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# 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

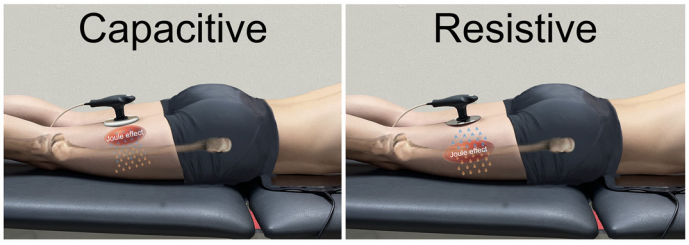


**Figure 1** — Example of capacitive and resistive biceps femoris treatment. The blue drops (closer to the electrode) represent tissues with more water. The brown drops (further away from the electrode) represent tissues with more resistance.

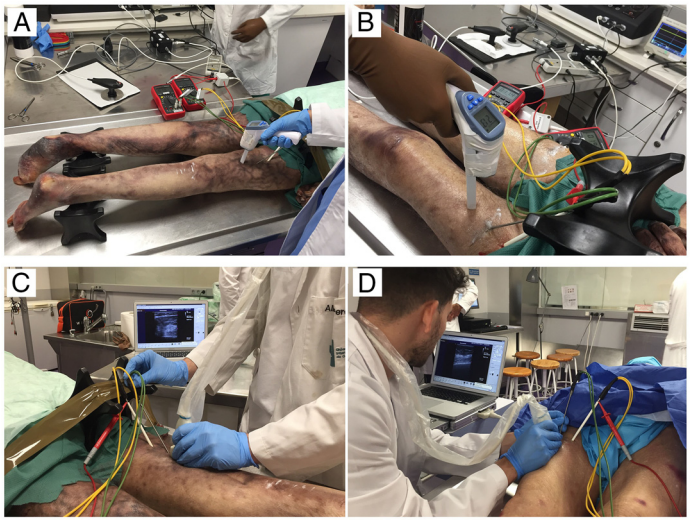


**Figure 2** — Superficial temperature measurement with digital thermometer (A) biceps femoris and (B) quadriceps; ultrasound placement of invasive middle and deep temperature meters in the (C) biceps femoris and (D) quadriceps.

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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