J. Phys. Ther. Sci. 28: 2400–2403, 2016

The Journal of Physical Therapy Science

Original Article

Determination of effective treatment duration of interferential current therapy using electromyography

Jong-In Youn, PhD[1)], Ho Sub Lee, PhD, MD[2)], Sangkwan Lee, PhD, MD[3)]*

[1)] *Department of Biomedical Engineering, Catholic University of Daegu, Republic of Korea*
[2)] *Hanbang Body-Fluid Research Center, Wonkwang University, Republic of Korea*
[3)] *Department of Internal Medicine and Neuroscience, College of Korean Medicine, Wonkwang University: Iksandae-Ro 460, Iksan, Jeonbuk 570-749, Republic of Korea*

Abstract. [Purpose] This study used electromyography to measure the effective treatment duration of interferential current therapy for muscle fatigue. [Subjects and Methods] Fifteen healthy adult men volunteered to participate in the study (age: 24.2 ± 1.3 years; weight: 67.6 ± 4.92 kg; height: 176.4 ± 4.92 cm). All subjects performed 5 min of isometric back extension exercise to produce muscle fatigue, and were then treated with interferential current therapy for 15 min, with electromyography monitoring (treatment group). After sufficient rest, the exercise was repeated for 5 min and an electromyography signal was acquired for 15 min with no treatment (control group). [Results] In the treatment group, the median frequency shifted to a higher level; the root mean square decreased over time, and then maintained a minimum amplitude. However, there were few changes in the electromyography signal after exercise in the control group. [Conclusion] Electromyography signals can provide information about the effective duration for muscle fatigue treatment as well as the muscle characteristics during treatment. This study should be helpful for clinicians by demonstrating the appropriate duration of therapy for relief of muscle stiffness.

Key words: Interferential current therapy, Electromyography, Effective treatment time

(This article was submitted Mar. 8, 2016, and was accepted May 26, 2016)

INTRODUCTION

Interferential current (IFC) therapy is a form of transcutaneous electrical stimulation using medium frequency current, generally at about 4 kHz[1, 2)]. The interaction of 2 slightly different medium-frequency currents generates an amplitude-modulated low-frequency current (0–250 Hz). Because the kHz-region has low skin impedance, amplitude-modulated frequency currents reach deeper tissues and relieve various musculoskeletal pains, fibromyalgia, and knee osteoarthritis[3–8)]. These types of pain are related to the muscle fatigue that results from metabolic, energetic, and structural changes in muscles; these changes are due to deficiencies in oxygen and nutrients supplied by the blood vessels, or to altered efficiency of the nervous system[9)]. Muscle fatigue has been defined as the eventual inability to generate a desired or expected force; repeated and constant activation leads to poor functional or therapeutic results[10)]. A consistently fatigued muscle can develop various disorders and disturbances in the microcirculation that can lead to the sensitization of pain receptors, discomfort, and muscle stiffness[11)]. Sufficient treatment and diagnosis of muscular fatigue are important, and electrotherapies such as transcutaneous electrical nerve stimulation and IFC therapy have been used to reduce fatigue and stiffness in the musculature[12)]. Muscular fatigue has been diagnosed by using the Visual Analogue Scale, Modified Ashworth Scale, Functional Reach Test, and Berg Balance Scale, among others[13)]. However, these evaluations only estimate subjective musculoskeletal fatigue, and cannot quantitatively analyze muscle condition to acquire information about therapeutic effects in real-time, in order to determine appropriate treatment duration.

Electromyography (EMG) is widely used to measure muscular activity, and may be used to determine the production of

---

*Corresponding author. Sangkwan Lee (E-mail: sklee@wonkwang.ac.kr) force and to continuously analyze local muscle fatigue with a quantitative approach[9)]. The EMG signal is used to measure electrical activity and muscle action potentials, and can be used to evaluate muscular disease of the low back, biceps brachii, quadriceps, and masseter, as well as to predict risk for muscular disorders[14–19)].

EMG parameters that represent the condition of muscle include the root mean square (RMS) value and median frequency (MDF). The RMS is used to quantify muscle fatigue and relaxation during therapy, as it represents the level of muscle activity during contraction. Some studies have reported a correlation between the RMS value and muscle fatigue[14, 20)]. The reports showed that greater muscle fatigue is observed when the amplitude of the RMS is large due to muscle contraction. Conversely, when the amplitude of the RMS is relatively small, there is less muscle fatigue related to muscle contraction. Muscle fatigue has been associated with a decrease in MDF and an increase in RMS values[21–23)]. Furthermore, EMG signals can be analyzed in both the time and frequency domain by using wavelet transformation. The wavelet transform provides the best performance by localization in both the time and space domains. It has been used widely for EMG pattern analysis and classification due to its ability to separate fine details in a signal, with simultaneous localization and mapping of time and frequency domains[24, 25)].

In the present study, EMG signals were measured during IFC therapy, and the RMS value and MDF were analyzed to determine the recovery state of muscle. The study was performed to demonstrate improvement in muscular fatigue using raw EMG signals analyzed by fast Fourier transform and wavelet transformation. An effective treatment duration for relief of muscle fatigue was determined through the analysis of EMG signals; the findings can be helpful in monitoring muscle activity during IFC therapy.

SUBJECTS AND METHODS

Fifteen healthy adult males volunteered to participate in the study (age: 24.2 ± 1.3 years; weight: 67.6 ± 4.92 kg; height: 176.4 ± 4.92 cm) and provided written informed consent prior to the experiment. All experimental procedures conformed to the principles of the Declaration of Helsinki and were approved by the Ethics Committee of Catholic University of Daegu.

An EMG system (EMG sensor, Vernier, USA) was used during treatment of muscle fatigue with an IFC therapy device (STI500, Stratek, Korea). All subjects performed 5 min of isometric thoracolumbar extension exercise to produce muscle fatigue; then, the EMG signal was captured for 15 min without any treatment (control group). After sufficient rest, the exercise was repeated for 5 min, followed by IFC therapy for 15 min with monitoring of EMG signals (treatment group). Noise interference was negligible because there was no interference between the EMG and IFC devices. The acquired EMG signal was processed using LabVIEW2013 (National Instrument, USA) and analyzed in the frequency domain using the fast Fourier transform. A low-pass filter (0.1 Hz) and band-stop filter (60 Hz) were used to eliminate DC power and harmonic noise from a power supply, respectively. After filtering, the raw EMG signals were restored to a time domain using the inverse fast Fourier transform, and RMS values determined by the square root of the averaged values of EMG signals were used to represent muscle activity. Wavelet transformation was performed to provide simultaneous localization and to examine fine details in the time and frequency domains.

RESULTS

Table 1 here shows the RMS ratio and MDF of the EMG signal for each of the subjects obtained from control (untreated) conditions and during IFC therapy. The RMS ratio is a valuation measure that compares the level of initial RMS value to the level of final RMS value during specific time windows from measurement of an EMG signal for 900 s. The RMS values in the treatment group were decreased when compared with those in the control group. MDF shifts to higher frequencies were observed by applying IFC therapy. The MDF values of each subject derived from the raw EMG signal during IFC treatment were increased when compared with controls. Significant differences between the 2 conditions were examined for statistical significance with the t-test ($p<0.05$).

Figure 1 here represents the time-dependent distributions of RMS signals measured (a) for the untreated condition and (b) during IFC therapy of a representative subject. Similar tendencies were found for both conditions in the other subjects. In Fig. 1 (a), conservation of the RMS amplitude by muscle contraction can be observed in the untreated state (control); there were small changes in the RMS signal caused by minor muscle vibrations after the exercise, but these were negligible. However, the RMS signal increased significantly when the IFC therapy ($t=0$ s) began, then decreased over time, and finally maintained a minimum amplitude at a specific time ($t=670$ s), as shown in Fig. 1 (b).

Figure 2 here shows frequency analysis of EMG signals using wavelet transformation in a time series. The distribution of the frequency measured in the control group indicates that there were few changes in the amplitude of the frequency fluctuation caused by muscle contraction (Fig. 2 (a)). On the other hand, Fig. 2 (b) shows that there was a significant reduction of amplitude in the frequency distribution after 670 s of treatment, similar to the tendency shown for the RMS signals in Fig. 1 (b).

DISCUSSION

In this study, relief of muscle stiffness with IFC therapy was quantitatively measured by analysis of muscular fatigue using the MDF and RMS. When muscle fatigue occurs, biochemical byproducts such as H+ and lactic acid accumulate in

Table 1. The data for RMS ratio and MDF of the EMG signal for each subject obtained from controls (untreated condition) and during IFC therapy

Subject No.	$\text{RMS}_{\text{ratio}}$		MDF (Hz)	
	Control	IFC*	Control	IFC*
N1	0.64	0.29	62	65
N2	0.44	0.33	51	60
N3	0.81	0.37	50	57
N4	0.68	0.43	56	63
N5	0.58	0.24	42	53
N6	0.67	0.32	58	63
N7	0.55	0.43	61	66
N8	0.41	0.35	53	59
N9	0.66	0.46	48	54
N10	0.61	0.49	41	52
N11	0.69	0.48	55	60
N12	0.83	0.53	59	65
N13	0.71	0.53	53	63
N14	0.63	0.54	56	63
N15	0.51	0.23	49	57

*Significantly different from control ($p<0.05$)

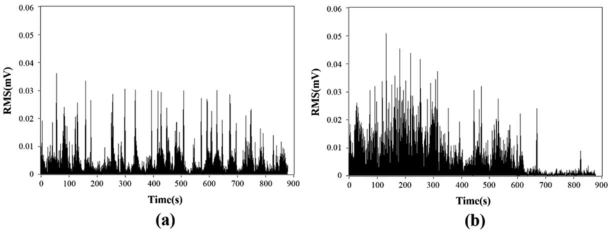

Fig. 1. The time-dependent distributions of RMS signals measured from (a) controls (untreated condition) and (b) during IFC therapy in a representative subject

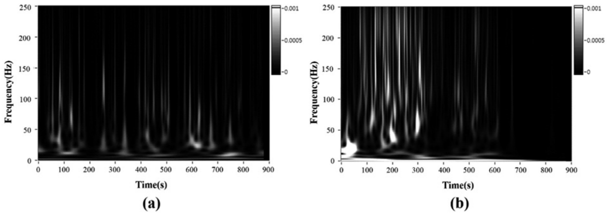

Fig. 2. The change of frequency amplitude by wavelet transformation in analysis of time series measured from (a) controls (untreated condition) and (b) during IFC therapy in a representative subject

the muscle, causing the action potential conduction velocity to decrease[23–26]. As a result, the MDF of the EMG signals shifts from higher to lower frequencies under conditions of muscle fatigue[27]. In the present study, MDF shifts towards higher frequencies were observed during IFC therapy (Table 1). The results of this study are consistent with those of others that reported a correlation between MDF shifts and muscle fatigue[26, 27]. Based on the results, reduction of muscle fatigue was confirmed by MDF shifts toward the higher range of frequencies, indicating that muscle stiffness was relieved by IFC therapy.

The RMS signal was also measured, and a ratio was calculated using the levels of the initial and final values during specific time windows of 900 s. The smaller the ratio, the greater the relaxation in the fatigued muscle, because the time course of muscle contraction is reduced when muscle stiffness is decreased; an RMS ratio close to 1 is known to prolong muscular fatigue. The results indicate that muscle fatigue was alleviated because muscle contraction was relaxed during IFC therapy; sustained levels of the RMS demonstrated that muscular fatigue persisted in the untreated group. Relaxation of muscle stiffness by IFC therapy can be observed through analysis of the MDF and the ratio of RMS signals.

Figure 1 indicates that sustained RMS amplitude reflecting persistent muscle fatigue after exercise was reproducible, because electrical signals from the initial and final state during contraction were almost the same. Significantly increased amplitude of the initial RMS indicates the beginning of muscle contraction during IFC therapy. Moreover, simultaneous localization and mapping of EMG patterns were analyzed to correlate muscle fatigue in time and frequency domains through wavelet transformation. The steady amplitude of the EMG signal without significant fluctuation in Fig. 2 (a) reflects muscle fatigue after back extension exercise. However, the change in amplitude during IFC treatment represents the beginning of muscle contraction during IFC therapy, which finally relieves muscular fatigue during treatment. Therefore, relief of muscle fatigue was observed through a time-dependent amplitude change of frequency during IFC therapy.

This study also found that the effective treatment duration for IFC therapy can be measured in real-time using changes in RMS signals. During measurement, the RMS signals did not decline after a specific duration (t=670 s) because the muscle did not respond to IFC therapy; therefore, the treatment may not work after a specific duration (t>670 s). Studies have shown that applications for a short duration are not sufficient to promote therapeutic effects, and that the muscle relaxing effect can be correlated with an increase in local blood flow at the motor level[12]. In general, effective treatment durations for IFC therapy were found to vary between 10 and 30 min, depending on the muscle condition and therapist, but there was no standard duration of treatment. In this study, the effective treatment duration for IFC therapy could be determined by monitoring the changes in RMS amplitude in real-time using EMG signals. In conclusion, this study provided information about the effective duration for treatment of muscle fatigue by analyzing EMG signals, and should be helpful to clinicians by demonstrating the appropriate duration of therapy for the relaxation of muscle stiffness.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea [NRF] grant funded by the Korea government (2008-0062484, 2010-0008977, 2012R1A1A2039274) and a grant of the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare Republic of Korea (HI14C0665)

REFERENCES

1) Jorge S, Parada CA, Ferreira SH, et al.: Interferential therapy produces antinociception during application in various models of inflammatory pain. Phys Ther, 2006, 86: 800–808. [Medline]
2) Fuentes C J, Armijo-Olivo S, Magee DJ, et al.: Does amplitude-modulated frequency have a role in the hypoalgesic response of interferential current on pressure pain sensitivity in healthy subjects? A randomised crossover study. Physiotherapy, 2010, 96: 22–29. [Medline] [CrossRef]
3) Philipp A, Wolf GK, Rzany B, et al.: Interferential current is effective in palmar psoriaris: an open prospective trial. Eur J Dermatol, 2000, 10: 195–198. [Medline]
4) Fuentes C J, Armijo-Olivo S, Magee DJ, et al.: A preliminary investigation into the effects of active interferential current therapy and placebo on pressure pain sensitivity: a random crossover placebo controlled study. Physiotherapy, 2011, 97: 291–301. [Medline] [CrossRef]
5) Zambito A, Bianchini D, Gatti D, et al.: Interferential and horizontal therapies in chronic low back pain: a randomized, double blind, clinical study. Clin Exp Rheumatol, 2006, 24: 534–539. [Medline]
6) Facci LM, Nowotny JP, Tormem F, et al.: Effects of transcutaneous electrical nerve stimulation (TENS) and interferential currents (IFC) in patients with nonspecific chronic low back pain: randomized clinical trial. Sao Paulo Med J, 2011, 129: 206–216. [Medline]
7) Almeida TF, Roizenblatt S, Benedito-Silva AA, et al.: The effect of combined therapy (ultrasound and interferential current) on pain and sleep in fibromyalgia. Pain, 2003, 104: 665–672. [Medline] [CrossRef]
8) Adedoyin RA, Olaogun MO, Fagbeja OO: Effect of interferential current stimulation in management of osteo-arthritic knee pain. Physiotherapy, 2002, 88: 493–499. [CrossRef]
9) Cifrek M, Medved V, Tonković S, et al.: Surface EMG based muscle fatigue evaluation in biomechanics. Clin Biomech (Bristol, Avon), 2009, 24: 327–340. [Medline] [CrossRef]
10) Forestier N, Nougier V: The effects of muscular fatigue on the coordination of a multijoint movement in human. Neurosci Lett, 1998, 252: 187–190. [Medline] [CrossRef]
11) Armstrong TJ, Buckle P, Fine LJ, et al.: A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand J Work Environ Health, 1993, 19: 73–84. [Medline] [CrossRef]
12) Silva AP, Acedo AA, Antunes AC, et al.: Electromyography analysis of upper trapezius relaxation induced by interferential current in subjects with neck discomfort. J Appl Res, 2011, 11: 11–19.
13) Suh HR, Han HC, Cho HY: Immediate therapeutic effect of interferential current therapy on spasticity, balance, and gait function in chronic stroke patients: a randomized control trial. Clin Rehabil, 2014, 28: 885–891. [Medline] [CrossRef]
14) Fukuda TY, Echeimberg JO, Pompeu JE, et al.: Root mean square value of the electromyographic signal in the isometric torque of the quadriceps, hamstrings and brachial biceps muscles in female subjects. J Appl Res, 2010, 10: 32–39.
15) Hagberg M, Kvarnström S: Muscular endurance and electromyographic fatigue in myofascial shoulder pain. Arch Phys Med Rehabil, 1984, 65: 522–525. [Medline]
16) Beck TW, Housh TJ, Johnson GO, et al.: Comparison of Fourier and wavelet transform procedures for examining the mechanomyographic and electromyographic frequency domain responses during fatiguing isokinetic muscle actions of the biceps brachii. J Electromyogr Kinesiol, 2005, 15: 190–199. [Medline] [CrossRef]
17) Mathur S, Eng JJ, MacIntyre DL: Reliability of surface EMG during sustained contractions of the quadriceps. J Electromyogr Kinesiol, 2005, 15: 102–110. [Medline] [CrossRef]
18) L'Estrange PR, Rowell J, Stokes MJ: Acoustic myography in the assessment of human masseter muscle. J Oral Rehabil, 1993, 20: 353–362. [Medline] [CrossRef]
19) Coorevits P, Danneels L, Cambier D, et al.: Assessment of the validity of the Biering-Sørensen test for measuring back muscle fatigue based on EMG median frequency characteristics of back and hip muscles. J Electromyogr Kinesiol, 2008, 18: 997–1005. [Medline] [CrossRef]
20) Yoshitake Y, Ue H, Miyazaki M, et al.: Assessment of lower-back muscle fatigue using electromyography, mechanomyography, and near-infrared spectroscopy. Eur J Appl Physiol, 2001, 84: 174–179. [Medline] [CrossRef]
21) Lam WK, Leong JC, Li YH, et al.: Biomechanical and electromyographic evaluation of ankle foot orthosis and dynamic ankle foot orthosis in spastic cerebral palsy. Gait Posture, 2005, 22: 189–197. [Medline] [CrossRef]
22) Schulte E, Kallenberg LA, Christensen H, et al.: Comparison of the electromyographic activity in the upper trapezius and biceps brachii muscle in subjects with muscular disorders: a pilot study. Eur J Appl Physiol, 2006, 96: 185–193. [Medline] [CrossRef]
23) Kankaanpää M, Taimela S, Laaksonen D, et al.: Back and hip extensor fatigability in chronic low back pain patients and controls. Arch Phys Med Rehabil, 1998, 79: 412–417. [Medline] [CrossRef]
24) Shao L, Gao R, Liu Y, et al.: Transform based spatio-temporal descriptors for human action recognition. Neurocomputing, 2011, 74: 962–973. [CrossRef]
25) Kilby J, Gholam Hosseini H: Wavelet analysis of surface electromyography signals. Conf Proc IEEE Eng Med Biol Soc, 2004, 1: 384–387. [Medline]
26) Bigland-Ritchie B, Woods JJ: Changes in muscle contractile properties and neural control during human muscular fatigue. Muscle Nerve, 1984, 7: 691–699. [Medline] [CrossRef]
27) Kisiel-Sajewicz K, Siemionow V, Seyidova-Khoshknabi D, et al.: Myoelectrical manifestation of fatigue less prominent in patients with cancer related fatigue. PLoS ONE, 2013, 8: e83636. [Medline] [CrossRef]