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The Short and Long Term Effects of Tibialis Anterior Local Cooling on Dorsiflexion Force

by
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The goal of this study was to analyze and compare the superficial temperature, dorsiflexion force and electromyographic (EMG) signal of tibialis anterior muscle before and after superficial cooling application. Seventeen healthy untrained volunteers were divided into two groups. Subjects were submitted to seven procedures of maximal voluntary isometric contractions of dorsiflexion, once before and six times after thirty minutes of either superficial cooling of the anterolateral side of the leg with an ice pack (LC group) or rest (control group). Superficial temperature, dorsiflexion force and EMG of the tibialis anterior muscle were evaluated immediately, 5, 15, 30, 45 and 60 minutes after cooling intervention. The results showed that the superficial temperature reduced significantly for 60 minutes post cooling, dorsiflexion force and amplitude of EMG signal was reduced only immediately after cooling application, whereas median frequency of EMG signal was significantly reduced up to 60 minutes post cooling application. The study concludes that superficial cooling with ice pack for thirty minutes can decrease the dorsiflexion force and EMG activity only immediately after the cooling application, while it causes a prolonged decrement on the superficial local temperature and on the median frequency of the EMG signal. These findings suggest that clinicians should be aware of the immediately alterations in motor output performance that result from muscle local cooling interventions which are followed by rapid recovery.

Key words: electromyography, median frequency, motor output, ice packs.

Introduction

Local cooling is commonly used in sports medicine to treat tissue injuries or to prepare tissue to exercise (Richendollar et al., 2006; Zemke et al., 1998) due to its capacity to reduce cellular metabolism, secondary hipoxy, oedema, pain, muscle spasm, and inflammatory processes, as well as facilitate the accomplishment of movement and help tissue recovery (Atnip & Mccrory, 2004; Bleakley et al., 2004; Hubbard et al., 2004; Knight, 1995). In addition, local cooling has been used by athletes during sports rehabilitation and training, before and during practice sessions and even in between game periods (Atnip & Mccrory, 2004; Hubbard et al., 2004). Local cooling interventions can be carried out using ice packs or immersion in cold water (Van Lunen et al., 2003; Verducci, 2000). When ice packs are applied over the muscle belly it leads to the reduction of skin and muscle temperatures resulting in changes in the

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physiological proprieties of the muscle (Castle et al. 2006; Petrofsky & Laymon, 2005; Rutkove, 2001). It has been shown that local muscle cooling may influence muscle resistance (Castle et al., 2006; Verducci, 2000) and force production (Oksa 2002; Oksa et al., 1997; Holewijn & Heus, 1992).

Muscle strength immediately following a local cold application has been investigated throughout isometric contractions (Farina et al., 2005; Thornley et al., 2003; Oksa 2002; Oksa et al., 1997; Barnes & Larson, 1985; Oliver et al., 1979) and the results indicate a decrease of muscle strength immediately after muscle cooling. Muscle cooling also reduces sarcolemma conduction, what is reflected by the changes in EMG signal (i.e. decrease of spectral parameters) (Petrofsky & Laymon, 2005; Oksa 2002), and peripheral nerve conduction (Franssen & Wieneke, 1994; Halar et al., 1980), compromising the neural input to central nervous system from muscle receptors. In addition, muscle cooling can affect the contractile apparatus of skeletal muscles (Ricker et al., 1977).

The findings about the long-term effects of muscle cooling on motor output performance are restricted to two (Coppin et al., 1978; Johnson & Leider, 1977) that demonstrated handgrip strength reduction up to 80 minutes after forearm immersion. It is important to note that the different methods of cooling (i.e., ice pack or immersion) may cause different motor output responses, especially because during immersion not only a specific muscle has its temperature lowered but normally several muscles and joints. Immersion has been extensively used in scientific studies (Petrofsky & Laymon, 2005; Douris et al., 2003; Cross et al., 1996; Holewijn & Heus, 1992; Coppin et al., 1978; Johnson & Leider, 1977), but during sports competitions and rehabilitation programs local cooling is much more common (Richendollar et al., 2006; Zemke et al., 1998).

The present study was undertaken to investigate the influence of local cooling, through ice pack application, on the dorsiflexion force and electromyographic activity of tibialis anterior muscle immediately and up to 60 minutes after local cooling. We hypothesized that local cooling of the tibialis anterior will cause a decrease in dorsiflexion force immediately after and up to 60 min after cooling intervention.

Methods

Subjects

Eighteen subjects (11 men and 7 women) with no previous history of ankle pain or pathology of this joint took part in this study; their average height, mass and age were 1.72 (SE = 0.04) m, 74 (SE = 6) Kg and 22 (SE = 1) years. The study was approved by the local ethics committee (Protocol #: H167/CEP/2006) and all subjects gave informed written consent to participate in the study.

Experimental protocol

The subjects were randomly divided in two groups called LC (n = 9; 6 men and 3 women) and CONT (n = 8; 4 men and 4 women). All subjects were submitted to seven procedures of maximal voluntary isometric contractions (MVIC) of dorsiflexion with their dominant leg during 6 seconds. The first MVIC was separated of the second by 30 min of local (superficial) cooling application, for the group LC, or rest at environmental temperature (i.e., 26^{o} C) for the group CONT. The second MVIC was called POS 0 and the others MVIC POS 5, POS 15, POS 30 and POS 60 according to the time after procedure (cooling or control) (Figure 1).

The ice was applied in the form of crushed ice in a standardized plastic ice pack (1 kg of ice in a 10 L plastic bag with the air evacuated) strapped by elastic band over the anterolateral aspect of the dominant leg for 30 minutes to obtain effective cooling of the tibialis anterior muscle belly. The plastic ice pack strapped by elastic band was chosen because it reproduces a common clinical conduct used in physiotherapy and sports medicine.

Figure 1

Experimental protocol: POS 0 – immediately after procedure (cooling or rest), POS 5 – five minutes after procedure, POS 15 – fifty minutes after procedure, POS 30 – thirty minutes after procedure and POS 60 – sixty minutes after procedure

Table 1

Mean ± Standard Error (SE) of absolute values of RMS, MDF from FFT, force and superficial temperature

Variable	Group	PRE	POS0	POS5	POS15	POS30	POS45	POS60
Temperature (°C)	LC	31.3±0.4	11.9±0.7	18.6±0.7	22.9±0.7	25.9±0.8	27.5±0.8	28.7±0.6
	CONT	31.0±0.3	30.±0.5	31.0±0.5	31.0±0.5	30.9±0.5	30.7±0.5	31.0±0.4
Force (N)	LC	273±23	236±18	238±20	261±26	255±23	285±28	288±29
	CONT	245±27	246±26	245±26	239±26	245±23	247±24	239±26
EMG (µV)	LC	341±24	265±23	327±31	368±33	382±22	371±27	353±23
	CONT	309±40	313±36	284±32	276±27	315±21	299±28	295±31
MDF (Hz)	LC	99±5	60±4	59±6	72±4	76±3	84±3	85±5
	CONT	88±6	90±5	94±4	94±4	91±5	86±4	101±5

Procedures and Materials

The dorsiflexion force was assessed using a strain gauge (range 0-2000N, EMG System, Brazil) coupled in a manufactured device, specially made for the study. The experimental schematic of the measurement of the isometric force of dorsiflexion is depicted in Figure 2. Subjects were placed in a supine position, the foot was secured to a footplate by Velcro straps and the dorsiflexors were stretched to their optimal length for maximal force by setting the ankle angle at 10° plantar flexion (0° = neutral position) (Marsh et al., 1981). The strain gauge was placed in a 90° to the force direction to improve the reliability of the measure.

The EMG signals were obtained from the tibialis anterior muscle during the performance of the unilateral isometric dorsiflexion of the subject's dominant leg. After a careful preparation of the skin (shaving, abrasion and cleaning with alcohol) bipolar surface EMG electrodes (Meditrace) were placed with a 20 mm inter-electrode distance on the belly portion of the tibialis anterior. The signals were obtained using an eight channel module (model EMG800C, EMG System, Brazil) with a total amplifier gain of 2000 and a common mode rejection ratio of 120 dB. A 12 bit converter digitalized the analog signals with a sampling frequency of 3000 Hz for each channel and an input range of 5 mV. After initial preparation, electrode placement location was determined following SENIAM guidelines (Hermens et al., 1999).

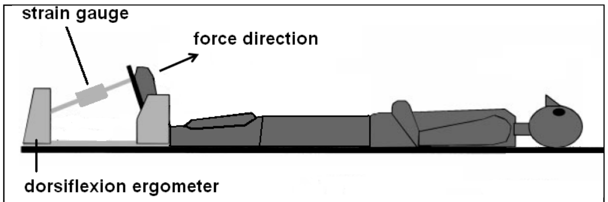

Figure 2

Mean ± Standard Error (SE) of absolute values of RMS, MDF from FFT, force and superficial temperature

Superficial temperature of the anterolateral portion of leg was measured under the belly portion of tibialis anterior using an infrared thermometer (model TD-955; Icel Manaus, Brazil) with precision of 0,1 °C. The measures were done before each MVIC for both groups.

Data Analysis

The EMG signals for 6 seconds were analyzed in time and frequency domain. For the time domain the EMG signals were filtered by band-pass filter (20-500Hz) and the signal amplitude (µV) was calculated through the root mean square (RMS). For the frequency domain the Fast Fourier Transform was done for the identification the median frequency (MDF) of the total power spectrum. All data analysis was done in Matlab 7.0.1 (MathWorks Inc.).

Statistics

All variables were studied at absolute values and normalized values taking the measure before experimental protocol (cooling or control) as reference (i.e. measure PRE). To compare the variables between groups only the normalized values were used. Analysis of variance with repeated measures was used to compare dorsiflexion force, RMS and MDF of the local cooling and control groups before (PRE) and several times after the intervention (POS0, 5, 15, 30, 45 and 60). When a significant F ratio was obtained, one-way analysis of variance with a Bon-

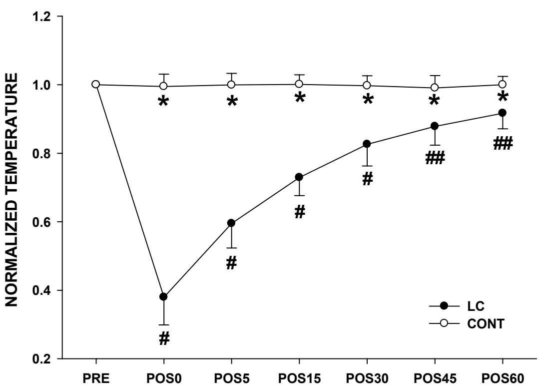

Figure 3

Mean (±SE) of normalized surface temperature before (PRE) and at different moments after (POS) experimental procedure (cooling or rest). (*) Difference between groups in all measures; (#) Different from all other measures in group LC; (##) Different from PRE, POS0, POS5, POS15, POS30 in group LC (p < 0.05)

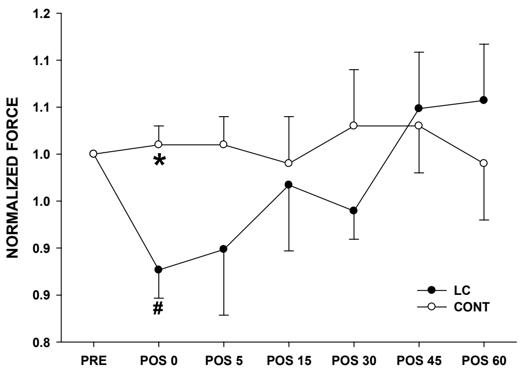

Figure 4

Mean (±SE) of normalized dorsiflexion force before (PRE) and at different moments after (POS) experimental procedure (cooling or rest). (*) Difference between groups in POS 0; (#) Different from PRE in group LC (p < 0.05)

ferroni's post hoc test was applied, and significance was accepted at $p < 0.05$. Pearson's product moment correlation coefficient was calculated for identification of possible linear association between the local skin temperatures and spectral parameters of the EMG signal.

Results

The absolute values of the variables studied (EMG, dorsiflexion force and surface temperature) are presented in table 1.

The surface temperature was significantly reduced after cooling and increased in the course of time after procedure without reaching its initial values ($F_{6, 48} = 155.526$; $p < 0.001$). There were differences in normalized surface temperature between groups in all measures after cooling ($p < 0.001$) (Figure 3).

The dorsiflexion force was significantly reduced (12%) immediately after cooling (POS0) when compared to PRE and POS60 measures ($F_{6, 48} = 3.629$; $p<0.01$). When compared to normalized dorsiflexion force of CONT group, LC group also demonstrated significantly reduction ($p < 0.01$) (Figure 4). Similar results were observed considering normalized RMS, which was reduced 20% immediately after cooling ($F_{6, 48} = 4.090$; $p < 0.01$) (Figure 5).

Median frequency (MDF) of power spectrum obtained through FFT demonstrated a significant reduction ($F_{6, 48} = 14.997$; $p < 0.001$) after cooling up to POS30 and there were differences between groups on normalized MDF (FFT) at POS0, POS5, POS15,

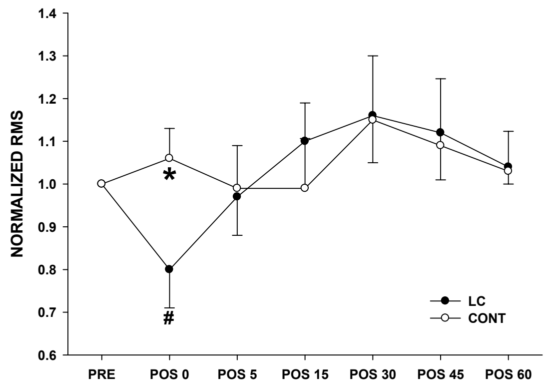

Figure 5

Mean (±SE) of normalized EMG activity before (PRE) and at different moments after (POS) experimental procedure (cooling or rest). (*) Difference between groups in POS 0; (#) Different from PRE in group LC (p < 0.05)

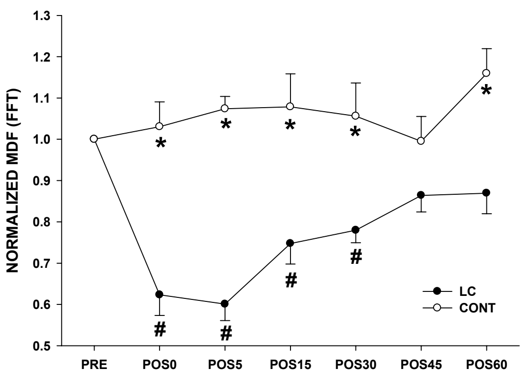

Figure 6

Mean (±SE) of normalized median frequency (MDF) using FFT before (PRE) and at different moments after (POS) experimental procedure (cooling or rest). (*) Difference between groups at PRE, POS0, POS5, POS15, POS30 and POS60; (#) Different from PRE in group LC (p < 0.05)

POS30 and POS60 ($p < 0.001$) (Figure 6).

In addition, Median frequency demonstrated a positive correlation with superficial the temperature ($r^2 = 0.67$; $p < 0.0001$).

Discussion

This study analyzed and compared the superficial temperature, dorsiflexion force and EMG signals of tibialis anterior before, immediately after and up to 60 minutes after superficial cooling application. One of the main results of this study is that dorsiflexion force decreases immediately after local cooling, but this effect does not remain for long periods of time. Additionally, we found that local cooling can cause long term changes in the median frequency of the EMG signal and that the median frequency correlates to the local temperature.

Dorsiflexion Force and EMG amplitude

In agreement with our hypothesis (Oksa et al., 1997; Cross et al., 1996), our results demonstrated that local cooling of the tibialis anterior can cause a significant decrease in dorsiflexion force immediately after cooling intervention. tibialis anterior EMG amplitude behaved similar to dorsiflexion force (Petrofsky & Laymon, 2005).The immediately cooling-induced decrease on dorsiflexion force may be explained by the interaction of many factors that include reduced release of calcium from the sarcoplasmic reticulum and the decline of ATP availability, which impairs the cross-bridge formation (Howard et al., 1994; Douris et al., 2003), impairment in the conduction velocity of muscle fibers (Kimura et al., 2003) and acetylcholine (ACh) binding kinetics (Rutkove 2001). Cross et al. (1996) reported an immediately reduction in muscle performance after cooling. The authors identify the decrease in performance of strength tests (vertical jump and shuttle run), but the cooling method was leg immersion and it was applied for 20 minutes. Holewijn and Heus (1992) also observed a fall in the maximal grip force after 30 min of local cooling (15°C), and Oksa et al. (1997) found reduced maximal muscle performances during dynamic exercise performed at a lowered room air temperature (10–5°C). All cited studies are in agreement with the reduction of strength after cooling, despite the different cooling methods have been used (i.e., immersion and environment exposure). These methods of cooling might reduce strength through different mechanisms than an ice pack coupled under a specific muscle, because during immersion and environment exposure not only an specific muscle has its temperature lowered but several muscles and joints. In addition, the cited studies investigated the cooling-induced strength decrease only immediately, without the knowledge about the long term effect, what was investigated in our study.

Contrary to what we expected (Coppin et al., 1978; Johnson & Leider, 1977), our results demonstrated that effects of local cooling of the tibialis anterior in the dorsiflexion force lasted for less than 5 minutes after cooling intervention was over. Previously, Johnson and Leider (1977) and Coppin et al. (1978) had showed a significant reduction on hand-grip strength up to 40 minutes after immersion (10°C) of the forearm for 30 minutes.

Muscle temperature and EMG median frequency

Our results demonstrated a positive correlation between temperature and EMG median frequency (Petrofsky & Laymon, 2005; Oksa, 2002; Bigland-Ritchie et al., 1981). This correlation may be explained by changes in the neuromuscular junctions, as changes in the kinetics of Ca^{++} influx and acetylcholine (ACh) binding what may influence the formation of the endplate potential (EPP) (Rutkove, 2001). In addition, the cooling may decrease the conduction velocity of muscle fibers as demonstrated by Kimura et al. (2003), changing the central frequency of EMG signal to lower frequencies (Petrofsky & Laymon, 2005; Oksa, 2002; Masuda et al., 1999; Kupa et al., 1995; Bigland-Ritchie et al., 1981; Stulen & DeLuca, 1981).

It is also relevant to mention that infrared thermometers are indicated to measure the skin and the near structures temperatures (Burnham et al. 2006; Matsukawa et al. 2000) and the values of temperature obtained in this study are similar to values obtained by Burnham et al. (2006) for leg region. These authors indicate the use of infrared thermometer to quantify the skin temperatures and advocate an advantage of this method compared to intramuscular thermistors, which has limitations in clinical practice.

Spectral changes in the EMG signal of the tibialis anterior may be associated to the strength reduction at POS0, however the EMG median frequency was reduced from POS0 up to POS60, while the dorsiflexion strength was reduced only at POS0. One possible reason for the apparent dissociation between force and EMG median frequency may be the compensatory activation of other dorsiflexor muscles, such as the extensor digitorum longus and the extensor hallucis longus muscles from POS5 to POS60.

Conclusion

Our results show that dorsiflexion force is reduced only immediately after tibialis anterior local cooling despite the long term reduction in the superficial temperatures and spectral structure of EMG signal. In addition, median frequency of the EMG signal demonstrated to have a similar behavior to local temperature.

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