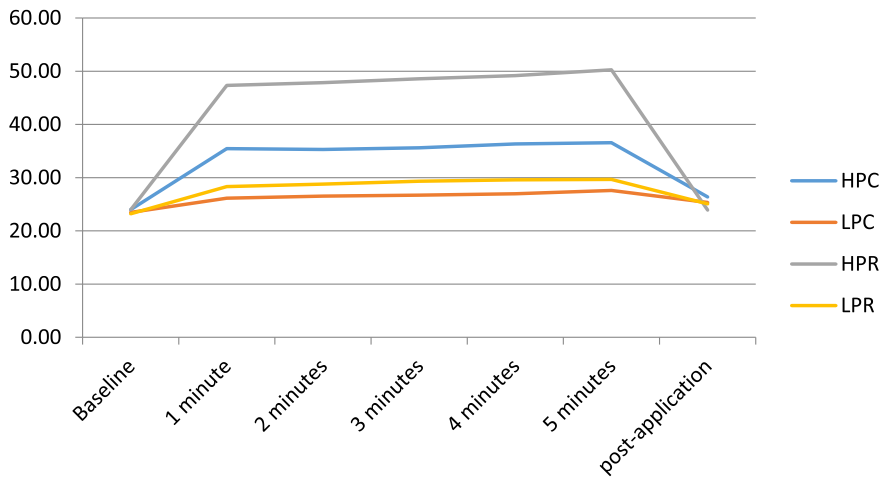

Fig. 4 Achilles tendon temperature. HPC: high-power capacitive; LPC: low-power capacitive; HPR: high-power resistive; LPR: low-power resistive

from baseline. In the other protocols, the increase was less than 5.3% (Fig. 5).

The differences between all protocols at the end of the application were statistically significant ($P < 0.004$) except between LPC and LPR ($P < 0.684$). The same was true for the difference at 5 min post-application, which reached statistical significance ($P < 0.023$) except between LPC and LPR ($P < 0.796$).

Discussion

CRet therapy is one of the methods that has been used in patients with Achilles tendonitis using both the resistive and capacitive modes. Other studies in living subjects have found improved pain levels and increased capillary permeability combining resistive and capacitive mode therapy in healthy male adults [22] and in athletes with different insertional tendonitis [9].

No studies on impedance variation in musculoskeletal tissue between living and cadaveric subjects have been found. It is most likely that the data between living and non-living subjects will vary due to the decrease in blood volume, modifying the resistance values of the tissues. Despite this, there are studies that find differences in impedance in the same subject [24–26] between both extremities [27]. In our study the impedance values in the same subject were similar within the same limb, but varied between limbs. It is likely that the data were slightly different and the temperature would have increased less in the living subjects due to the dispersion generated by the circulatory system.

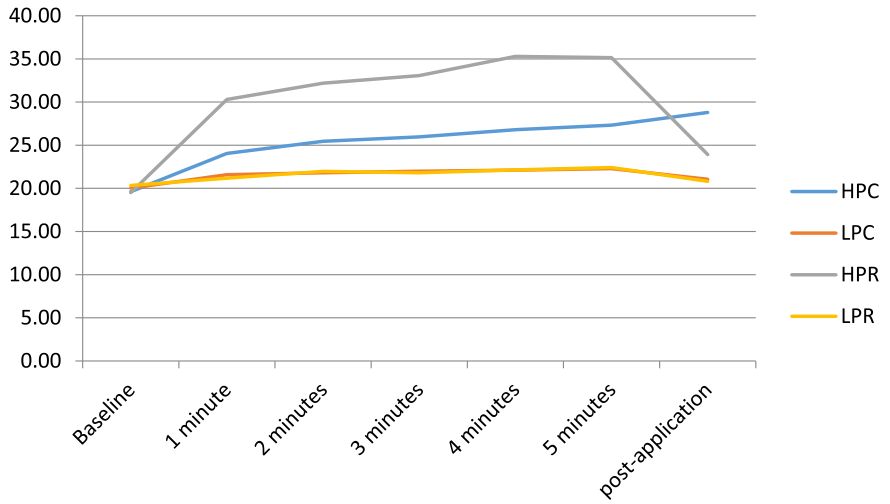

Fig. 5 Musculotendinous junction temperature. HPC: high-power capacitive; LPC: low-power capacitive; HPR: high-power resistive; LPR: low-power resistive

To our knowledge, this study is the first that evaluates the effects of CRet on temperature and electrical current in deep structures in cadavers. The main findings divided by protocol type are explained below.

Low-power capacitive

This protocol increases the superficial temperature with a small increase in Achilles tendon and musculotendinous junction temperature. However, despite the small thermal effect, we observed a current flow (0.039 A ± 0.02): this has been associated with cell proliferation in deep structures [14, 16]. This protocol could hypothetically be interesting in acute inflammatory Achilles tendinopathy or acute muscle strain in which it is important to increase cell proliferation [14, 16] and tissue reconstruction without increasing temperature too much [28].

Low-power resistive

This protocol is similar to the LPC; however, we can see that it has a lower superficial thermal effect, a greater thermal effect at the Achilles tendon and a similar effect at the musculotendinous junction. LPR has a greater current flow (0.063 A ± 0.02) than the LPC, which suggests it may be better at generating cell proliferation [14, 16]. This protocol could be useful in acute inflammatory Achilles tendinopathy or acute muscle strain in which it is important to improve cell proliferation [14, 16] and tissue reconstruction without increasing temperature too much [28]. Previous studies have reported good clinical results with a combination of capacitive and resistive modes [9, 22].

High-power capacitive

With this protocol, we found an increase in the thermal effect at all depths, especially superficial. In addition, we observed a high current flow (0.095 A ± 0.03), which is associated with a cell proliferation effect [14, 16]. This protocol may be useful in more chronic phases in which the main objective is to improve the viscoelasticity of tissues, especially in chronic tendinopathies or in fibrous scars after sprains such as “tennis leg” [28–30].

High-power resistive

This protocol achieved the greatest temperature increase at the Achilles tendon and musculotendinous junction. It also registered the highest current flow (0.120 A ± 0.03), which is associated with a cell proliferation effect [14, 16]. This protocol has a greater effect on deeper structures than HPC and could be combined with it to generate further increase in superficial temperature. It could be interesting to combine them if you want to work on chronic superficial and deep pathological structures of the same region [9, 22]. These thermal and current effects may generate mechanical effects on the viscoelastic properties of the structures, which are mainly related with chronic tendinopathies or fibrous scars after sprains [28–30].

Limitations

As this was a cadaveric study, in which the bodies did not have thermoregulatory blood circulation, it is possible that the effects in living subjects may be minor. It is likely that the living population would not have such a large temperature increase, as circulating blood dissipates heat toward adjacent areas, maintaining the temperature of the treated structures within the desired limits. This process avoids unwanted hyperthermia in nearby tissues, as well as excessive heat during treatment, which can be enough to cause a skin burn [13]. In this type of treatment, patient feedback is important; clearly in this study that was impossible. The temperature increase recorded in this study is probably higher that which would occur in living subjects. In addition, despite being fresh corpses, it is very likely that the muscular properties were not the same as those of living subjects and the average age of the corpses is considerably high compared to the average age of the patients who suffer injuries in this region. However, using body donors allowed us to measure the deep temperature, at the Achilles tendon and musculotendinous junction and make hypotheses about what happens when we apply these treatments in living real patients.

Conclusion

The low-power treatments had very little thermal effect on the Achilles tendon and musculotendinous junction, but current flow was observed. They may be useful in inflammatory pathologies in which increased temperature is not an objective.

The high-power treatments achieved a greater increase in Achilles tendon and musculotendinous junction temperature, and a greater current flow than the low-power treatments. HPR generated the greatest increase in Achilles tendon and musculotendinous junction temperatures. It may be useful in chronic pathologies in which an increase in deep temperature is desired, to generate viscoelastic changes in the structures.

Capacitive treatments, both low- and high-power, achieve a greater increase in superficial temperature.

More studies are needed in living subjects and other cadaveric studies with an artificial blood system to support these theories.

Abbreviations

CRet: Capacitive-resistive electric transfer; HPC: High-power capacitive; HPR: High-power resistive; LPC: Low-power capacitive; LPR: Low-power resistive

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Author's contributions
LdCC He performed the statistical analysis, the writing of results section and the calibration of the instruments. HGC made the intervention applications and wrote the discussion. PBA wrote the introduction section and he prepared the cadaver and performed superficial temperature measurements. FMP wrote part of the introduction, part of the methods and revised the manuscript. He was responsible for the registration of temperatures. GRV was in charge of the realization of the measuring points and the incisions in the cadavers. She Contributed to the writing of the results section too. JMTM contributed to the writing of the discussion section and the preparation of the manuscript. He contributed to the recording of temperatures too. OS made measurements of impedance and current flow. She contributed to the writing of the introduction section. JRS wrote and designed the methods section. He was in charge of ultrasound measurements. All authors have read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
The Ethics Committee "Comitè d'Ètica de Recerca (CER) from the Universitat Internacional de Catalunya (UIC Barcelona)" approved the study with CBAS201907 reference number.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Thermal and non-thermal effects of capacitive–resistive electric transfer application on different structures of the knee: a cadaveric study

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Capacitive–resistive electric transfer therapy is used in physical rehabilitation and sports medicine to treat muscle, bone, ligament and tendon injuries. The purpose is to analyze the temperature change and transmission of electric current in superficial and deep knee tissues when applying different protocols of capacitive–resistive electric transfer therapy. Five fresh frozen cadavers (10 legs) were included in this study. Four interventions (high/low power) were performed for 5 min by a physiotherapist with experience. Dynamic movements were performed to the posterior region of the knee. Capsular, intra-articular and superficial temperature were recorded at 1-min intervals and 5 min after the treatment, using thermocouples placed with ultrasound guidance. The low-power protocols had only slight capsular and intra-capsular thermal effects, but electric current flow was observed. The high-power protocols achieved a greater increase in capsular and intra-articular temperature and a greater current flow than the low-power protocols. The information obtained in this in vitro study could serve as basic science data to hypothesize capsular and intra-articular knee recovery in living subjects. The current flow without increasing the temperature in inflammatory processes and increasing the temperature of the tissues in chronic processes with capacitive–resistive electric transfer therapy could be useful for real patients.

Abbreviations

ROM	Range of motion
ACL	Anterior cruciate ligament
CRet	Capacitive–resistive electric transfer
HPC	High-power capacitive
LPC	Low-power capacitive
HPR	High-power resistive
LPR	Low-power resistive

The knee is one of the most frequently injured joints in physically active individuals[1–4]. Injury severity can range from asymptomatic injuries to damaged ligaments or menisci[5,6]. In the USA, anterior cruciate ligament injuries (ACL) are reported to occur in 250,000 individuals per year, with over 127,000 arthroscopic ACL reconstructions

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Location	ICC	SEM	MDD
Superficial	0.94	0.07	0.19
Capsular	0..90	0.06	0.17
Intra-articular	0.99	0.05	0.15

Table 1. Reliability of superficial, capsular and intra-articular temperature measurements. *ICC* Intra-class correlation coefficient, *SEM* Standard error of measurement, *MDD* Minimum detectable difference.

(ACLR) performed annually. ACL injuries are often not isolated: 43–70% of those undergoing ACLR have meniscal lesions, 20–25% have cartilage lesions (about 5% full-thickness) and over 80% have bone bruises[4,6–10].

Many post-surgical rehabilitation guidelines are based on time from surgery and permit individuals to return to sports-specific activities after 4–9 months[11]. However, they don´t take into account joint junction. Knee pain, joint swelling, stiffness, instability, weakness, and joint effusion, are common reasons many athletes cite for not returning to preinjury activity levels[12–14]. All these pathologies can alter knee motion[4,15,16].

Immobilization or limitation of range of motion (ROM) due to pain can induce joint contracture. This contracture may be influenced by two anatomical components around the joint: arthrogenic and myogenic components. Arthrogenic components, particularly of the joint capsule, are reported to be important factors in the formation of joint contractures. Previous studies have suggested that joint capsule fibrosis and overexpression of type I collagen occur and progress within 1 week after immobilization, and an increase in myofibroblasts is associated with this fibrosis[17], especially in the posterior knee capsule[18].

The increased concentration of type I collagen seen in capsular injuries causes a decrease in the ROM of the knee[19]. Thermosensitive hydrogels can absorb heat and provoke viscoelastic increased in this collagen. A temperature rise of 1 °C can have various effects on the human body, such as changes in nerve conduction velocity, enzyme activity and oxyhemoglobin release[20–23]. Tissue hypoxia results in tissue fibrosis and the production and release of algesic substances, causing pain, muscle spasm and joint contracture[24,25]. A temperature rise can improve oxygenated haemoglobin saturation[25].

Physical therapies based on electrical or electromagnetic stimulation have been used in rehabilitation. Capacitive–resistive electric transfer (CRet) therapy has been used in physical rehabilitation to treat muscle, bone, ligament and tendon injuries[26–29]. CRet is a non-invasive electrothermal deep therapy, which is based on the application of electric currents within the radio frequency range of 300 kHz–1.2 MHz. This therapy can generate warming of deep muscle tissues and improve hemoglobin saturation[25]. The physiological effects of this type of physical therapy are generated by the application to the human body of an electromagnetic field with a frequency of about 0.5 MHz. The effects attributed to this technique include increased deep and superficial blood circulation, vasodilation, increased temperature, elimination of excess fluid and increased cell proliferation[30]. Some of these reactions, such as the increase in blood perfusion, are known to be linked to the temperature increase, but others, such as enhanced cell proliferation, seem to be mainly related to the passage of current[30].

A previous article studied the changes in temperature with CRet vs hot pack. CRet was found to be more effective in treating musculoskeletal disorders than a hot pack. An important limitation that the authors discussed was that they used a non-invasive device to monitor deep tissue temperature instead of an invasive method using needles[25].

The purpose of our in vitro study was to analyze the effects of different CRet protocols on the thermal behavior and transmission of electric current in superficial and deep knee tissues, by performing invasive temperature measurements on cadaveric specimens.

Results

Reliability. Reliability coefficients for all temperature locations were excellent. Standard errors of measurement and minimum detectable differences at 95% confidence interval were small (Table 1).

Baseline measurements. Descriptive outcomes of superficial, capsular and intra-articular temperature are shown in Table 2. The starting temperatures showed no statistically significant differences between treatment protocols in any of the positions (superficial $p < 0.520$; capsular $p < 0.978$; intra-articular $p < 0.660$). The current flow was stable, with averages of 0.104 A ± 0.06 (High Power Capacitive, HPC); 0.056 A ± 0.02 (Low Power Capacitive, LPC); 0.205 A ± 0.09 (High Power Resistive, HPR) and 0.092 A ± 0.5 (Low Power Resistive, LPR).

All protocols showed a progressive increase in temperature at all depths, with subsequent decrease at 5 min post-application ($p < 0.001$ Friedman test), with the exception that the LPC and LPR treatments resulted in a slight decrease in temperature at 1 min in the intra-articular measurement and increased thereafter. LPR showed a slightly lower temperature than baseline at the 5 min post-application measurement.

Superficial temperature. The biggest increase in superficial temperature was found at the end of the treatment application in the HPC protocol: a superficial temperature of 37.95 °C, which represented an 84.2% increase from the starting temperature. However, this temperature decreased in the 5 min post-application to 28.25 °C, representing a 36.9% increase from baseline. The second highest superficial temperature was with HPR: 34.27 °C, representing a 65.4% increase from baseline. At 5-min post-treatment, the HPR protocol had the highest temperature, at 31.59 °C (52.4%), a decrease of 2.68 °C from the end of treatment, a milder decrease than the HPC that decreased 9.7 °C at the same measurement (Fig. 1).

	Baseline	1 min	2 min	3 min	4 min	5 min	5 min post-application
Superficial							
HPC	20.64 ± 1.25	27.71 ± 1.35	31.35 ± 1.54	34.35 ± 1.54	36.25 ± 1.80	37.95 ± 2.86	28.25 ± 2.14
LPC	20.47 ± 1.20	24.02 ± 1.20	26.21 ± 3.01	26.25 ± 1.55	27.13 ± 1.74	27.92 ± 1.83	22.73 ± 1.24
HPR	20.70 ± 0.96	26.60 ± 1.72	28.90 ± 2.42	31.05 ± 2.46	32.98 ± 2.74	34.27 ± 2.63	31.59 ± 3.12
LPR	19.95 ± 1.36	21.91 ± 1.35	22.32 ± 1.40	23.61 ± 3.56	22.91 ± 1.23	23.39 ± 1.27	22.02 ± 1.56
Capsular							
HPC	22.70 ± 1.55	24.73 ± 1.77	25.00 ± 1.88	25.46 ± 2.11	26.89 ± 2.27	26.29 ± 2.35	25.94 ± 1.89
LPC	22.67 ± 1.44	23.83 ± 1.38	24.14 ± 1.45	24.38 ± 1.41	24.55 ± 1.49	24.68 ± 1.54	24.77 ± 1.48
HPR	22.86 ± 1.38	28.12 ± 3.75	29.88 ± 4.18	31.35 ± 4.88	32.48 ± 5.28	34.22 ± 5.98	31.24 ± 4.00
LPR	22.79 ± 1.53	24.39 ± 1.81	24.87 ± 1.88	25.24 ± 2.00	25.54 ± 2.19	25.91 ± 2.26	25.47 ± 1.95
Intra-articular							
HPC	21.23 ± 2.65	23.38 ± 2.42	23.80 ± 2.75	24.10 ± 2.93	24.40 ± 3.08	24.73 ± 3.17	22.50 ± 1.65
LPC	22.15 ± 2.14	21.33 ± 1.79	21.49 ± 1.77	21.56 ± 1.79	21.67 ± 1.82	21.72 ± 1.84	21.19 ± 1.50
HPR	21.00 ± 2.48	24.55 ± 3.34	25.69 ± 4.12	26.51 ± 4.73	27.16 ± 5.05	28.14 ± 5.63	24.55 ± 3.71
LPR	21.88 ± 1.94	21.83 ± 1.34	22.10 ± 1.43	22.28 ± 1.48	22.45 ± 1.61	22.62 ± 1.67	21.45 ± 1.58

Table 2. Descriptive outcomes: temperature (°C). *HPC* high-power capacitive, *LPC* low-power capacitive, *HPR* high-power resistive, *LPR* low-power resistive.

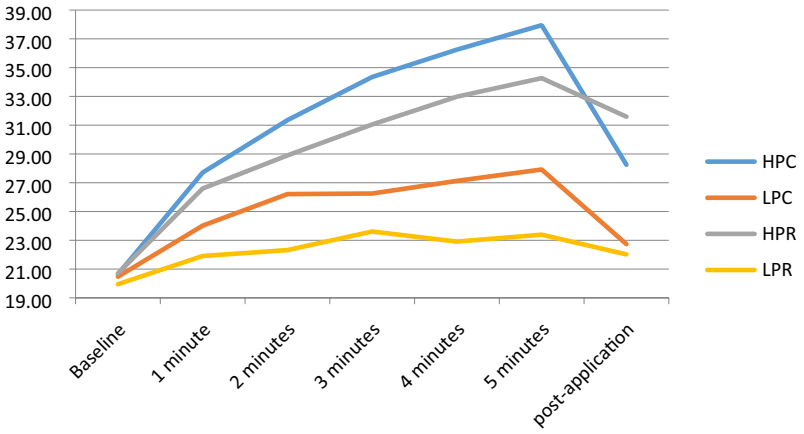

Figure 1. Superficial temperature. HPC high-power capacitive, LPC low-power capacitive, HPR high-power resistive, LPR low-power resistive.

The other two interventions (LPR and LPC) had lower percentage increases: 36.4% for LPC and 17.4% for LPR. These two protocols also had less of a temperature increase than the HPC and HPR at the post-application assessment, at 11.1% for LPC and 10.5% for LPR. There were statistically significant differences between the protocols for the difference between baseline and 5 min (of treatment) and between baseline and 5 min post-treatment, with the exception of the difference between LPC and LPR for baseline vs 5 min post-treatment ($p < 0.579$).

Capsular temperature. In capsular temperature, HPR produced the biggest increase at 5 min: 34.22 °C, representing a 49.3% increase from baseline. This value decreased 2.98 °C in the 5 min post-treatment. In the other interventions, there was less of a temperature increase, the maximum being a 15.9% increase in the HPC protocol (Fig. 2).

Differences between HPC and LPC ($p < 0.043$), HPC and HPR ($p < 0.001$), LPC and HPR ($p < 0.001$) and between HPR and LPR ($p < 0.001$) were statistically significant. In the other interventions, no statistically significant difference was reached for baseline vs 5 min of treatment. A statistically significant difference was found between baseline and 5 min post-application, for HPR vs all other protocols ($p < 0.001$).

Intra-articular temperature. The intra-articular temperature reached its highest value at 5 min with the application of HPR: 28.14 °C, representing a 34.3% increase from baseline. The second highest increase was 17.9 °C with HPC, and a decrease was even seen with LPC, of 0.43 °C, representing a 1.6% decrease. At

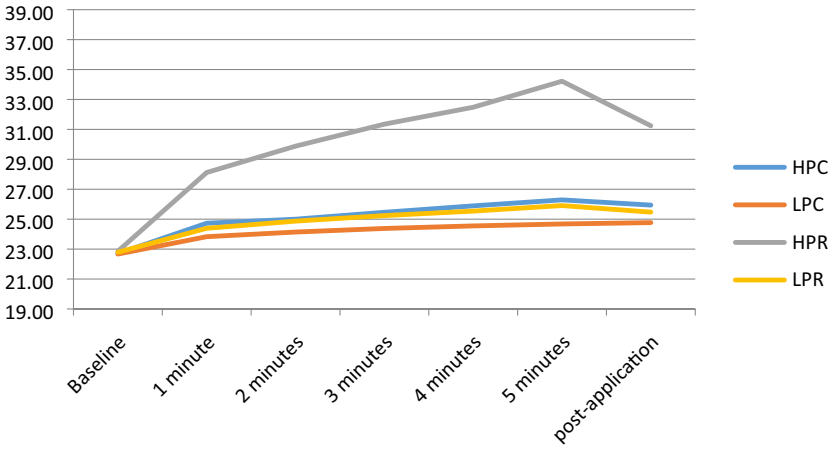

Figure 2. Capsular temperature. HPC high-power capacitive, LPC low-power capacitive, HPR high-power resistive, LPR low-power resistive.

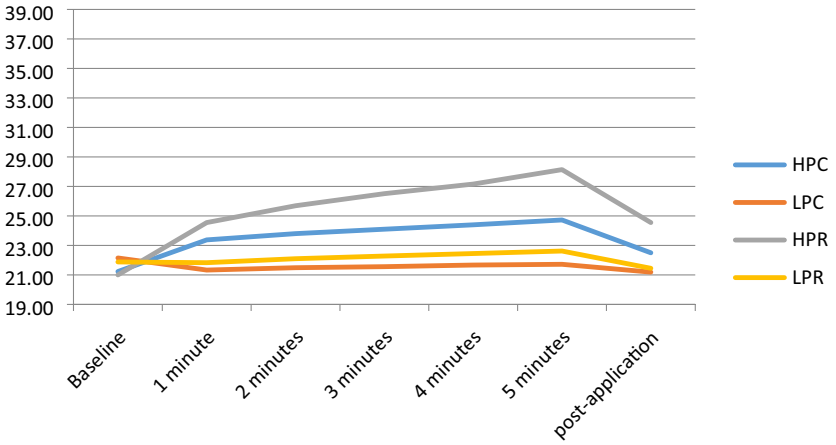

Figure 3. Intra-articular temperature. HPC high-power capacitive, LPC low-power capacitive, HPR high-power resistive, LPR low-power resistive.

5 min post-application, temperature increased by 17.1% with HPR while with HPC it increased only 6.6%. LPC decreased by 4%, and LPR decreased by 1.8% (Fig. 3).

Differences were statistically significant between HPC and LPC ($p < 0.007$), LPC and HPR ($p < 0.001$), and HPR and LPR ($p < 0.001$) at 5 min of application. Differences between the other interventions did not reach statistical significance at this point. At 5 min post-application, there were statistically significant differences between HPC and LPC ($p < 0.023$), HPC and HPR ($p < 0.019$), LPC and HPR ($p < 0.001$) and HPR and LPR ($p < 0.001$).

Discussion

As far as we know, this study is the first that evaluates the effects of CRet on temperature and current in deep structures in cadavers. The main findings divided by the protocol used are explained below.

At the end of treatment (5 min of treatment), Low-power capacitive obtained a 7.45 °C (35.40%) increase in superficial temperature, a 2.01 °C (8.96%) increase in capsule temperature and a 0.43 °C (1.62%) decrease in intra-articular temperature. This protocol slightly increases the superficial temperature without increasing the capsular or intra-articular temperature. However, despite the non-thermal effect, we observed a current flow (0.056 A ± 0.02), which has previously been shown to be related to cell proliferation in deep structures[30,31]. Recent literature reported that this type of application could be interesting in acute inflammatory intra-articular pathologies in which it is important to improve cell proliferation[30,31] and tissue reconstruction without increasing the temperature, for example in ACL injury[4,6–10,25], or even the treatment of scars[32].

At 5 min of treatment, Low-power resistive obtained a 3.44 °C (17.48%) increase in superficial temperature, a 3.12 °C (13.69%) increase in capsule temperature and a 0.74 °C (3.81%) increase in intra-articular temperature.

This type of application is similar to the LPC, however we can see that it has a lower superficial thermal effect and a non-thermal capsular and intra-articular effect with a greater current flow (0.092 A ± 0.5) than LPC[30,31,33]. This treatment may be useful in intra-articular pathologies, to increase cell proliferation[30,31] with very little temperature change. It could be indicated for early intra-articular or capsular rehabilitation phases as reported in the literature[4,6–10,25].

At 5 min, High-Power capacitive obtained a 17.31 °C (84.22%) increase in superficial temperature, a 3.59 °C (15.90%) increase in capsule temperature and a 3.50 °C (17.96%) increase in intra-articular temperature. With this protocol, we found an increase in temperature at all depths, especially the superficial level. In addition, we observed a high current flow (0.104 A ± 0.06), which is known to be associated with a cell proliferation effect[30,31]. This application could be interesting in more chronic phases in which the main objective is to improve the viscoelasticity of tissues, especially the capsule and ligaments, since, as reported in the literature, these structures are directly related to limitation of ROM after prolonged immobilization or chronic pathologies[17,18,25].

At 5 min, High-Power resistive obtained a 13.57 °C (65.42%) increase in superficial temperature, an 11.36 °C (49.13%) increase in capsule temperature and a 7.14 °C (34.26%) increase in intra-articular temperature. This setting achieved the greatest increase in temperature in the capsule and intra-articular structures. It also recorded the highest current flow (0.205 A ± 0.09), which has been associated with a cell proliferation effect[30,31,33]. This application has a greater effect on deep structures than HPC and could be combined with it. The thermal and current effect may generate mechanical effects on the viscoelastic properties of the structures, which are associated with pain and loss of ROM[17,18,25].

Conclusion

The low-power treatments demonstrated minimal capsular and intra-capsular thermal effects, but an electric current flow was observed. These low-power CRet protocols could be indicated for treatments in inflammatory pathologies in which a temperature increase is not of interest.

High-power treatments achieved a greater increase in capsular and intra-articular temperature and a higher current flow than low-power treatments. HPR gave the highest capsular and intra-capsular temperatures. It could be indicated for treatment in chronic pathologies in which it is desirable to increase the deep temperature to generate viscoelastic changes in deep structures.

Low- and high-power capacitive treatments achieve a greater increase in superficial temperature.

More studies are needed in living subjects to support these findings.

Limitations

The results of this study on cadavers may differ from studies on living subjects. Functional thermoregulation mechanism was not possible in our sample and it is probable that tissues from living subjects may experiment less increase of temperature as circulating blood would dissipate the heat throughout adjacent body areas. This thermoregulation and the patient feedback also ease avoiding an unwanted hyperthermia and a potential burning of the skin[25]. In addition, despite being fresh corpses, it is very likely that the capsular and muscular properties were not the exactly the same as those of living subjects. Nonetheless, this in vitro study with cryopreserved cadavers allowed to measure the tissue temperature in the deep tissues of the knee joint and to make hypothesis about what happens when the CRet therapies are applied in living real patients.

Methods

Study design. This was a cross-sectional study designed to determine the effect of resistive energy/electrical capacitive transfer of the T-Plus Wintecare device on temperature in the intra-articular, capsular and superficial region of the knee in cadaveric specimens. The body donor program of the Faculty of Medicine and Health Science of Universitat Internacional de Catalunya (UIC) provided all specimens. Permission for the use of the cadavers in the study was obtained from the Anatomy Lab of this university. A local committee (CER, Comite d'Ètica de Recerca, UIC) approved the study.

Cadaveric specimens. The study sample included 5 fresh frozen cadavers, 4 males and 1 female (10 legs). The mean age at the time of death was 69.80 ± 6.04 years. The cadavers were stored at 3 °C and brought to room temperature before testing. None of the cadavers used for this study had evidence of trauma or surgical scars on the limbs.

Intervention. To simulate the conditions of a real CRet clinical application and to understand the consequent temperature change and the passage of electric current, we used a T-Plus model with similar power limits as applied during treatments with real patients. This was based on the power level, which is easily identifiable and controllable by the therapist during therapy, and the watts (the absorbed power) shown by the device during the application[34].

The power range of a very large T-Plus device ranges from 1 to 300 watts in resistive mode and from 1 to 450 VA in capacitive mode.

Two thresholds were identified for *high power* and *low power,* based on the real powers that the therapist typically applies when he/she wants to induce a thermal or non-thermal reaction, respectively. CRet therapy provides two different treatment modes: capacitive and resistive. Both treatment modes induce different tissue responses depending on the resistance of the treated tissue[34]. Capacitive mode is provided with an insulating ceramic layer and the energetic transmission generates heat in superficial tissue layers, with a selective action in tissues with low-impedance (water rich)[34]. Resistive mode has no insulating ceramic layer, the radiofrequency energy passes directly through the body in the direction of the inactive electrode, generating heat in the deeper

Figure 4. Intervention with T-Plus Wintecare.

and more resistant tissues (with less water content)[34]. Based on this, *high power* was defined as application at **130 VA in capacitive mode** (HPC) **and 100 watts in resistive mode** (HPR), while *low power* was defined as application at **50 VA in capacitive mode** (LPC) **and 20 w in resistive mode** (LPR). Compared to the average real-life use, these low-power thresholds (20 w; 50 VA) respect the limit of 0.3 A, while the high-power thresholds (100 watts; 130 VA) will be above 0.3 A and therefore expected to generate thermal effects.

The 4 interventions (capacitive and resistive mode; low- and high-power) were performed for 5 min each, by a physiotherapist with experience in the use of T-Plus. The time of application was established in a previous study, similar to the one carried out[34]. Dynamic movements similar to those used with real patients were performed with constant pressure to the posterior region of the knee (Fig. 4). For the resistive applications conductive cream was applied during the treatment. For capacitive applications no cream was applied during treatment.

Experimental procedures. Each cadaver was placed in the prone position. The hips were positioned in a neutral rotation, the knee in 30° of flexion, and the ankle joint position was maintained using a thermoplastic splint.

The order of the 4 treatment protocols was previously randomized, as was as the specimen (leg). For the randomization process, an external evaluator generated a random assignment list before the study begins with a computer program (www.random.org) that generated a list of sequential numbers. The temperature generated in the cadaver was allowed to return to baseline before the next treatment was applied.

All instrumentation received a calibration certificate prior to this study. Thermocouples "Hart Scientific PT25 5628–15" were used to monitor the intra-articular and capsular temperature (°C) of the knee. A digital thermometer "Thermocomed" was used to measure the superficial temperature (Fig. 5a). The thermocouples were placed under ultrasound guidance "US Aloka Prosound C3 15.4", with a high-frequency linear transducer (USTTL01, 12L5), by an expert in the use of the instrument (Fig. 5b)[34]. The deeper thermocouple was placed intra-articularly and the other in contact with the posterior tibiofemoral capsule (Fig. 5c).

The return electrode of the T-Plus was placed on the abdomen of the specimen and the treatment was carried out with the movable electrode of the T-Plus on the back of the knee for 5 min. The superficial, capsular and intra-articular temperatures were measured. These measurements were recorded at 1-min intervals for 5 min, then at 5 min after the end of each treatment. Prior to the treatment, impedance was always measured (Multimeter Fluke 8846A) to ensure that the values marked by the T-Plus Wintecare device were correct. In addition, the current flow of each application was calculated (average voltage divided by the initial impedance)[34].

Statistical analysis. Analyses were performed using SPSS Statistics version 22.0.

The intra-class correlation coefficient (ICC) at a 95% confidence interval (CI), the standard error of measurement (SEM) and the minimum detectable difference (MDD) were calculated for the superficial, capsule and intra-articular temperature measurements. The following interpretation of ICCs was considered (0.00 to 0.25 = little to no relationship, 0.26 to 0.50 = fair degree of relationship, 0.51 to 0.75 = moderate to good relationship, and 0.76 to 1.00 = good to excellent relationship)[35].

The normality of the distribution was assessed with the Shapiro–Wilk test ($p > 0.05$). Mean and standard deviation of the superficial, intra-articular and capsular temperature were calculated.

The percentages of temperature change respect to baseline temperature were calculated.

The Friedman test and Wilcoxon signed-rank test were used for intra-treatment differences. The Kruskal–Wallis test and Mann–Whitney U test were performed for between-treatment comparisons. A p value < 0.05 was considered statistically significant[34].

Ethics approval. The Comité d´Ètica de Recerca from Universitat Internacional de Catalunya approved the study (CBAS 2019-07). The investigation conformed with the principles outlined in the Declaration of Helsinki. The informed consent from "body donors" was obtained before the death and any personal data was hidden.

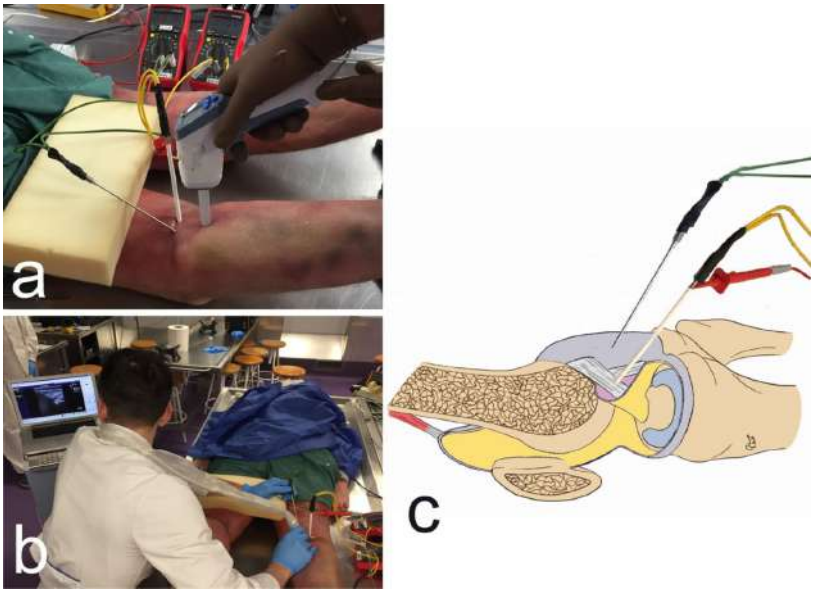

Figure 5. (**a**) Temperature measurement with digital thermometer, (**b**) Thermocouple placement under ultrasound guidance, (**c**) Thermocouple placement.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions
All authors have read and approved the manuscript. J.R.S. wrote and designed the methods section. He was in charge of ultrasound measurements. A.P.B. wrote the introduction section and he prepared the cadaver and performed superficial temperature measurements. L.dC.C. He performed the statistical analysis, the writing of results section and the calibration of the instruments. L.L.O.M. wrote part of the introduction, part of the methods and revised the manuscript. He was responsible for the registration of temperatures. V.G.R. was in charge of the realization of the measuring points and the incisions in the cadavers. She Contributed to the writing of the results section too. T.M.J.M. contributed to the writing of the discussion section and the preparation of the manuscript. He contributed to the recording of temperatures too. M.S. made measurements of impedance and current flow. She contributed to the writing of the introduction section. C.H.G. made the intervention applications and wrote the discussion.

Competing interests
The authors declare no competing interests.

Additional information
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Article

Thermal and Current Flow Effects of a Capacitive–Resistive Electric Transfer Application Protocol on Chronic Elbow Tendinopathy. A Cadaveric Study

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Abstract: Lateral elbow tendinopathy, or "tennis elbow," is a pathology that affects around 1.3% of the general population. Capacitive–resistive electric transfer therapy aims to provoke temperature and current flow changes in superficial and deep tissues. The aim of this in vitro study was to analyze the thermal behavior and transmission of electric current on the superficial and deep tissues of the elbow during the application of different modalities of a capacitive–resistive electric transfer treatment protocol for chronic elbow tendinopathy. A cross-sectional study was designed; five fresh cryopreserved cadavers (10 elbows) were included in this study. A 30 min intervention was performed based on a protocol commonly used in clinics for the treatment of chronic lateral elbow tendinopathy by diathermy using the "T-Plus." Common extensor tendon, radiohumeral capsule, and superficial temperatures were registered after each application for the duration of the 30 min treatment protocol. During all applications, we observed a current flow of over 0.03 A. The protocol showed a statistically significant increase in superficial temperature by 24% (5.02°) ($p < 0.005$), the common extensor tendon by 19.7% (4.36°) ($p < 0.007$), and the radiohumeral joint capsule by 17.5% (3.41°) ($p < 0.005$) at the end of the 30 min protocol compared with the baseline temperature. The different applications of the protocol showed specific effects on the temperature and current flow in the common extensor tendon and radiohumeral capsule. All applications of the protocol produced a current flow that is associated with the generation of cell proliferation. These results strengthen the hypothesis of cell proliferation and thermal changes in deep and distal structures. More studies are needed to confirm these results.

Keywords: tennis elbow; cadaver; diathermy; physical therapy

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1. Introduction

Lateral elbow tendinopathy, or "tennis elbow," is a pathology that affects around 1.3% of the general population, with equal affectation in men and women [1]. People in manual labor, those who use vibration tools, and throwing athletes have a greater risk of suffering this pathology [2]. Lateral elbow tendinopathy is primarily caused by repeated stress in the extensor tendon, in particular the extensor carpi radialis brevis, although it can also be caused by direct traumatism or overstretching [2,3]. Although the pathophysiological mechanism of tendinopathy has not been elucidated, it is believed that chronic tendinopathy is produced by a degenerative mechanism of the extensor tendon. This happens through hypoxia and tendon fibrosis, which could lead to the formation of

calcium deposits [3]. As a result of this tissue hypoxia, fibrosis and the liberation of algesic substances occur, causing pain and muscle spasm [4,5].

Vascular supply is an important component in the repair of the tendon tissue [6]. Studies performed in animals have shown that the interruption of vascular supply in the tendon produces changes, for instance, in the fascicles of the tendon or in the collagen strands. These adaptations caused by the change of vascular supply in an animal's tendon are similar to those observed in human chronic tendinopathy [7,8].

For this reason, different rehabilitation techniques attempt to increase the blood supply of the musculotendinous tissue by increasing the temperature. Different studies have shown that increasing the temperature by 1 °C also increases the nerve conduction velocity, the enzymatic action, and the release of oxyhemoglobin [9–12].

Capacitive–resistive energy transfer (CRet) therapy is a noninvasive electrothermal therapy classified as deep thermotherapy, which is based on the application of an electric current in the radio frequency range of 300 kHz–1.2 MHz. This type of therapy can generate the heating of deep muscle tissue, which simultaneously improves the hemoglobin saturation [5]. The physiological effect of this type of therapy is generated by the application of an electromagnetic field in the human body with a frequency of approximately 0.5 MHz [13]. The effects attributed to this technique include increased deep and superficial blood flow, vasodilation, increased temperature, removal of excess liquid, and increased cell proliferation [14,15].

It has been observed that increase in blood perfusion is related to increase in temperature, but others, like cell proliferation, seem to be primarily related to current flow [14,15]. It has been proven that cell proliferation begins at 0.00005 A per square millimeter of current flow [15].

There are clinical publications that support the use of CRet therapy, although the amounts of energy and current that must be transferred to obtain the desired changes in temperature and current flow are unknown. Furthermore, the control of these reactions is still highly based on the empirical experience of the therapist [5,16–18]. There are only two in vitro studies that analyzed changes in temperature and current flow in cadavers [13,19]. These studies analyzed these variables in the Achilles tendon and myotendinous junction [13] and in the different structures of the knee [19] by applying different capacitive and resistive programs at high and low powers for 5 min [13]. Nevertheless, no study to date has studied changes in current flow and temperature when a standardized treatment protocol for chronic elbow tendinopathy is applied. These inconveniences engender the interest in performing in vitro studies to validate the therapeutic effects of frequently applied clinical protocols.

The aim of this in vitro study was to analyze the thermal behavior and transmission of electric current in the superficial and deep tissues of the elbow during the application of different modalities of a CRet treatment protocol for chronic elbow tendinopathy.

2. Materials and Methods

2.1. Study Design

An experimental in vitro study was designed to determine the effect of a CRet treatment protocol for chronic elbow tendinopathy, using the "Wintecare T-Plus" device, on temperature and electric current. The body donation program of the Facultad de Medicina y Ciencias de la Salud de la Universitat Internacional de Catalunya provided all the cadavers. This study was approved by the ethics committee "Comitè d'Ètica de Recerca (CER) de la Universitat Internacional de Catalunya" with reference number CBAS-2019-18.

2.2. Anatomic Sample

The anatomic sample was composed of 10 elbows from 5 cryopreserved full cadavers (3 men and 2 women). The corpses were stored at −16 °C and were kept at room temperature for 48 h until the day of the study. The mean age of the cadavers was 80.6 ± 14.6.

None of the cadaveric specimens used for this study had evidence of traumatic injuries or surgical scars in the upper extremities [20].

2.3. Intervention

A 30 min intervention was performed based on a CRet protocol commonly used in clinics for the treatment of chronic lateral elbow tendinopathy (Figure 1). Throughout the whole treatment, the therapist could identify and control the power level used during the therapy and the watts (the absorbed power) shown by the device during the application. A T-Plus device application range varies from 1 to 300 watts in the resistive mode and from 1 to 450 VA in the capacitive mode [13].

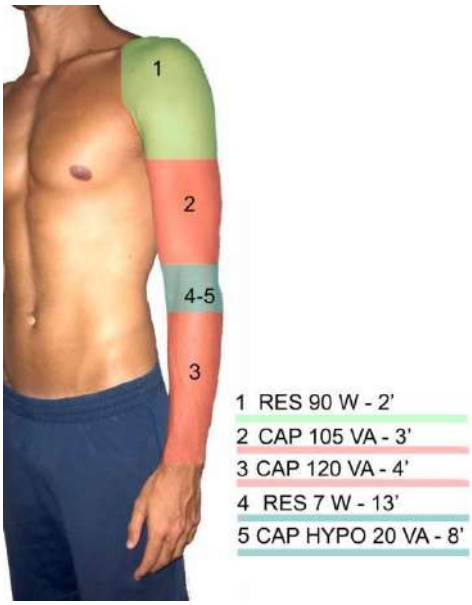

Figure 1. Applications used during the protocol. RES, resistive; W, watts; CAP, capacitive; VA, volt-amperes; CAP HYPO, hypothermic capacitive.

The protocol consists of different applications. During the first 2 min, a resistive application of 90 W in the shoulder region was applied. This application was made with the clinical aim of generating an increase in blood perfusion. In the next 3 min, a capacitive application of 105 VA within the bicep brachialis region was applied. The clinical aim of this application was to generate vasodilation [13]. Afterwards, a capacitive application of 120 VA was applied for 4 min. In this case, the aim was to increase the temperature in the muscle bellies of the wrist extensors [13]. Subsequently, the main treatment was applied in the lateral epicondyle region of the elbow with a resistive approach of 7 W [13]. The purpose of this part of the protocol was to repair the tissue through cell proliferation caused by the current flow. Finally, a capacitive application of 20 VA was implemented for 8 min in the elbow region with a hypothermic electrode. The objective of this last application was to normalize the temperature and generate tissue drainage.

Dynamic movements were made, similar to those applied in real patients, with a constant pressure. The treatments were made by a physiotherapist with experience in the utilization of the T-Plus.

2.4. Experimental Procedure

Each cadaver was placed in supine position with their forearms in pronation, slight elbow flexion, and neutral shoulder flexion/extension.

The order of the protocol application on the arms of each cadaver was randomly assigned prior to the start of the study. This randomization was done by an external

investigator using the web program "random.org." Before the treatment application, it was ensured that each cadaver's basal temperature was stable.

All of the instrumentations used in this study possessed a calibration certificate. "Hart Scientific PT25 5628-15" thermocouples were employed to measure the temperature (°C) of the common extensor tendon in its proximal insertion and the radiohumeral capsule (Figure 2). A "Thermocomed" digital thermometer was used to measure the surface temperature of the elbow region. The invasive thermocouples were set by an investigator with sonographic experience with the help of a "U.S. Aloka Prosound C3 15.4" ultrasound with a high-frequency linear transducer (USTTL01, 12L5).

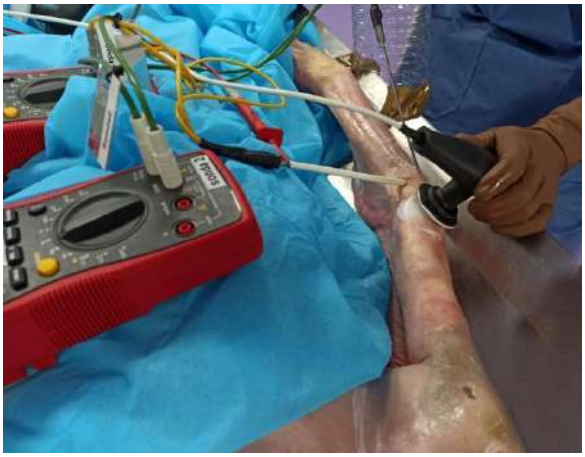

Figure 2. Invasive placement of the thermocouples in the common extensor tendon and the radiohumeral capsule.

The return electrode of the CRet equipment was placed in the lumbar region of the cadavers. The treatment was performed using the hand electrode of the CRet equipment according to the previously described treatment protocol. The initial superficial temperature and the common extensor and radiohumeral capsule temperatures were measured to establish a baseline. These measurements were also registered after each application for the duration of the 30 min treatment protocol. Before the treatment, the impedance (Multimeter Fluke 8846A) was always measured to guarantee that the values shown by the T-Plus Wintecare device were correct. Furthermore, the current flow was calculated in each application using the average voltage divided by the initial impedance.

2.5. Statistical Analysis

The statistical analysis was realized by using the SPSS Statistics software (IBM, Armonk, NY, USA) for Windows. The normality of the distribution was calculated using the Shapiro–Wilk test ($p > 0.05$). The mean, standard deviation, and percentage of change in the superficial, common extensor tendon, and radiohumeral capsule temperatures at the end of each part of the protocol were measured.

The differences between the application moments were calculated using the Wilcoxon test. A $p < 0.05$ value was considered statistically significant.

3. Results

Descriptive outcomes in the common extensor tendon and radiohumeral joint capsule are shown in Table 1 and Figure 3.

Table 1. Descriptive outcomes of the superficial, common extensor tendon (tendon), and radiohumeral capsule (capsule) temperatures.

	Baseline	RES 90 W 2′	CAP 105 VA 3′	CAP 120 VA 4′	RES 7 W 13′	CAP HYPO 20 VA 8′
Superficial	20.95 ± 1.69	20.77 ± 1.76	20.74 ± 1.73	23.22 ± 3.77	26.60 ± 4.27	25.97 ± 2.00
Tendon	22.11 ± 1.95	22.56 ± 1.78	24.87 ± 6.96	25.08 ± 5.54	28.27 ± 4.99	26,47 ± 2.78
Capsule	19.53 ± 3.18	19.02 ± 2.07	20.57 ± 3.83	24.88 ± 11.44	24.08 ± 3.53	22.94 ± 2.48

Abbreviations: RES, resistive; W, watts; CAP, capacitive; VA, volt-amperes; CAP HYPO, hypothermic capacitive.

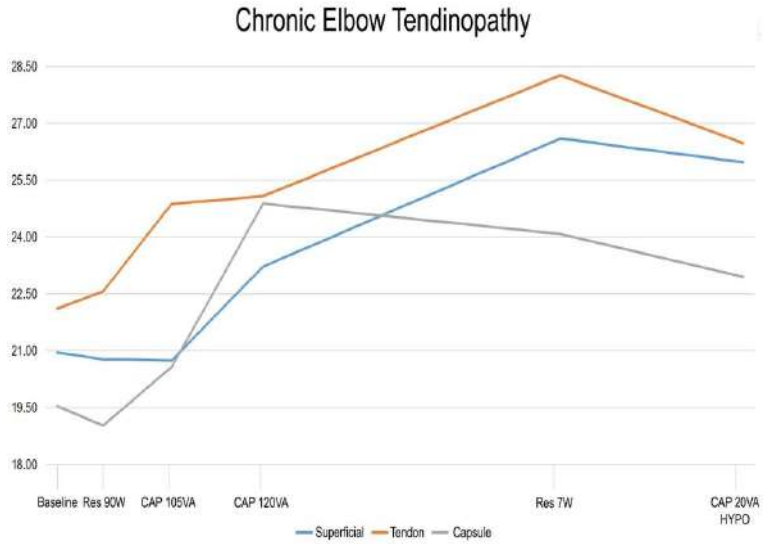

Figure 3. Graphic of the temperature variation during the whole treatment protocol. RES, resistive; W, watts; CAP, capacitive; VA, volt-amperes; CAP HYPO, hypothermic capacitive.

The current flows during the different parts of the protocol were 0.34 ± 0.22 A (RES 90 W), 0.14 ± 0.57 A (CAP 105 VA), 0.17 ± 0.46 A (CAP 120 VA), 0.24 ± 0.11 A (RES 7 W), and 0.12 ± 0.03 A (CAP 20 VA).

The application showed a statistically significant increase in temperature in all the evaluated points at the end of the 30 min protocol compared with the baseline temperature. The superficial temperature increased by 24% (5.02°) ($p < 0.005$), the common extensor tendon by 19.7% (4.36°) ($p < 0.007$), and the radiohumeral joint capsule by 17.5% (3.41°) ($p < 0.005$).

In the first two applications, the superficial temperature presented a slight drop of 0.18° and a progressive increase during the next two applications. The CAP 120 VA application was the only application that obtained a statistically significant difference ($p < 0.005$) compared with the baseline value with an increase of 2.48° of the superficial temperature. During the application of CAP 20 VA, a nonsignificant decrease in temperature of 0.63° was observed.

The temperature of the common extensor tendon increased during the duration of the protocol, except for the last application (CAP 20 VA), which registered a drop of 1.80°, reaching a statistically significant difference ($p < 0.007$). The other applications of the protocol achieved an increase between 0.21° and 3.19°. A statistically significant difference was attained with the RES 90 W application (0.45°, $p < 0.007$) and CAP 105 VA (2.31°, $p < 0.011$).

The radiohumeral capsule showed a slight decrease in the RES 90 W application from the baseline temperature, with a 0.51° drop, that did not reach a statistically significant difference ($p < 0.476$). A drop in temperature was also observed in the last two applications,

RES 7 W with a statistically insignificant decrease of 0.80° ($p < 0.386$) and CAP 20 VA with a statistically significant drop of 1.14° ($p < 0.005$). A rise in temperature was found during the CAP 105 VA (1.55°) and CAP 120 V (4.31°) applications. These applications reached statistically significant differences of $p < 0.019$ and $p < 0.028$, respectively.

In Figure 3, the progression of the temperature in the different tissues throughout the whole protocol can be observed.

4. Discussion

The different applications used during the CRet treatment protocol in this in vitro study produced variable responses and specific effects in temperature and current flow in the common extensor tendon and radiohumeral capsule. As far as the authors know, there are no current studies regarding these variables in the elbow region, neither in cadavers nor in alive subjects.

During all the applications, we observed a current flow of over 0.03 A, which indicates that the application would be capable of generating cell proliferation in the measured structures (extensor tendon of the elbow and radiohumeral capsule) [13–15].

The objective of the first application (application 1 in Figure 1—RES 90 W) was to generate a rise in blood perfusion in the adjacent tissues of the elbow. We observed a significant increase in temperature in the common extensor tendon of the elbow despite the application site in the shoulder region. These findings might sustain the theory that this phenomenon happens due to the rise in temperature being directly related to the current flow and increase in blood perfusion because of the Joule effect [21].

During the second application (application 2 in Figure 1—AP 105 VA), the aim was to generate vasodilation in the bicep brachialis region, a structure adjacent to the elbow. We observed a significant rise in temperature at the common extensor tendon and radiohumeral capsule, which is directly related to vasodilation [5,15].

Next, the application on the forearm was carried out (application 3 in Figure 1—CAP 120 VA) with the objective of increasing the temperature and massaging the extensor muscles without influencing the extensor tendon. The objective of this application was to generate an increase in temperature. We observed a significant rise in the superficial and radiohumeral capsule temperatures. Different studies indicate that these types of applications can be useful for the treatment of chronic tendinopathies [13], or fibrosed scars after muscular ruptures, due to the rise in temperature being related to an improvement in tissue viscoelasticity [13,22].

The low-power resistive application (application 4 in Figure 1—RES 7 W) had the longest duration. Its objective was to generate repairment of the affected tissue, so it was directly applied to the lateral epicondyle area. During the application, no significant temperature change was observed, which is a typical finding for low-power applications [13,23]. This application generated the largest current flow with a lower increase in temperature, which is directly related to a rise in cell proliferation and tissue regeneration [13–15], a fundamental factor for tendinopathy recovery [13]. Previous studies obtained positive clinical results when resistive and capacitive applications were combined [17,24], similarly to our protocol. However, we cannot compare the obtained results due to the absence of previous bibliography.

The capacitive hypothermic application (application 5 in Figure 1—CAP 20 VA) was the last application. Its goal was to generate drainage and reduce the temperature. Our results showed a significant decrease in temperature in the common extensor tendon of the elbow and radiohumeral capsule. To date, this effect has only been empirically hypothesized, and no study has validated the hypothermic electrode application. Nonetheless, although more research is needed, it seems that these preliminary data could support the clinical reduction of temperature with this application.

5. Limitations

This study presents several limitations. First, this study was performed in cadavers, which have no thermoregulation or active blood flow. This factor probably influenced the temperature rises because thermoregulation causes heat dissipation in alive human beings. This effect would help avoid unwanted hyperthermia during treatment in real patients [5]. Another limitation is that even though the cadavers were cryopreserved, the muscle and tendinous properties could vary compared with those of alive subjects. The average age of the used corpses was relatively high. Despite that, the authors considered that the use of the donors' bodies allowed them to know how a clinically utilized CRet protocol affects the temperature and current flow values in the common extensor tendon and radiohumeral capsule, something that is nonviable in alive subjects. More studies are needed to confirm these effects clinically. There are several CRet protocols for the treatment of lateral elbow pain, so the results of this study cannot be extrapolated to all applications.

6. Conclusions

The different applications of the CRet protocol showed specific effects on the temperature and current flow in the common extensor tendon and radiohumeral capsule. All applications of the protocol produced a current flow that is associated with the generation of cell proliferation. The RES 90 W and CAP 105 VA applications significantly increased the temperature of the common extensor tendon. CAP 105 and CAP 120 VA significantly increased the temperature of the radiohumeral capsule. Additionally, CAP 120 VA was the only application that significantly increased the superficial temperature. CAP 20 VA was the only one that generated a significant reduction in the temperatures of the common extensor tendon and radiohumeral capsule.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Universitat Internacional de Catalunya (CBAS-2019-18; data of approval 09/12/19).

Informed Consent Statement: All the bodies used in this study are from a body donor program.

Data Availability Statement: All data regarding this article were uploaded to the Harvard Dataverse and can be found under the DOI 10.7910/DVN/G2GSBX with the title "Replication Data for: CRET on the elbow."

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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RESEARCH ARTICLE Open Access

Temperature and current flow effects of different electrode placement in shoulder capacitive-resistive electric transfer applications: a cadaveric study

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Abstract

Background: Impingement syndrome is currently estimated to represent 60% of all shoulder pain disorders. Capacitive-Resistive electric transfer therapy is aimed to provoke temperature and current flow changes in superficial and deep tissues. This in vitro study has evaluated the variation of temperature and current flow in the shoulder tissues during two different areas of application of the movable capacitive-resistive electric transfer electrode.

Methods: A cross-sectional study designed, five fresh cryopreserved cadavers (10 shoulders) were included in this study. Four interventions (capacitive and resistive modes; low- and high-power) were performed for 5 min each by a diathermy "T-Plus" device in two shoulder regions: postero-superior and antero-lateral. Supraspinatus tendon, glenohumeral capsule and superficial temperatures were recorded at 1-min intervals and 5 min after treatment.

Results: A statistically significant difference was found only for the superficial area and time interaction, with high power-resistive application at the postero-superior shoulder area ($P < 0.035$). All the applications showed a 5 min after treatment temperature increase compared with the basal data, in all the application points. Superficial temperature in the high power-resistive application showed the greatest percent increase (42.93% ± 22.58), followed by the temperature in the tendon area with the same high power-resistive application (22.97% ± 14.70). The high power-resistive application showed the greatest percent of temperature increase in the applications, reaching 65.9% ± 22.96 at 5-min at the superficial level, and 32% ± 24.25 at 4-min at the level of the supraspinatus tendon. At the capsule level, high power-resistive was also the application that showed the greatest percent of increase, with 21.52% ± 16.16. The application with the lowest percent of temperature increase was the low power-capacitive, with a mean value of 4.86% at supraspinatus tendon level and 7.47% at capsular level.

Conclusion: The shoulder postero-superior or antero-lateral areas of application of capacitive-resistive electric

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transfer did not cause statistically significant differences in the temperature changes in either supraspinatus tendon or glenohumeral capsule tissues in cadaveric samples. The high power-resistive application in the postero-superior area significantly increased superficial temperature compared with the same application in the antero-lateral position area.

Keywords: Supraspinatus tendon, Cadaver, CRet, Shoulder, Glenohumeral capsule, Physical therapy

Background

Impingement syndrome is currently estimated to represent 44–65% of all shoulder pain disorders [1]. The most normal causes of symptoms are extrinsic causes such as work and sport overload [2]. These factors can cause the appearance of various types of rotator cuff pathologies, especially in athletes and manual labourers [1]. Usually affecting the supraspinatus tendon, these pathological conditions have been called "impingement" and have produced strong interest in treatment methods [2]. Another important disorder that affects this population is capsulitis, especially postoperative capsulitis from interventions related to rotator cuff repair and shoulder arthroplasty [3]. Lengthy immobilisation or surgical entry sites can cause excess fibrous tissue, limiting movement and producing symptoms in tendinous areas [4].

The increase in the concentration of type I collagen that is seen in capsular disorders, such as adhesive capsulitis, leads to decreased range of movement [3]. Increasing the temperature by 1 °C can have several effects in the human body, such as changes in nerve conduction speed, enzyme activity and oxyhaemoglobin release [5–8]. Tissue hypoxia produces tissue fibrosis and the generation and release of algesic substances, which cause pain, muscle spasms and joint rigidity [9]. An increase in temperature can improve oxygenated haemoglobin saturation [9].

Likewise, it is known that vascular supply affects tendon tissue repair [10]. Animal studies have demonstrated that when the blood supply in the tendon is interrupted, there are changes such as separation of the tendon fascicles, loss of the normal properties of the tenocytes in the interfascicular spaces (which shorten or degenerate) and collagen fibre fragmentation. It has also been shown that the changes observed in chronic degenerative tendon disorders are the same as those produced when blood supply to the rabbit tendon is altered [11]. Consequently, vascular supply is one of the key factors in the approach to muscle and tendon tissues.

Capacitive-resistive electric transfer (CRet) is usually used to treat muscle, joint and tendon injuries in the areas of traumatology and sports [12]. CRet is a non-invasive electrothermal therapy classified as deep thermotherapy; it is based on applying electric flow in the radiofrequency range of 300 kHz-1.2 MHz [7]. In contrast to superficial thermotherapy, which has a very limited capacity to reach muscle tissue [13], CRet can generate heat in deep muscle tissue, improving haemoglobin saturation [9]. The physiological effects of this type of therapy stem from applying an electromagnetic field of approximately 0.5 MHz to the human body. The effects attributed to this technique include increasing blood circulation and deep and superficial temperature, vasodilation, lymphatic effects and raising cell proliferation [14]. It has been observed that the increased blood perfusion is linked to the temperature increase, but other effects –such as the cell proliferation– seem to be mainly related to current flow [14, 15]. Cell proliferation has been shown to begin from a current flow of 0.00005 A per square millimetre [15].

The temperature increase in the tissues that the CRet device generates is a physical reaction to the current flow (Joule effect) [7, 16]. Although there are clinical studies that support this mechanism, the amounts of energy and current that should be transferred to obtain the desired temperature increase in structures such as the supraspinatus tendon and the joint capsule are still unknown. In addition, controlling these reactions is still based, to a great extent, on empirical experience from therapists and commercial brand protocols [9, 12, 17].

A single study analysing temperature and current flow changes in the Achilles tendon and the myotendinous junction of the gastrocnemius muscles in cadavers has been found [7]. However, we have not found any studies on these measurements in shoulder structures. Furthermore, no study has been found that evaluates whether varying the placement of the application electrode produces relevant differences in the target tissue during shoulder treatment.

The hypothesis was that alternating electrode position would generate the same current flow and differences in temperature changes in both superficial and deep tissues of the shoulder during the application of capacitive and resistive CRet protocols in cadaveric specimens.

Methods

Aim

The main objective of this study was to verify whether changing the position of the electrodes modified current flow and temperature in superficial and deep shoulder tissues by measuring these factors invasively during the

application of capacitive and resistive CRet protocols in cadaveric specimens.

Study design

A cross-sectional study was designed to establish the effect of transferring electrical capacitive/resistive energy from the Wintecare T-Plus device on the temperature and current flow in the shoulder area (superficial, supraspinatus tendon and glenohumeral capsule) in cadaveric specimens. The body donation programme at the Faculty of Medicine and Health Sciences of the Universitat Internacional de Catalunya (Spain) provided all the samples. The study was approved by the "Comitè d'Ètica de Recerca" (CER) research ethics committee at the Universitat Internacional de Catalunya (Reference number CB12020).

Cadaveric specimens

The sample was composed of 5 complete, fresh, cryopreserved cadavers (3 men and 2 women; 10 limbs). The cadavers were stored 3 weeks at − 14 °C, then they were kept at 3 °C 2 days before the testing and brought to room temperature a day before the study. The study was done progressively as the body donors arrived. Mean cadaver age was 80.6 ± 14.6 years. None of the cadaveric samples used in this study had evidence of trauma or surgical scars on the limbs.

Intervention

For better understanding of the temperature changes and electric current flow in conditions similar to rehabilitation treatments, we adapted a power threshold similar to that normally used during treatments on real patients with the T-Plus model [7, 18] but without the possibility of receiving patient's feedback. This is based on the power level that the therapist can easily identify and control during the therapy, and the watts (absorbed power) that the device samples during application. The power range of a T-Plus device varies from 1 to 300 watts in resistive mode and from 1 to 450 V-ampere (VA) in capacitive mode [7].

Two thresholds for high and low power were identified, based on the empirical evidence that the therapist applies clinically when inducing a thermal or non-thermal reaction, respectively, is desired. The power depends on the protocol used, which is a function of the area to be treated. In the shoulder area, high power-capacitive (HPC) application is defined as applying 130 VA in capacitive mode, and high power-resistive (HPR), as applying 100 watts in resistive mode; for the low power applications, low power-capacitive (LPC) is defined as applying 40 VA and low power-resistive (LPR), 20 watts. In comparison with treatments typically used in real patients, these low power thresholds respect the limit of 0.3 A, while the high power thresholds are above 0.3 A, so thermal effects are expected [7].

Four interventions (HPC, HPR, LPC and LPR) of 5 min each were performed, with the return electrode on the lower back of the cadaveric specimen and the movable electrode on the antero-lateral shoulder area. The same 4 interventions were applied changing the movable electrode position to the postero-superior part of the shoulder area, near the acromioclavicular joint. Dynamic movements similar to those used with real patients were made using constant pressure. The treatments were given by a Tecar-certified physiotherapist with 5 years of experience in the use of the T-Plus (Fig. 1).

Experimental procedures

Each cadaver was placed in a supine position with the forearm in a neutral pronation-supination position, the elbow extended and the shoulder in neutral flexion-extension.

The order of the 8 treatment protocols and the arm of each cadaver were randomly assigned before the study. An external researcher randomised these 2 factors using the computer programme "random.org". Before applying each treatment, it was ensured that the basal temperature of each cadaver had returned to the initial values.

Before beginning the CRet application, all instruments used were verified to have a calibration certificate. Hart Scientific PT25 5628–15 temperature devices were used to measure the tendinous and capsular temperature (°C) of the shoulder. A "Thermocomed" digital thermometer was used to measure the superficial skin temperature in the shoulder area. Thermocouples were placed under ultrasound guidance (US Aloka ProSound C3 15.4″) with a high-frequency linear transductor (USTTL01, 12 L5) in the middle of the supraspinatus tendon and in the glenohumeral joint capsule by a researcher expert in the use of the instrument. The return electrode of the T-Plus was placed on the lower back of the cadavers. Each treatment was performed with the T-Plus movable electrode on the previously-explained treatment areas for 5 min. The initial superficial temperatures and those registered by the invasive temperature monitors were measured. These measurements were registered at intervals of 1 min during the 5-min treatment period and then at 5 min after the end of each treatment. Prior to treatment, the impedance was always recorded (Fluke 8846A Digital Multimeter) to guarantee that the values marked by the Wintecare T-Plus device were correct. The current flow existing at that time was also calculated for each application, using the mean voltage divided by the initial impedance.

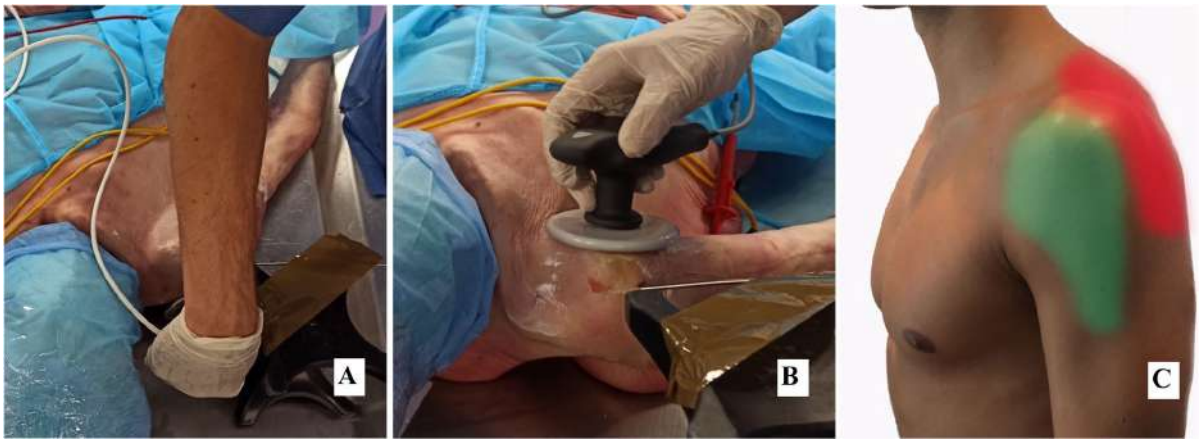

Fig. 1 Application of the interventions in the different electrode localization in the shoulder region. **a** Postero-superior application. **b** Antero-lateral application. **c** Application areas (Green = Antero-lateral; Red = Postero-superior). Experimental Procedure

Statistical analysis

Statistical analysis was performed with the SPSS Statistics version 22.0 programme. Normal distribution was calculated using the Shapiro-Wilk test ($P > 0.05$). The mean, standard deviation and difference between applications were calculated, as well as the percent of temperature increase.

Two-way repeated measures analysis of variance (ANOVA) was used for the comparative analysis. Statistical significance was set to $p < 0.05$.

Results

The descriptive values of the temperature recorded during the various applications, in the different superficial measurement intervals (Table 1), in the supraspinatus tendon (Table 2) and in the joint capsule were calculated (Table 3). A statistically-significant difference was found only for the area and time interaction, with HPR application at the postero-superior level ($P < 0.035$).

Current flow during antero-lateral application was 0.27±0.01 A (HPC 130 VA); 0.15±0.01 A (LPC 40 VA); 0.40±0.01 A (HPR 130 W); and 0.22±0.01 (LPR 30 W). In the postero-superior application, it was 0.21±0.01 A (HPC 130 VA); 0.14±0.02 A (LPC 40 VA); 0.45±0.01 A (HPR 130 W); and 0.31±0.02 (LPR 30 W).

All the applications showed a 5 min after treatment temperature increase compared with the basal data, in all the application points. Superficial temperature in the HPR application showed the greatest percent increase (42.93% ± 22.58), followed by the temperature in the

Table 1 Descriptive values of the temperature recorded during the various applications in the different superficial measurement intervals

	Superficial	Baseline	1 min	2 min	3 min	4 min	5 min	5 min after treatment	ANOVA F; *p* Value
HPC	Antero-Lateral	21.09 ± 2.10	25.35 ± 2.31	27.19 ± 2.74	28.09 ± 3.08	29.77 ± 3.15	31.50 ± 4.11	22.97 ± 2.07	*F*=0.871 *p*< 0.522
	Postero-Superior	22.32 ± 2.33	27.44 ± 3.81	29.84 ±5.18	31.53 ± 6.20	34.06 ± 6.58	34.14 ± 6.41	25.51 ± 3.37	
	Difference	1.23 ± 2.62	2.09 ± 3.75	2.65 ± 5.10	3.44 ± 6.37	4.29 ± 6.64	2.64 ± 6.94	2.54 ± 3.58	
LPC	Antero-Lateral	20.63 ± 3.09	21.88 ± 1.55	22.07 ± 1.81	22.74 ± 2.05	23.24 ± 1.66	23.93 ± 2.34	20.94 ± 2.37	*F*=1.073 *p*< 0.390
	Postero-Superior	22.48 ± 2.52	25.21 ± 3.62	25.87 ± 4.24	25.65 ± 4.44	25.69 ± 4.70	22.83 ± 14.56	22.67 ± 2.09	
	Difference	1.85 ± 1.60	3.33 ± 3.17	3.80 ± 3.48	3.91 ± 3.45	3.45 ± 3.69	1.10 ± 14.17	1.73 ± 1.63	
HPR	Antero-Lateral	19.69 ± 2.48	24.81 ± 5.60	25.86 ± 5.96	27.07 ± 5.71	27.91 ± 5.89	29.09 ± 6.50	25.41 ± 3.86	*F*=2.469 **p< 0.035**
	Postero-Superior	21.46 ± 2.77	28.76 ± 6.47	31.10 ± 7.23	33.22 ± 8.16	35.44 ± 9.23	35.65 ± 8.02	30.75 ± 6.82	
	Difference	1.77 ± 2.51	3.95 ± 5.46	5.24 ± 7.50	6.15 ± 6.66	7.53 ± 6.61	6.56 ± 6.72	5.34 ± 3.80	
LPR	Antero-Lateral	20.67 ± 2.25	21.78 ± 2.11	22.91 ± 3.05	23.46 ± 3.54	23.42 ± 2.51	23.96 ± 3.51	21.62 ± 3.39	*F*=1.093 *p*< 0.378
	Postero-Superior	21.87 ± 2.37	24.22 ± 3.27	25.21 ± 3.82	25.72 ± 4.79	26.10 ± 4.22	26.91 ± 5.38	23.84 ± 3.67	
	Difference	1.20 ± 2.06	2.44 ± 2.36	2.30 ± 1.77	2.26 ± 3.12	2.68 ± 2.60	2.95 ± 3.78	2.22 ± 2.35	

Abbreviations: *HPC* High Power Capacitive, *LPC* Low Power Capacitive, *HPR* High Power Resistive, *LPR* Low Power Resistive

Table 2 Descriptive values of the temperature recorded during the various applications in the supraspinatus tendon

	Supraspinatus tendon	Baseline	1 min	2 min	3 min	4 min	5 min	5 min after treatment	ANOVA F; *p* Value
HPC	Antero-Lateral	21.44 ± 2.82	22.72 ± 2.46	23.39 ± 2.34	23.99 ± 2.58	24.42 ± 2.49	24.99 ± 2.96	24.71 ± 2.07	*F*=0.180 *p*< 0.981
	Postero-Superior	23.52 ± 1.32	24.78 ± 1.74	25.52 ± 2.06	26.28 ± 2.44	26.91 ± 2.55	27.40 ± 2.79	27.29 ± 2.31	
	Difference	2.08 ± 2.85	2.06 ± 3.05	2.13 ± 3.46	2.29 ± 4.33	2.49 ± 4.42	2.41 ± 5.05	2.58 ± 3.49	
LPC	Antero-Lateral	22.24 ± 2.73	22.93 ± 2.55	23.07 ± 2.72	23.30 ± 2.33	23.57 ± 2.08	23.68 ± 1.97	23.86 ± 2.36	*F*=0.769 *p*< 0.597
	Postero-Superior	24.05 ± 2.03	25.11 ± 2.05	25.54 ± 2.16	25.81 ± 2.39	25.99 ± 2.49	26.24 ± 2.54	25.99 ± 1.55	
	Difference	1.81 ± 1.92	2.18 ± 2.01	2.47 ± 2.48	2.51 ± 2.41	2.42 ± 2.47	2.56 ± 2.66	2.13 ± 1.97	
HPR	Antero-Lateral	21.14 ± 2.75	26.30 ± 1.93	27.02 ± 1.75	28.96 ± 2.15	30.12 ± 2.03	31.63 ± 3.10	28.01 ± 1.87	*F*=1.075 *p*< 0.389
	Postero-Superior	23.13 ± 2.55	28.27 ± 5.32	28.13 ± 4.50	28.87 ± 5.06	30.48 ± 6.37	30.64 ± 5.94	28.35 ± 4.04	
	Difference	1.99 ± 1.88	1.97 ± 4.19	1.11 ± 4.54	−0.09 ± 4.78	0.36 ± 6.69	−0.99 ± 7.33	0.34 ± 3.80	
LPR	Antero-Lateral	21.34 ± 3.66	22.69 ± 3.14	23.15 ± 3.07	23.68 ± 2.90	24.05 ± 3.03	24.41 ± 3.09	24.23 ± 2.99	*F*=1.636 *p*< 0.155
	Postero-Superior	24.14 ± 1.94	25.65 ± 1.85	25.77 ± 1.84	26.04 ± 1.60	26.50 ± 2.19	26.60 ± 2.04	25.82 ± 1.69	
	Difference	2.80 ± 2.75	2.96 ± 2.97	2.62 ± 3.23	2.36 ± 3.41	2.45 ± 3.18	2.19 ± 3.53	1.59 ± 2.48	

Abbreviations: *HPC* High Power Capacitive, *LPC* Low Power Capacitive, *HPR* High Power Resistive, *LPR* Low Power Resistive

Table 3 Descriptive values of the temperature recorded during the various applications in the glenohumeral capsule

	Joint Capsule	Baseline	1 min	2 min	3 min	4 min	5 min	5 min after treatment	ANOVA F; *p* Value
HPC	Antero-Lateral	19.02 ± 2.21	20.67 ± 3.62	20.78 ± 3.25	20.88 ± 3.27	21.13 ± 3.42	21.82 ± 4.27	20.01 ± 2.43	*F*=0.567 *p*< 0.755
	Postero-Superior	19.94 ± 1.68	21.64 ± 3.15	21.93 ± 3.27	22.22 ± 3.52	22.32 ± 3.52	22.45 ± 3.55	21.23 ± 1.28	
	Difference	0.92 ± 1.53	0.97 ± 1.82	1.15 ± 1.84	1.34 ± 1.96	1.19 ± 2.05	0.63 ± 2.86	1.22 ± 1.72	
LPC	Antero-Lateral	19.14 ± 2.97	21.24 ± 5.30	20.62 ± 3.46	20.84 ± 3.53	21.04 ± 3.60	21.13 ± 3.71	20.30 ± 2.69	*F*=0.859 *p*< 0.531
	Postero-Superior	20.33 ± 1.74	21.12 ± 1.91	21.27 ± 1.89	21.44 ± 1.98	21.40 ± 1.92	21.41 ± 1.94	21.24 ± 1.63	
	Difference	1.19 ± 1.75	−0.12 ± 3.96	0.65 ± 2.52	0.60 ± 2.78	0.36 ± 2.67	0.28 ± 2.77	0.94 ± 2.10	
HPR	Antero-Lateral	19.04 ± 4.23	20.72 ± 3.73	21.30 ± 3.21	21.56 ± 3.27	22.10 ± 3.35	22.08 ± 3.55	20.69 ± 2.67	*F*=0.550 *p*< 0.768
	Postero-Superior	19.04 ± 2.34	21.42 ± 3.97	21.43 ± 2.82	21.42 ± 2.38	22.33 ± 3.71	23.22 ± 4.95	21.68 ±3.14	
	Difference	0.00 ± 2.97	0.70 ± 3.53	0.13 ± 2.18	−0.14 ± 2.15	0.23 ± 3.35	1.14 ± 4.64	0.99 ± 1.68	
LPR	Antero-Lateral	18.48 ± 2.77	19.60 ± 2.27	19.71 ± 2.26	19.94 ± 2.13	20.17 ± 2.05	20.36 ± 2.04	20.37 ± 2.15	*F*=0.659 *p*< 0.683
	Postero-Superior	19.70 ± 2.96	20.50 ± 2.39	20.74 ± 2.19	20.92 ± 2.08	21.05 ± 1.98	21.16 ± 1.89	21.26 ± 1.94	
	Difference	1.22 ± 2.11	0.90 ± 1.99	1.03 ± 1.91	0.98 ± 1.72	0.88 ± 1.67	0.80 ± 1.58	0.89 ± 1.60	

Abbreviations: *HPC* High Power Capacitive, *LPC* Low Power Capacitive, *HPR* High Power Resistive, *LPR* Low Power Resistive

tendon area with the same HPR application (22.97% ± 14.70).

The HPR application showed the greatest percent of temperature increase in the applications, reaching 65.9% ± 22.96 at Minute 5 at the superficial level, and 32% ± 24.25 at Minute 4 at the level of the supraspinatus tendon. At the capsule level, HPR was also the application that showed the greatest percent of increase, with 21.52% ± 16.16.

The application with the lowest percent of temperature increase was the LPC, with a mean value of 4.86% at supraspinatus tendon level and 7.47% at capsular level.

Discussion

CRet therapy is a technique whose use is growing steadily in clinical treatments. However, a significant lack of studies using this tool currently keeps us from being able to evaluate its effectiveness or better know its capacities and limitations. One of the main questions posed using this type of therapy is whether we get the same results applying the same dose in different zones in the same area. To date, this is the first study to compare the thermal and current flow effects from CRet therapy in the shoulder area, comparing applications (HPR, LPR, HPC and LPC) in different zones (antero-lateral and postero-superior) of the same area.

Our study results suggest that there are no significant differences in temperature of the glenohumeral joint capsule and the supraspinatus tendon between the different zones (postero-superior and antero-lateral) among any of the applications performed (HPR, LPR, HPC and LPC) in cadavers. The only significant difference found was the superficial temperature during HPR application, with a greater temperature increase being produced with postero-superior application.

All the applications, whether antero-lateral or postero-superior, generate a current flow above 0.03 A. These findings indicate that all the applications would be capable of causing cell proliferation in live subjects in the structures in which it is being measured (supraspinatus tendon and joint capsule) [7, 14, 15]. Clinically, this cell proliferation has been linked to increased blood supply and to tendinous tissue repair [10].

There is a single study that has analysed changes in temperature and current flow in cadavers in the Achilles tendon and the myotendinous junction of the gastrocnemius muscles [7]. This study also observed current flows higher than the minimum to cause cell proliferation and found a thermal increase at the level of the monitored and deep structures similar to those found in our study. However, neither in that study or any other are there comparisons about the location of the applications by zones. Considering the extrapolation of this in vitro thermal increase into an in vivo clinical situation, the absolute temperature values throughout our in vitro study will not probably be present [19] in a living body as vasodilation and increased blood flow will appear to keep homeostasis preventing excessive tissue warming and damage. This vasodilation and the increased blood flow is a functional body response that will ease the cooling of the tissues by convection. Presumably, on one hand, the increased temperature will increase the cellular and metabolic activity, the extensibility of the collagen fibers and the nerve conduction velocity, alter the vascular and synovial viscosity and will reduce the muscle tone in the treated tissues [13]. On the other hand, the increase of blood flow will ease the drainage and elimination of waste products in the tissues with oedema. However, all this potentially beneficial events in the living body need to be validated in shoulder pathologies like rotator cuff or capsular shoulder pathology.

Capacitive applications are concentrated in the tissues containing more electrolytes (muscles and soft tissues); conversely, resistive applications are concentrated in the structures with the greatest resistances (bones, tendons and joints) [20, 21]. Capacitive applications typically penetrate more deeply in the skin perpendicularly to the deep structures, while in resistive applications, in contrast, the current conversely searches for “the shortest path” to the return electrode through the resistance of the tissues and structures [20, 21].

In this study, no differences between the antero-lateral and postero-superior applications have been found. These results might be due to the fact that the two zones are very close to each other and the mechanism of action of the capacitive and resistive applications was not altered. However, the lack of evidence prevents us from stating this conclusively. On the other hand, these results might indicate that applying different CRet dosages at the shoulder level could produce similar changes in adjacent zones. This would be useful in clinical practice to treat patients with symptoms by using adjacent areas that are less symptomatic and have an effect on the affected tissue zone.

The lack of evidence on CRet therapy in both the shoulder area and in applying the therapy in different zones in the same area makes new studies necessary. These studies should compare applications in areas further apart to ascertain whether the effect found in this study is similar or, on the contrary, different.

Conclusion

Varying the electrode position does not cause statistically-significant differences in the temperature changes in either superficial or deep shoulder tissues in cadaveric samples. The application of postero-superior HPR was the only one that significantly increased

superficial temperature compared with the same application in antero-lateral position.

Study limitations

The limitations of this study are discussed in this section. Our study uses cadaveric specimens in which there is no thermoregulation or active blood circulation. This factor has probably impacted the temperature changes. In live subjects, the thermoregulation effect exists in the body; it controls heat dissipation, so the temperature increases in such subjects would predictably have been lower. This effect helps to avoid undesired hyperthermia during treatment in real patients [9]. Another limitation is that, although the cadavers were cryopreserved, the muscle and tendinous tissue properties might vary from those of live subjects. In addition, the average age of the corpses used was relatively high. Despite these limitations, the authors consider that the use of donated bodies has made it possible to ascertain how the various CRet applications impact temperature and current flow values in structures typically affected, which is ethically inviable in live subjects. As discussed previously, the lack of evidence on these procedures in cadavers makes extrapolating the results to clinical practice complicated.

Abbreviations

CRet: Capacitive-resistive electric transfer; HPC: High-power capacitive; LPC: Low-power capacitive; HPR: High-power resistive; LPR: Low-power resistive

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Authors' contributions

CLdC performed the statistical analysis, the writing of results section and the calibration of the instruments. JRS wrote and designed the methods section, contributed to the writing of the discussion section and the preparation of the manuscript. He contributed to the recording of temperatures and was in charge of ultrasound measurements. CHG made the intervention applications, wrote the discussion, reviewed and adapted the manuscript. APB wrote the introduction section and he prepared the cadaver and performed superficial temperature measurements. PFM wrote part of the introduction, part of the methods and revised the manuscript. He was responsible for the registration of temperatures. MCV was in charge of the realization of the measuring points and the incisions in the cadavers and made measurements of impedance and current flow. He contributed to the writing of the results section too. All the authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The Ethics Committee "Comitè d'Ètica de Recerca (CER) from the Universitat Internacional de Catalunya (UIC), Barcelona" approved the study with CB12020 reference number.

All methods were carried out in accordance with relevant guidelines and regulations.

Informed consent was obtained from donor or the next of kin as cadaver was used in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Human Kinetics
ORIGINAL RESEARCH REPORT

Is Tecar Therapy Effective on Biceps Femoris and Quadriceps Rehabilitation? A Cadaveric Study

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Background: Capacitive-resistive electric transfer therapy is an interesting rehabilitation treatment to use in musculoskeletal injuries. The purpose is to analyze the temperature change and current flow in superficial and deep biceps femoris and quadriceps tissues when applying different protocols of capacitive-resistive electric transfer therapy. ***Methods:*** Five cryopreserved cadavers (10 legs) were included in this study. Four interventions (high/low power) were performed for 5 minutes. Dynamic movements were performed to the biceps femoris and quadriceps. Superficial, middle, and deep temperature were recorded at 1-minute intervals and 5 minutes after the treatment using invasive temperature meters placed with ultrasound guidance. ***Results:*** Low-power applications have generated a very low thermal effect and an important current flow. The high-power capacitive application achieves a greater increase in superficial temperature compared with low power ($P < .001$). The high-power resistive application recorded a greater increase in superficial, middle, and deep temperatures with a greater current flow compared with the other applications ($P < .001$). ***Conclusion:*** This study could serve as basic science data to justify the acceleration of the processes of muscle recovery, improving cell proliferation without increasing the temperature in acute muscle injuries and increasing the temperature and viscoelasticity of the tissues in chronic processes with this therapy.

Keywords: cadaver, CRet, physical therapy

Anatomic studies have provided evidence that many muscles, especially the biceps femoris[1] and the rectus femoris[2,3] include a tendon in their muscular belly,[4,5] and the lesions in the muscular belly occur at the musculotendinous union. This type of injury amounts to 72% in the biceps femoris[6] and 60% in the rectus femoris,[2,3] both clinically and radiologically.[7–10]

Acute lesions usually occur with edema and blood products that extend along the torn muscle fibers.[8,11] It has been seen that the differentiation of satellite cells starts from the third-day postinjury and reaches its peak at 2 weeks.[12] This differentiation is stimulated by somatomedin (insulin growth factor I), basic fibroblast growth factor and, to a lesser extent, nerve growth factor.[12–14] These factors are of great importance for proper muscle regeneration instead of scarring with fibrous tissue.[13,14] It has been shown that cell proliferation is responsible for stimulating this type of growth factors,[12] and inhibiting others responsible for generating fibrous tissue, such as the growth factor of acidic fibroblasts.[12] The most advisable option would be to stimulate cell proliferation from the early stages of the lesion to avoid the generation of fibrous tissue and promote the differentiation of muscle tissue. The initial phases are accompanied by inflammatory processes; therefore, it is important to apply therapies that do not have a harmful thermal effect.[15,16]

Another possible situation generated by poor muscle regeneration is muscle repair through fibrous tissue.[14] In these situations, the therapeutic objective should be to generate a viscoelastic change of the less flexible fibrous tissue. The temperature increase in this type of tissue has been shown to have beneficial effects on the decrease of fibrous tissue and the improvement in muscle regeneration.[17] A temperature rise of 1 °C can have various effects on the human body, such as changes in nerve conduction velocity, enzymatic activity, and improved blood perfusion.[18–21] Insufficient tissue oxygenation leads to hypoxic conditions in the tissues, the production and release of algesic substance and tissue fibrosis, causing pain, muscle spasms, and capsular dysfunctions.[22,23]

Capacitive-resistive electrical transfer therapy (CRet) is a non-invasive electrothermal therapy classified as deep thermotherapy based on the application of electric currents[24–27] within the radio frequency range of 300 kHz to 1.2 MHz.[28] Due to the properties of the tissues, currents in CRet therapy can generate heating of deep muscle tissues, causing improvements in hemoglobin saturation and increasing the temperature,[23] vasodilation, elimination of excess fluids, and improved cell proliferation.[23,29] Some of these reactions, such as the increase in blood perfusion, are related to the increase in temperature, but others such as the increase in cell proliferation seem to be related mainly to the passage of current flow.[29] CRet therapy provides 2 different treatment modes: capacitive and resistive. Capacitive mode is provided with an insulating ceramic layer and the energetic transmission generates heat in superficial tissue layers, with a selective action in tissues with low impedance (water rich). Resistive mode has no insulating ceramic layer, the radiofrequency

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energy passes directly through the body in the direction of the inactive electrode, generating heat in the deeper and more resistant tissues (with less water content).[30]

Current flow and thermal changes have been evidenced in 4 recent in vitro studies.[30–33] However, there are no studies carried out on muscle tissue. Although there are already clinical publications that support this mechanism, the amount of energy and current flow that must be transferred to obtain them is unknown. In addition, the location of these reactions in the body according to the application parameters, such as the absorbed power and the position of the electrodes, continues to be based largely on the empirical experience of those who use the instrument.[23,24,27,34]

Ignorance of the quantification of thermal changes and current flow is mainly due to the type of measures used in these studies. Having conducted these studies on living subjects, it is not possible to perform invasive measurements on certain structures, especially deep ones, where it is interesting to know the amount of energy that passes, and the thermal changes that occur.[23]

The objective of this in vitro study is to analyze the thermal behavior and transmission of electric current in different tissues of the quadriceps and the biceps femoris using different CRet protocols, and making invasive temperature measurements in nonliving subjects.

Material and Methods

Study Design

A cross-sectional study was designed to analyze the effect of CRet on the temperature increase in the deep region of the crural muscle, the musculotendinous junction of the rectus femoris and the superficial region of the quadriceps in cadaveric samples. It was also analyzed in the deep region of the biceps femoris muscle, the musculotendinous junction of the biceps femoris, and the superficial region of this muscle in cadaveric samples. The body donation program of the Faculty of Medicine and Health Sciences of the Universitat Internacional de Catalunya provided all the samples. The Research Committee (CER) of Universitat Internacional de Catalunya approved the study (CBAS-2019-18).

Cadaveric Samples

The study included 5 fresh cryopreserved specimens: 2 male and 3 female (10 legs). The age range at the time of death was between 60 and 86 years (mean 67.42 [6.36]). The bodies were stored at 3 °C and brought to room temperature for 36 hours before the test. None of the cadaverous specimens used in this study had evidence of traumatic injuries or surgical scars on the lower extremities.

Intervention

The power limit that was applied was set based on the power levels typically applied with a T-Plus (Wintecare® S.A., Chiasso, Switzerland) during treatments in real patients. The use of the T-Plus equipment allows the number of watts (absorbed power) to be regulated easily by the therapist during therapy, showing the watts in real time on the device during the application.

The light range of a T-Plus device ranges from 1 to 300 watts in resistive and from 1 to 450 VA in capacitive.

Two "high-power" and "low-power" thresholds have been identified that have been quantified from the real applications that the therapist usually uses when he wants to obtain thermal or nonthermal reactions.

Based on the above, applications at 130 VA for capacitive (high-power capacitive [HPC]) and 100 watts for resistive (high-power resistive [HPR]) are identified at high power, while applications with 50 VA in capacitive (low-power capacitive [LPC]) and 20 watts in resistive (low-power resistive [LPR]) are defined as low power. On average for real applications, the threshold of 20 watts and 50 VAs respects the limit of 0.3 amps, while applications at 100 watts and 130 Vas are widely in the thermal area.

Each of the 4 interventions (capacitive and resistive of low and high power) were performed for 5 minutes by a physiotherapist with more than 10 years of experience in using the T-Plus device. Dynamic movements were performed, similar to those used in real patients, with constant pressure on the skin at the height of the muscular belly of the rectus femoris and on the skin at the height of the muscular belly of the biceps femoris (Figure 1).

Experimental Procedure

Each specimen was placed in a prone position for application on the biceps femoris. The hip was placed in a neutral rotation position, and the knee was stabilized at 30° of flexion with a positioning device, consisting of a thermoplastic splint to maintain the ankle joint. For the quadriceps intervention, each specimen was placed supine with neutral hip rotation.

The 4 types of treatment were previously randomized, as was the sample. It was taken into account that the temperature that was generated in each specimen with each treatment returned to normal before the next application. All instrumentation received the certificate of validity and calibration before beginning the study. "Hart Scientific PT25 5628-15" invasive temperature meters were used to measure the deep region of the crural muscle, the musculotendinous junction of the rectus femoris, the deep region of the biceps femoris muscle, and the musculotendinous junction of the biceps femoris. A "Thermocomed" digital thermometer was used to measure the superficial temperature of the skin at the height of the biceps femoris (Figure 2A) and the skin at the height of the anterior rectum (Figure 2B). The superficial measurement was always carried out at the same point, marking at the beginning of the study the skin with a dermographic marker. The invasive temperature meters were placed through ultrasound "US Aloka Prosound C3 15.4′"; with a high-frequency linear transducer (USTTL01, 12L5). Ultrasound placement was performed by a researcher experienced in the use of this instrument and was placed in the region of the biceps femoris (Figure 2C) and the quadriceps (Figure 2D). The deepest invasive meter was placed in the deep region of the crural muscle, and the middle meter in the musculotendinous junction of the rectus femoris for the quadriceps region. For the region of the biceps femoris, the deepest meter was placed in

Figure 1 — Example of capacitive and resistive biceps femoris treatment. The blue drops (closer to the electrode) represent tissues with more water. The brown drops (further away from the electrode) represent tissues with more resistance.

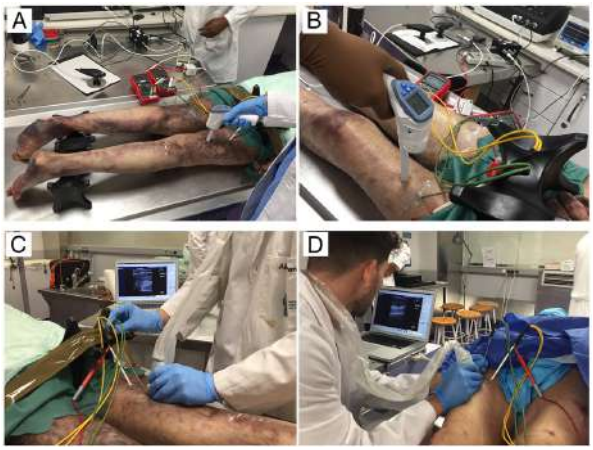

Figure 2 — Superficial temperature measurement with digital thermometer (A) biceps femoris and (B) quadriceps; ultrasound placement of invasive middle and deep temperature meters in the (C) biceps femoris and (D) quadriceps.

the deep region of the biceps femoris muscle, and the middle meter at the musculotendinous junction of the biceps femoris.

Despite the fact that the measurement instrumentation presented a calibration certificate, a reliability study was conducted prior to its use for superficial, middle, and deep temperature measurements in 3 biceps femoris and 3 quadriceps. The intraclass correlation coefficient with a 95% was .97 to 1.00, the standard measurement error was 0.02 to 0.03, and the minimum detectable difference was 0.06 to 0.08.

The temperature meters were placed, and the temperature was taken every minute for 5 minutes and again 5 minutes later. This simulated the same procedure that was to be performed in the measurements during the applications of the CRet. The following interpretation of the intraclass correlation coefficient was considered (.00–.25 = little or no relationship, .26–.50 = fair degree of relationship, .51–.75 = moderate to good ratio, and .76–1.00 = good to excellent ratio).[35]

The intraclass correlation coefficient for all temperatures were excellent. The SEM and MDD in the 95% confidence interval were small.

For treatment applications, the T-Plus return electrode was placed in the posterior area of the lumbar spine for applications in the quadriceps region. In the applications of the biceps femoris, the return electrode was placed in the abdomen of the donor. The treatment was performed with the T-Plus mobile electrode at the mid-height of the muscular belly of the rectus femoris for the quadriceps region at the mid-height of the muscular belly of the biceps femoris for subsequent application. The initial superficial temperature (quadriceps and biceps femoris), middle (myotendinous junction of the rectus femoris and biceps femoris), and deep (deep part of the crural muscle and biceps femoris) were measured. These measurements were recorded every minute for 5 minutes, and 5 minutes after the end of each application.

The impedance (Fluke 8846 A multimeter; Fluke Corporation) was always measured before application to ensure that the values marked by the T-Plus device were correct. In addition, the current flow of each application was calculated using the average voltage divided by the initial impedance.

Statistical Analysis

Statistical analysis was performed using the SPSS Statistics (version 22.0) program. The normality of the distribution was analyzed using the Shapiro–Wilk test ($P > .05$). The mean and SD for superficial, medium, and deep temperatures were calculated. The percentages of temperature change with respect to the basal temperature were calculated.

For intragroup differences, the Friedman test and the signed Wilcoxon rank test were used. Intergroup comparisons were performed using the Kruskal–Wallis and Mann–Whitney *U* tests. A value of $P < .05$ was considered statistically significant.

Results

The temperature recorded during the different applications in the temporal sequence, both at the superficial, middle, and deep levels, for both the biceps femoris and the quadriceps, are shown in Table 1. The initial temperature values in the different applications showed no difference. The current flow was stable, with averages of 0.08 A (0.03) (HPC); 0.05 A (0.01) (LPC); 0.22 A (0.07) (HPR); and 0.11 A (0.03) (LPR) in the biceps femoris. In the quadriceps, the means were 0.06 A (0.03) (HPC); 0.04 A (0.02) (LPC); 0.19 A (0.05) (HPR); and 0.09 A (0.03) (LPR).

In all applications and depths, a similar pattern is produced in both the biceps femoris and the quadriceps (Table 1). The variations throughout the study for the superficial and average temperature in all applications, and for the HPC application, are statistically significant $P < .01$ with the Friedman test in the biceps femoris, but not for the rest of applications in the deep temperature ($P > .33$). In the region of the quadriceps, the variations of the superficial and average temperature are statistically significant ($P < .01$), in addition to the HPR application in the deep temperature. In the rest of the applications, the temperature progression does not reach statistical significance ($P > .11$).

Superficial Temperature

There is an increase in the 2 regions, with the applications of HPC and LPC (biceps femoris: 32.5° HPC and 33.7°; quadriceps: 34.4° HPC and 43.5° HPR), decreasing slightly after 5 minutes posttreatment. The biggest change was 12.5° for the HPR and 10.6° for the HPC with a 61% and 46.5% percentage change, respectively, in the biceps femoris. In the quadriceps region, it was 12.5° for the HPC and 21.8° for the HPR, assuming 52.6% and 101.1% change, respectively (Table 2).

The differences between applications were statistically significant both in the difference between the start and the 5 minutes of application, and between the start and the 5 minutes postapplication ($P < .01$), except for the difference between LPC and HPR between the initial difference, and 5 minutes postapplication ($P < .85$).

Middle Temperature

At the middle temperature in the 2 regions, all temperatures reached a statistically significant difference ($P < .01$) at the end of the application. The temperature of the HPR is the one that produced the greatest change, reaching a temperature difference at the end of the application of 6.6° in the region of the biceps femoris assuming this a 30.1% increase in temperature, and 7.9° in the region of the quadriceps that supposed a 35.5% increase. The rest of the applications achieved an increase of less than 2.8° with percentages between 3.8% and 11.1% (Table 2).

Table 1 Descriptive Outcomes Temperature

	Baseline	1 min	2 min	3 min	4 min	5 min	5-min postapplication
Biceps femoris							
Superficial							
HPC	21.95 (2.32)	26.13 (5.18)	27.88 (6.72)	29.79 (8.68)	32.14 (11.23)	32.55 (11.11)	27.14 (6.42)
LPC	20.82 (1.24)	23.25 (3.50)	23.84 (4.33)	24.58 (5.31)	24.96 (5.64)	25.76 (6.16)	22.54 (3.52)
HPR	21.22 (3.32)	26.31 (3.97)	28.52 (4.55)	29.23 (5.96)	32.60 (6.29)	33.77 (6.28)	30.79 (6.12)
LPR	22.00 (3.05)	22.82 (2.89)	23.31 (2.95)	23.70 (2.93)	24.06 (3.10)	24.62 (3.39)	23.52 (3.43)
Middle							
HPC	25.53 (0.66)	26.92 (2.45)	27.16 (2.84)	26.65 (2.42)	26.86 (3.49)	27.23 (3.64)	26.35 (1.03)
LPC	24.33 (0.91)	24.88 (0.90)	25.04 (0.93)	25.13 (0.94)	25.19 (0.91)	25.26 (0.95)	25.49 (0.86)
HPR	23.48 (3.25)	26.58 (2.67)	27.22 (2.41)	28.41 (2.66)	29.46 (2.50)	30.14 (2.45)	29.50 (2.02)
LPR	24.65 (1.60)	25.50 (1.42)	25.74 (1.48)	25.99 (1.43)	26.24 (1.39)	26.42 (1.30)	26.37 (1.40)
Deep							
HPC	20.98 (1.25)	21.63 (1.98)	21.60 (1.93)	21.59 (1.98)	21.53 (2.06)	21.51 (2.09)	21.06 (1.13)
LPC	20.63 (1.38)	21.12 (1.46)	21.18 (1.42)	21.22 (1.45)	21.34 (1.52)	21.26 (1.39)	21.04 (0.96)
HPR	19.08 (3.30)	22.06 (3.16)	22.58 (3.16)	23.07 (3.02)	23.72 (3.15)	24.69 (4.95)	21.86 (2.04)
LPR	20.41 (1.82)	21.57 (3.23)	21.81 (3.21)	21.89 (3.10)	22.04 (3.26)	22.18 (3.45)	21.11 (1.38)
Quadriceps							
Superficial							
HPC	22.43 (2.66)	26.56 (4.70)	29.16 (6.60)	30.14 (8.16)	33.34 (7.85)	34.48 (9.13)	29.06 (4.98)
LPC	22.21 (2.28)	24.04 (2.53)	24.45 (2.58)	25.07 (2.94)	25.76 (2.83)	26.08 (3.46)	23.80 (2.14)
HPR	21.74 (2.59)	32.38 (5.22)	36.32 (5.94)	39.74 (7.53)	41.45 (6.41)	43.58 (6.02)	39.09 (6.16)
LPR	21.98 (3.02)	23.60 (2.89)	25.00 (3.28)	26.00 (3.25)	26.73 (3.30)	26.98 (3.57)	24.38 (3.50)
Middle							
HPC	22.80 (1.95)	23.59 (2.10)	23.92 (2.22)	24.06 (2.20)	24.33 (2.17)	24.57 (2.16)	24.69 (2.32)
LPC	22.03 (2.83)	22.80 (2.38)	22.95 (2.37)	23.05 (2.36)	23.15 (2.33)	23.28 (2.32)	23.34 (2.31)
HPR	22.47 (3.03)	25.87 (3.63)	27.54 (4.93)	28.38 (4.60)	29.53 (4.98)	30.39 (4.78)	29.38 (4.56)
LPR	21.71 (3.50)	22.77 (3.39)	23.06 (3.53)	24.45 (5.66)	23.80 (3.70)	24.08 (3.67)	24.08 (3.42)
Deep							
HPC	20.31 (7.05)	20.44 (7.82)	20.31 (7.73)	20.34 (7.88)	20.28 (7.84)	20.46 (8.16)	18.03 (4.10)
LPC	18.89 (6.49)	18.95 (6.11)	18.94 (6.10)	18.96 (6.15)	18.95 (6.06)	19.04 (6.28)	17.50 (4.02)
HPR	18.38 (5.93)	20.36 (8.46)	20.46 (8.15)	20.59 (7.93)	20.65 (7.48)	20.89 (7.61)	19.40 (5.94)
LPR	18.64 (6.61)	18.34 (5.78)	18.45 (6.02)	18.57 (6.23)	18.66 (6.25)	18.75 (6.39)	18.01 (4.75)

Abbreviations: HPC, high-power capacitive; HPR, high-power resistive; LPC, low-power capacitive; LPR, low-power resistive.

The one with the greatest increase was the HPR in the 2 regions, with 6°, which represents 27.4% in the region of the biceps femoris, and 6.9° which represents 30.8% in the region of the quadriceps. Likewise, these differences are statistically significant in all applications ($P < .01$).

Deep Temperature

All temperatures increase in both regions. HPR and LPR applications in biceps femoris were statistically significant ($P < .01$) with temperatures of 5.6° in the HPR (31.2% change) and 1.7° for the LPR (8.4% change). In the quadriceps region, the changes did not reach a statistically significant difference and the greatest increase was in the HPR, with 2.5° (14.1% change).

The temperature dropped again after 5 minutes postapplication, but only in the biceps femoris was there a small, maintained increase between 0.08° and 2.7° on average, being again the highest temperature for HPR ($P < .01$). However, in the region of the quadriceps, the temperature dropped slightly in all applications giving a negative value except for the HPR that maintains a minimum positive increase of 1°. These differences in the quadriceps region were not statistically significant in any application.

Discussion

The results of this in vitro study suggest that low-power applications produced low thermal effects with an important current flow, and the HPR application seems to be the one that reaches the highest temperature increase in superficial, middle, and deep temperatures with a greater current flow compared with the other applications.

These applications are used in studies with living subjects, founding improvements in pain levels, and increasing capillary permeability after the intervention.[24,36]

Table 2 Descriptive Outcomes Temperature Percentage

	Baseline	Difference Baseline – 5 min		Difference Baseline – 5-min postapplication	
	Mean (SD)	Mean (SD)	%	Mean (SD)	%
Biceps femoris					
Superficial					
HPC	21.95 (2.32)	10.60 (9.62)	46.5	5.19 (4.59)	22.6
LPC	20.82 (1.24)	4.94 (5.34)	23	1.72 (2.68)	7.9
HPR	21.22 (3.32)	12.55 (5.65)	61	9.57 (4.90)	45.9
LPR	22.00 (3.05)	2.62 (1.85)	12.3	1.52 (1.57)	7.1
Middle					
HPC	25.53 (0.66)	1.70 (3.71)	6.7	0.82 (0.58)	3.2
LPC	24.33 (0.91)	0.93 (0.53)	3.8	1.16 (0.51)	4.8
HPR	23.48 (3.25)	6.66 (3.28)	30.1	6.02 (3.07)	27.4
LPR	24.65 (1.60)	1.77 (0.89)	7.3	1.72 (0.84)	7.1
Deep					
HPC	20.98 (1.25)	0.53 (1.36)	2.4	0.08 (0.58)	0.4
LPC	20.63 (1.38)	0.63 (0.97)	3.1	0.41 (0.89)	2.2
HPR	19.08 (3.30)	5.61 (4.55)	31.2	2.78 (2.79)	16.9
LPR	20.41 (1.82)	1.77 (2.42)	8.4	0.70 (0.95)	3.7
Quadriceps					
Superficial					
HPC	22.43 (2.66)	12.05 (7.41)	52.6	6.63 (3.64)	29.6
LPC	22.21 (2.28)	3.87 (2.07)	17.4	1.59 (1.19)	7.4
HPR	21.74 (2.59)	21.84 (4.65)	101.1	17.35 (4.62)	80
LPR	21.98 (3.02)	5.00 (2.20)	23.3	2.40 (2.68)	11.5
Middle					
HPC	22.80 (1.95)	1.77 (0.75)	7.8	1.89 (0.79)	8.2
LPC	22.03 (2.83)	1.25 (1.10)	6.2	1.31 (1.03)	6.4
HPR	22.47 (3.03)	7.92 (2.80)	35.5	6.91 (2.54)	30.8
LPR	21.71 (3.50)	2.37 (0.97)	11.1	2.37 (1.10)	11.3
Deep					
HPC	20.31 (7.05)	0.15 (5.91)	1.9	–2.28 (3.67)	–7.7
LPC	18.89 (6.49)	0.15 (1.78)	1.9	–1.39 (2.93)	–3.8
HPR	18.38 (5.93)	2.51 (4.50)	14.1	1.02 (2.78)	6.7
LPR	18.64 (6.61)	0.11 (3.31)	2.5	–0.63 (2.73)	–0.1

Abbreviations: HPC, high-power capacitive; HPR, high-power resistive; LPC, low-power capacitive; LPR, low-power resistive.

As far as we know, this study is the first to evaluate the effects of CRet on temperature and current flow in deep structures of the biceps femoris and the quadriceps in specimens. In addition, the temperatures obtained in this study are within the safe ranges established to avoid muscle damage[37,38] and have produced a current flow sufficient to generate cell proliferation.[16]

Next, the main findings divided by type of protocol used, and its possible clinical utility are explained according to the most common pathologies in these regions.

The LPC protocol increases the superficial temperature with a small increase in the temperature in the musculotendinous junctions of the biceps femoris and the rectus femoris, as well as in the deep part of the biceps femoris and the crural muscle. However, despite the small thermal effect, we observed a current flow which indicates that there is a current path associated with cell proliferation in middle and deep structures.[16,29] This application could be interesting in the early stages of muscle tears that occur with edema and blood products,[8,11] since it could generate greater cell proliferation and faster muscle and tissue regeneration[39] without increasing the temperature, and without harming the initial inflammatory phase in the first days after this type of injury.[16,29]

This application could be indicated from the second or third day after the injury. Different studies have observed that as of the third day after the acute injury, the differentiation of the satellite cells begins, and its peak is reached at 2 weeks.[12–14] Cell proliferation is responsible for stimulating this type of growth factors related to tissue regeneration[13,14] and inhibiting others related to the formation of fibrous tissue.[12] With this application, the objective of stimulating cell proliferation from the early stages of the lesion would be achieved to avoid the generation of fibrous tissue and

promote the differentiation of muscle tissue without generating a temperature increase during the inflammatory process.[15,16]

The LPR protocol is similar to the LPC, with a slightly higher average thermal effect. However, the LPR generates a current flow that is more than double that generated in the LPC in biceps femoris and quadriceps. These findings suggest that this application is capable of generating greater cell proliferation,[16,29] so it could also be interesting in acute muscle injuries.[8,11] This application could generate a greater cellular proliferation, and a faster muscle and tissue regeneration,[39] without increasing the temperature, and without harming the initial inflammatory phase in the first days after this type of lesions.[16,29] As in the LPC, it would be advisable to perform this application during the first weeks of the injury. The differentiation of satellite cells peak at 2 weeks,[12–14] so perhaps it would be interesting to influence this application especially in the second week of the lesion, since it involves much more cell proliferation than LPC and the middle and deep temperature hardly increases.

With this application, the objective of stimulating cell proliferation from the early stages of the lesion would be achieved to avoid the generation of fibrous tissue and promote the differentiation of muscle tissue without generating a temperature increase during the inflammatory process.[15,16]

Previous studies have reported good clinical results with a combination of capacitive and resistive modes[24,36] in living patients in different clinical variables such as pain or function. Therefore, the combination of LPC and LPR during the first 2 weeks after acute muscle injury would be ideal to avoid poor tissue regeneration.

In HPC protocol, unlike those of low power, generates a considerably higher superficial thermal effect with current flow, which indicates cell proliferation .[16,29] It could be interesting in the treatment of muscle lesions located in the most superficial part of the rectus femoris[17] or skin scars,[40] since it generates an increase in superficial temperature that could be related to improvements in blood perfusion,[18–21] hypoalgesic effects, and reduction in muscle spasms.[22,23]

With the results obtained, this type of application could be recommended in less serious processes such as muscle spasms or contractures in which the main objective is to improve pain.[22,23] Since it has similar effects on blood perfusion to PRL, its use could be recommended in phases in which the muscle lesion does not develop with an inflammatory process.

The HPR protocol current flow indicates cell proliferation too.[16,29] This protocol found the highest temperature increase at all depths and the greatest current flow related to cell proliferation,[16,29] compared with the other 3 applications previously explained. These deep thermal effects can generate mechanical effects on the viscoelastic properties of the structures, which are mainly related to chronic muscular pathologies or fibrous scars after muscle tears.[39,41,42] This generates greater elasticity in the scars, and therefore, better functionality and a lower risk of relapse in muscle injury.[22,23] A temperature rise of 1 °C can have various effects such as changes in nerve conduction velocity, enzymatic activity, and improved blood perfusion.[18–21] This temperature increase in this type of tissues has been shown to have beneficial effects on the decrease of fibrous tissue and the improvement in muscle regeneration.[17]

Limitations

Since this experiment was conducted with cadavers, or bodies without thermoregulatory mechanisms, or functional blood circulation, it is possible that the properties in living subjects are slightly different. It is likely that the living population does not experience as much of an increase in temperature because circulating blood dissipates heat to adjacent areas, therefore, keeping the temperature of the treated structures within the desired limits. This process prevents unwanted hyperthermia in nearby tissues, as well as excessive heat during treatment, which is sufficient to cause skin burns.[23] In this type of treatment, patient feedback is important, and, in this case, it has been impossible to obtain it. However, the use of donor bodies is the only way to analyze the temperature in the musculotendinous junction of the biceps femoris, the femoral rectus, the deep region of the crural muscle, and the biceps femoris in an invasive and ethical way. Finally, studies in living subjects with muscle pathology should be performed to test the hypothesis on muscle regeneration and repair.

Clinical Recommendations

Low-power applications CRet could be indicated for treatments in acute muscular pathologies in which it is not interesting to increase the temperature, but it is interesting to improve cell proliferation.

The HPR application could be indicated for treatments in chronic pathologies in which the objective is to increase the temperature to generate viscoelastic changes of the structures.

It would be necessary to continue conducting studies in living subjects to corroborate these theories.

Conclusion

Low-power applications have demonstrated a very low thermal effect with an important current flow. The HPC application achieves a greater increase in superficial temperature compared with low power. The HPR application recorded a greater increase in superficial, middle, and deep temperatures with a greater current flow compared with the other applications.

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Comparison of resistive capacitive energy transfer therapy on cadaveric molars and incisors with and without implants

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Capacitive–resistive energy transfer therapy (CRet) is used to improve the rehabilitation of different injuries. This study aimed to evaluate and compare the changes in temperature and current flow during different CRet applications on upper and lower molars and incisors, with and without implants, on ten cryopreserved corpses. Temperatures were taken on molars and incisors with invasive devices and skin temperature was taken with a digital thermometer at the beginning and after treatments. Four interventions: 15 VA capacitive hypothermic (CAPH), 8 watts resistive (RES8), 20 watts resistive (RES20) and 75 VA capacitive (CAP75) were performed for 5 min each. All treatments in this study generated current flow (more than 0.00005 A/m^2) and did not generate a significant temperature increase ($p > 0.05$). However, RES20 application slightly increased surface temperature on incisors without implants ($p = 0.010$), and molar with ($p = 0.001$) and without implant ($p = 0.008$). Also, CAP75 application increased surface temperature on molars with implant ($p = 0.002$) and upper incisor with implant ($p = 0.001$). In conclusion, RES8 and CAPH applications seem to be the best options to achieve current flow without an increase in temperature on molars and incisors with and without implants.

Abbreviations

CRet	Capacitive–resistive electric transfer
CAPH	15 VA capacitive hypothermic electrode
RES8	8 Watts resistive
RES20	20 Watts resistive
CAP75	75 VA capacitive

Dental implants are the most commonly used procedure to replace missing teeth[1]. A Dental implant consists of a piece of metal, usually titanium or titanium alloys, inserted and integrated into the bone, giving solid support for the final dental prosthesis. It is estimated that 12–18 million implants are inserted worldwide every year[2]. Furthermore, it is supposed to be one of the most common surgeries in the health field. Successfully integrated implants have a survival rate of more than 96.7% after 8 years[3]. Nowadays, the insertion of a dental implant requires a low-invasive surgical technique[4]. However, inflammation during the healing phase may be present, and the use of anti-inflammatory drugs (ibuprofen, indomethacin, diclofenac or celecoxib) are usually prescribed[5].

Inflammation is a naturally occurring event following the early stages of tissue healing after an injury, or in this case, after a dental implant procedure. Ensuring a rapid and short inflammatory phase guarantees an early

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start of the proliferative phase. The invasion and proliferation of mesenchymal and endothelial (cells or tissue) will create the appropriate network for the dental implant osteointegration[6]. An excessive inflammatory reaction can cause the rejection of the implanted device[7–9]. This exacerbated inflammation can be multifactorial; some conditions or attitudes that conduce to rejection of implanted devices are: an inadequate surgical protocol, increased temperature of the bone bed, contamination of the surgical site and/or implanted device or an allergic adverse reaction[7–9]. After inflammation, the proliferative phase occurs, and new tissue grows to close the wound[6]. Any protocol or action towards increasing the speed of cell proliferation or migration results in favor of a successful osseointegration of dental implants. For this reason, capacitive-resistive energy transfer (CRet) can help increase the speed of cell proliferation and healing[10]. This technique is commonly used to treat muscular, bone, joint and tendinous lesions in the sports traumatology field[11–14]. CRet is a non-invasive electrothermic therapy classified as deep thermotherapy. Which consists of applying an electric current in the radiofrequency range of 300 kHz–1.2 MHz[15]. CRet therapy can be applied in two different treatment modes: capacitive and resistive. Capacitive mode is provided with an insulating ceramic layer and the energetic transmission generates heat in superficial tissue layers, with a selective action in tissues with low-impedance (water-rich)[16]. The resistive mode has no insulating ceramic layer; the radiofrequency energy passes directly through the body in the direction of the inactive electrode, generating heat in the deeper and more resistant tissues (with less water content)[16].

The physiological effects of CRet therapy are generated by the application of an electromagnetic field, with a frequency of approximately 0.5 MHz, to the human body. The effects attributed to this technique include increased blood circulation, lymphatic effects, increased cell proliferation and, if desired, a thermal increase of deep and superficial structures[15,17,18]. Some of these reactions, such as increased blood perfusion, are related to an increase in temperature in the tissue. However, others, such as cell proliferation, appear to be more related to the flow of electric current[17]. It has been described that at 0.00005 A/m^2 of current flow, the phenomenon of cell proliferation begins[19].

Currently, there are five studies analyzing thermal changes and current flow in cadavers using CRet therapy[15,16,18,20,21]. These studies focus on the Achilles tendon region and the myotendinous junction of the gastrocnemius muscles[15], on the capsular and intra-articular structures of the knee[18], on the tendon and capsular structures of the glenohumeral joint[20], on a clinical protocol for the elbow region[21] and biceps femoris and quadriceps[16]. However, no study has been found that assesses changes in temperature and current flow in intraoral structures such as teeth or dental implants. The relevance of generating current flow and cell proliferation (cell proliferation stimulated by current flow) without excessively increasing or even decreasing the temperature could set a precedent for a more effective recovery of acute dental implant patients during their consequent inflammatory phase. It is unknown whether the presence of an implant can generate a higher temperature increase. For this reason, it seems interesting to study the differences in order to be able to perform safe treatments in living patients.

The objective was to evaluate and compare the changes in temperature and current flow of different CRet applications on upper and lower molars and incisors with and without implants by performing invasive measurements on cadaveric specimens.

The null hypothesis was that there are no significant temperature differences in the application of CRet therapy in cadaveric specimens with and without implants and that there is no current flow in cadaveric specimens.

The alternative hypothesis was that there are significant temperature differences in the application of CRet therapy in cadaveric samples with and without implants and that there is current flow in the cadaveric samples.

Results

The current flow was stable during the applications. The incisor region without implants showed values of 0.12 A ± 0.1 (CAPH), 0.23 A ± 0.2 (CAP75), 0.24 A ± 0.1 (RES8) and 0.36 A ± 0.2 (RES20). In the incisor region with implants, we found values of 0.24 A ± 0.14 (CAPH), 0.29 A ± 0.22 (CAP75), 0.27 A ± 0.09 (RES8) and 0.47 A ± 0.15 (RES20).

In the molar region without implants, we found values of 0.09 A ± 0.1 (CAPH), 0.18 A ± 0.19 (CAP75), 0.18 A ± 0.15 (RES8) and 0.27 A ± 0.24 (RES20). In the molar region with implants, values of 0.13 A ± 0.02 (CAPH), 0.26 A ± 0.03 (CAP75), 0.31 A ± 0.05 (RES8) and 0.47 A ± 0.08 (RES20) were found.

The temperature recorded during the different applications at the beginning and at the end of the treatment, both in the superficial region and in the upper and lower molar/incisor region, is shown in Table 1 for the incisors and in Table 2 for the molars.

In the between-group analysis of the incisors, statistically significant differences were found in the superficial region temperature of the RES20 application ($p = 0.014$), the upper incisors temperature of the CAP75 application ($p = 0.013$) and RES20 ($p = 0.045$), in the lower incisor's temperature of the CAPH application ($p = 0.010$). In the within-group analysis of the incisors, statistically significant differences were found in the RES20 application in the superficial region temperature ($p = 0.010$) and in the upper incisor's temperature ($p = 0.006$) in the non-implant group with an increase in temperature of 1.81° and 2.40° respectively.

In the between-group analysis of molars only, statistically significant differences were found in the lower molar temperature of the CAPH application ($p = 0.028$). In the within-group analysis of the molars, statistically significant differences were found in the superficial region temperature of the CAP75 and RES20 applications. In the CAP75 application, the group with implants ($p = 0.002$) and without implants ($p = 0.033$) showed a superficial temperature increase of 6.41° and 4.70°, respectively. In the RES20 application, the group with implants ($p < 0.001$) and without implants ($p = 0.008$) showed a superficial temperature increase of 4.41° and 3.32°, respectively.

		Baseline	End of treatment	Difference (95% CI)	Within-group p
Superficial	CAPH—implants	19.32 ± 1.38	20.06 ± 1.76	0.74 [− 0.34, 1.82]	0.548
	CAPH—no implants	18.80 ± 2.23	19.04 ± 1.92	0.24 [− 0.84, 1.32]	1.000
				Between-group p = 0.262 F = 1.342	
	CAP75—implants	19.52 ± 1.47	20.09 ± 2.24	0.57 [− 1.51, 2.65]	1.000
	CAP75—no implants	19.70 ± 2.16	21.31 ± 3.73	1.61 [− 0.47, 3.69]	0.290
				Between-group p = 0.229 F = 1.553	
	RES8—implants	18.33 ± 1.38	19.06 ± 1.49	0.73 [− 0.35, 1.81]	0.598
	RES8—no implants	18.60 ± 1.92	19.24 ± 2.27	0.64 [− 0.44, 1.72]	1.000
				Between-group p = 0.838 F = 0.043	
	RES20—implants	18.49 ± 1.24	18.66 ± 1.16	0.17 [− 1.34, 1.68]	1.000
	RES20—no Implants	17.89 ± 2.28	19.70 ± 3.09	1.81 [0.30, 3.32]	0.010
				Between-group p = 0.014 F = 7.369	
Upper	CAPH—implants	25.94 ± 3.56	27.53 ± 4.81	1.59 [− 0.47, 3.65]	0.289
	CAPH—no implants	24.98 ± 3.79	25.14 ± 3.75	0.16 [− 1.90, 2.22]	1.000
				Between-group p = 0.100 F = 3.012	
	CAP75—implants	25.59 ± 4.18	27.59 ± 3.94	2.00 [0.83, 3.17]	< 0.001
	CAP75—no implants	25.16 ± 4.04	25.87 ± 4.46	0.71 [− 0.46, 1.88]	0.968
				Between-group p = 0.013 F = 7.576	
	RES8—implants	30.02 ± 2.26	31.43 ± 1.73	1.41 [− 0.54, 3.36]	0.417
	RES8—no implants	25.53 ± 4.42	26.41 ± 4.80	0.88 [− 1.07, 2.83]	1.000
				Between-group p = 0.506 F = 0.461	
	RES20—implants	30.57 ± 3.28	31.35 ± 2.06	0.78 [− 1.10, 2.66]	1.000
	RES20—no implants	23.81 ± 5.52	26.21 ± 4.87	2.40 [0.52, 4.28]	0.006
				Between-group p = 0.045 F = 4.654	
Lower	CAPH—implants	22.60 ± 2.08	24.77 ± 1.84	2.17 [− 0.05, 4.39]	0.059
	CAPH—no implants	21.00 ± 3.28	20.61 ± 4.10	− 0.39 [− 2.61, 1.83]	1.000
				Between-group p = 0.010 F = 8.320	
	CAP75—implants	21.74 ± 3.06	22.78 ± 2.89	1.04 [− 1.04, 3.12]	1.000
	CAP75—no implants	20.94 ± 4.37	20.62 ± 5.45	− 0.32 [− 2.40, 1.76]	1.000
				Between-group p = 0.121 F = 2.653	
	RES8—implants	24.73 ± 2.51	25.88 ± 2.30	1.15 [− 0.90, 3.20]	1.000
	RES8—no implants	20.74 ± 3.79	21.07 ± 5.03	0.33 [− 1.72, 2.38]	1.000
				Between-group p = 0.331 F = 0.997	
	RES20—implants	24.78 ± 2.55	24.80 ± 3.00	0.02 [− 3.05, 3.09]	1.000
	RES20—no implants	19.71 ± 6.05	20.56 ± 5.31	0.85 [− 2.22, 3.92]	1.000
				Between-group p = 0.508 F = 0.455	

Table 1. Incisor with and without implants. *CI* confidence interval, *CAPH* capacitive hypothermic, *CAP75*: capacitive 75 VA, *RES8* resistive 8 watts, *RES20* resistive 20 watts.

Discussion

Based on the results obtained, the alternative hypothesis, that there are significant temperature differences in the application of CRet therapy in the cadaveric samples with and without implants and that there is current flow in the cadaveric samples, can be accepted. Therefore, the null hypothesis, that there are no significant temperature differences in the application of CRet therapy in cadaveric specimens with and without implants and that there is no current flow in cadaveric specimens, can be rejected. However, in two applications (RES8 and CAPH) no significant temperature differences were observed between the implant and non-implant groups.

The highest significant temperature rise produced in the upper and lower molar and incisor applications was only 2.4° of temperature at the surface level. In addition, the living tissue would likely experience an even lower temperature rise since, in these subjects, the blood actively circulates through the body dissipating heat to adjacent areas[22]. This process, called thermoregulation, prevents unwanted hyperthermia in nearby tissues, as well as excessive heat during treatment[22].

As with any implantable device in hard tissues, dental implants need to be osseointegrated in the bone to be functional[23]. Osseointegration is an ordered cascade of events that lead to the integration of an implantable device into a hard-living tissue. Osseointegration follows the sequence of tissue healing, being among the first steps in the inflammatory phase. In a physiological environment, the inflammatory phase begins 10 min after the injury and takes hours to days to end[24]; a shorter time is considered better for the healing process. After the injury, platelets arrive, and first events occur, such as degranulation and histamine derived vasodilatation,

		Baseline	End of treatment	Difference (95% CI)	Within-group p
Superficial	CAPH—implants	17.76 ± 1.95	19.08 ± 1.43	1.32 [− 0.24, 2.88]	0.163
	CAPH—no implants	19.54 ± 2.48	19.97 ± 2.66	0.43 [− 1.13, 1.99]	1.000
				Between-group p = 0.170 F = 2.041	
	CAP75—implants	18.26 ± 1.80	24.67 ± 3.04	6.41 [1.94, 10.88]	0.002
	CAP75—no implants	20.25 ± 3.01	24.95 ± 6.01	4.70 [0.23, 9.17]	0.033
				Between-group p = 0.352 F = 0.915	
	RES8—implants	17.63 ± 1.56	19.37 ± 1.44	1.74 [− 0.13, 3.61]	0.086
	RES8—no implants	18.76 ± 1.90	20.57 ± 3.69	1.81 [− 0.61, 3.68]	0.064
				Between-group p = 0.927 F = 0.009	
	RES20—implants	18.32 ± 1.56	22.73 ± 2.10	4.41 [1.73, 7.09]	< 0.001
	RES20—no implants	19.16 ± 3.58	22.48 ± 5.29	3.32 [0.64, 6.00]	0.008
				Between-group p = 0.323 F = 1.032	
Upper	CAPH—implants	26.85 ± 3,64	27.16 ± 3.72	0.31 [− 1.24, 1.86]	1.000
	CAPH—no implants	23.78 ± 4,99	23.33 ± 5.54	-0.45 [-2.00, 1.10]	1.000
				Between-group p = 0.237 F = 1.497	
	CAP75—implants	26.59 ± 3.90	26.89 ± 5.39	0.30 [− 2.68, 3.28]	1.000
	CAP75—no implants	24.17 ± 4.85	24.17 ± 6.19	0.00 [− 2.98, 2.98]	1.000
				Between-group p = 0.804 F = 0.063	
	RES8—Implants	27.60 ± 5.16	28.47 ± 4.15	0.87 [− 0.90, 2.64]	1.000
	RES8—No Implants	24.57 ± 4.85	24.47 ± 6.31	− 0.10 [− 1.87, 1.67]	1.000
				Between-group p = 0.188 F = 1.873	
	RES20—implants	26.50 ± 4.61	27.40 ± 4.05	0.90 [− 0.84, 2.64]	1.000
	RES20—no implants	23.51 ± 5.60	25.05 ± 5.95	1.54 [− 0.20, 3.28]	0.121
				Between-group p = 0.370 F = 0.846	
Lower	CAPH—implants	23.11 ± 3.03	23.57 ± 3.00	0.46 [− 0.75, 1.67]	1.000
	CAPH—no implants	21.54 ± 4.54	20.84 ± 4.41	− 0.70 [− 1.91, 0.51]	1.000
				Between-group p = 0.028 F = 5.695	
	CAP75—implants	23.32 ± 3.12	24.69 ± 3.19	1.37 [− 0.95, 3.69]	1.000
	CAP75—no implants	20.48 ± 5.15	20.53 ± 5.36	0.05 [− 2.27, 2.37]	1.000
				Between-group p = 0.173 F = 2.011	
	RES8—implants	24.19 ± 2.51	23.87 ± 2.50	− 0.32 [− 2.13, 1.49]	1.000
	RES8—no implants	20.93 ± 4.75	21.26 ± 5.09	0.33 [− 1.48, 2.14]	1.000
				Between-group p = 0.383 F = 0.800	
	RES20—implants	23.93 ± 2.53	23.64 ± 2.87	− 0.29 [− 3.69, 3.05]	1.000
	RES20—no implants	20.04 ± 6.48	20.22 ± 6.06	0.18 [− 3.16, 3.52]	1.000
				Between-group p = 0.729 F = 0.124	

Table 2. Molar with and without implants. *CI* confidence interval, *CAPH* capacitive hypothermic, *CAP75* capacitive 75 VA, *RES8* resistive 8 watts, *RES20* Resistive 20 watts.

leading to increased blood flow and decreased stream velocity. Limiting the inflammatory phase, we ensure to move as quickly as possible to the proliferative phase. A recent publication studying the effects of CRet on cell proliferation and migration showed that 6 h after the application, migration and proliferation were increased. In this same study, results after 12 h of the CRet application showed a slight decrease in the phosphorylation of p38 proteins and a slight increase of other proteins related to a MAPK pathway, possibly indicating that the CRet treatments might have an anti-inflammatory effect (as well as a proliferative induction/effect)[10]. Achieving cellular proliferation could be indicated in inflammatory pathologies that need tissue regeneration, especially during the first 2 weeks[25,26].

The evolution from the inflammatory to the proliferative phase encompasses the formation of a new collagenous extracellular matrix and angiogenesis. The duration of this phase lasts from a few days to a few weeks. Fibroblasts will start to proliferate via integrins and migrate using an amoeboid movement from the healthy surrounding tissue into the wound, where the blood clot is forming, and inflammatory cells are present[27]. The proliferative phase also includes the formation of new blood vessels in the wound site, which is a mandatory prerequisite for tissue healing[27].

In this way, CRet therapy could be a strategy to increase cell proliferation without increasing the temperature (which would be negative in an inflammatory phase of the tissues)[19]. This improvement in cell proliferation would result in less pain for patients and possible better consolidation of the implant in a shorter time[15,17,18]. However, this hypothesis should be verified in future studies with living patients.

Figure 1. Schematic of the CRet device. (A) Return electrode (base plate); (B) T-Plus Control Center; (C) capacitive electrode; (D) resistive electrode.

This study has several limitations, which are described below. First, it is a study performed on cadavers in which there is no thermoregulation or active blood circulation. In living subjects, the body's thermoregulatory effect dissipates heat, probably producing more significant temperature increases in the cadaveric samples than those expected in living subjects[22]. Another limitation is found in the properties of the tissues. Another limitation is that cadaveric studies are performed with a small sample size, and despite being cryopreserved cadavers, the properties of the tissues may vary slightly from those of living subjects. Despite these limitations, the authors consider that the use of donor bodies has made it possible to know how different CRet applications affect the temperature and current flow values in the molar and incisor region and to know their effects and applicability before applying them to real patients.

In conclusion, all applications used in this study generated current flow and did not generate significant temperature increases in the tooth region with or without implants. However, the RES20 and CAP75 applications generated a thermal increase in some conditions. So, RES8 and CAPH applications seem to be the best options to achieve current flow without temperature increase in molars and incisors with and without implants. These basic science results may be the precedent for using RES8 and CAPH applications in living patients.

Methods

Study design. A cross-sectional study was conducted to determine the effect of electrical resistive/capacitive energy transfer of the T-Plus (Wintecare SA, Chiasso, Switzerland) device on temperature and current in the intraoral region (incisors and molars with and without implants) in cadaveric samples. The body donation program of the Faculty of Medicine and Health Sciences of the Universitat Internacional de Catalunya provided all the samples. This study was approved by the ethical committee "Comitè d'Ètica de Recerca (CER) of Universitat Internacional de Catalunya" with reference number CBAS-2019-17 approved on April 4, 2022.

Cadaveric sample. The sample consisted of 10 complete corpses (5 with implants and 5 without implants), cryopreserved and fresh. Measurements were taken on the right and left molars and the right and left incisors on each corpse. This generated a total sample of 10 molars with implants, 10 incisors with implants, 10 molars without implants and 10 incisors without implants. The cadavers were stored at 3 °C and kept at room temperature[18] for 36 h before the study[16]. The mean age of the cadavers was 67.7 [± 6.0] years. None of the cadaveric specimens used for this study had evidence of trauma or surgical scars in the craniomandibular region.

Intervention. The power range of a T-Plus (Wintecare SA, Chiasso, Switzerland) (Fig. 1) device used in this study varies from 1 to 300 watts in resistive mode and from 1 to 450 VA in capacitive mode[15]. The power was determined by the protocol used depending on the region to be treated. In the mandibular region, the aim was not to generate an undesired increase in temperature, knowing that an increase in temperature could lead to an increase in inflammation and thus a rejection of the dental implant[4].

In this study, low power applications were used, not exceeding the 0.3 A limit[15]. Applications were performed with a 15 VA capacitive hypothermic electrode (CAPH), 8 watts resistive (RES8), 20 watts resistive (RES20) and 75 VA capacitive (CAP75).

Four interventions were performed (CAPH, RES8, RES20 and CAP75) for 5 min each. The base plate was placed in the scapular area of the specimen contralateral to the side to be treated. The mobile electrode was placed in the lateral region of the jaws for treatment on the molars and the anterior area for the incisors (Fig. 2). Dynamic movements like those used with real patients were performed with constant pressure. The treatments were performed by a physiotherapist (HGC) with more than 10 years of experience in the use of T-Plus.

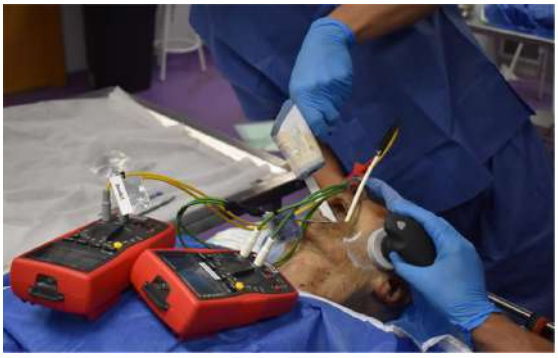

Figure 2. Example of application of CRet intervention (CAPH) in molars and placement of temperature gauges.

Experimental procedure. Each cadaver was placed in supine position with partially opened mouth.

A dentist (CSJ) with 10 years of experience performed the extraction of teeth from the cadavers and the placement of implants in the implicated specimens (Bone level tapered implants, 4.1 mm × 13 mm (diameter × length); Roxolid, Basel, Switzerland) in the incisors and molars. In the case of the samples without implants, only tooth extraction was performed to measure the implant's exact point.

The order of the treatment protocols and the treatment of the cadavers were randomized prior to the study. An external researcher carried out this randomization using the "random.org" software. Before applying each treatment it was ensured that the basal temperature of each corpse returned to the initial values before applying the next treatment.

Before starting the measurements it was ensured that all the instrumentation used had a calibration certificate. Invasive temperature devices "Hart Scientific PT25 5628-15 (Fluke, Everett, Washington, USA)" were used to measure the temperature (°C) of the molars and incisors. One of the gauges was placed on the lower molar/incisor and the other on the upper molar/incisor of the same side to be treated. In the case of the implant group, this gauge was placed in contact with the implant. In the case of subjects without implants, the temperature gauge was placed right in the tooth socket. A "Thermocomed (AB Medica Group, Barcelona, Spain)" digital thermometer was used to measure the superficial temperature of the skin in the mandibular region.

The T-Plus's return electrode (base plate) was placed on the scapular area of the cadavers. The treatment was performed with the mobile electrode of the T-Plus in the previously explained treatment region according to each application for 5 min. Initial surface and deep tissue temperatures were measured. These measurements were recorded before starting the application and immediately after finishing (at the end of the 5-min treatment). In addition, temperature changes during each minute of treatment were recorded as a temperature control measure. Before the treatment, impedance was always recorded (Multimeter Fluke 8846A) to ensure that the values marked by the T-Plus Wintecare device were correct. In addition, the actual current flow for each application was calculated using the average voltage divided by the initial impedance.

Statistical analysis. Statistical analysis was performed with SPSS (Version 22.0; IBM, Armonk, NY, USA). Normal distribution was calculated with the Shapiro–Wilk test ($p > 0.05$). The mean and standard deviation of the superficial temperature and of the temperatures taken with the invasive devices were calculated depending on each application. For within-group analysis, the repeated samples ANOVA (2×4) test with Bonferroni's post-hoc was used. For between-group analysis, the one-factor ANOVA test was used. The value of $p < 0.05$ was considered statistically significant.

Ethics approval. The Comité d´Ètica de Recerca from Universitat Internacional de Catalunya approved the study (CBAS-2019-17) approved on April 4, 2022. The investigation conformed with the principles outlined in the Declaration of Helsinki. The informed consent from "body donors" was obtained before the death and any personal data was hidden.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions
All authors have read and approved the manuscript. P.B.A. wrote the introduction and discussion sections, and he prepared the cadaver and performed superficial temperature measurements. C.S.J. Performed all dental procedures for the study and wrote introduction and discussion. J.R.S. wrote and designed the methods section. H.G.C. made the CRet interventions and assisted in the drafting of the article. G.R.V. worked on sample collection and review of article and critical review. G.V.S. worked on sample collection and review of article and critical review. Z.C.D. worked on sample collection and review of article. L.d.C.C. He performed the statistical analysis, the writing of results section and the calibration of the instruments.

Competing interests
The authors declare no competing interests.

Additional information
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