J. Phys. Ther. Sci.
24: 373–377 2012

The Effect of Muscle Fatigue Using Short Term Transcutaneous Electrical Nerve Stimulation

Ganbaatar Namuun, MD[1)], Yasuhiro Endo, RPT, MS[2)], Yota Abe, RPT[2)],
Rie Nakazawa, RPT, PhD[2)], Masaaki Sakamoto, RPT, PhD[2)]

[1)] *School of Health Technology, Health Science University of Mongolia: Bayangol District 6th Khoroo, Ulaanbaatar City, Mongolia.*
TEL: +976 11-681501, FAX: +976 11-687633, E-mail: dsqgq327@yahoo.co.jp
[2)] *Graduate School of Health Sciences, Gunma University*

Abstract. [Purpose] Several studies found have that transcutaneous electrical nerve stimulation (TENS) is effective for reducing pain and improving physical function. But the influence of TENS on muscle fatigue is still unclear. The purpose of this study was to determine the influence of TENS on muscle fatigue. [Methods] The subjects were ten healthy males. To establish the muscle activity, subjects performed maximum isometric exertion 15 times and electromyography was recorded (TaskI). After this, subjects of the study group received TENS and subjects of the control group rested for 5 minutes. After the intervention each group again performed maximum isometric exertion as in Task1 (TaskII), and VAS and muscle elasticity were measured. [Results] We found that in the study group, the significant decrease in muscle activity during TaskII began later than in TaskI. Furthermore, we found that the fourth trial had a larger in muscle activity than that of the first trial in TaskI in both groups and TaskII of the study group. Conversely, In TaskII performed by the control group, we observed significant decreases. [Conclusions] From the result of this research, we believe that TENS electronically influenced the nervous system to prevent muscle fatigue.
Key words: TENS, Muscle fatigue, Electromyography

(This article was submitted Oct. 13, 2011, and was accepted Dec. 8, 2011)

INTRODUCTION

Transcutaneous electrical nerve stimulation (TENS) is a noninvasive therapeutic modality, that was developed more than 30 years ago, and is one of the most widely accepted methods of nonpharmacological pain relief. TENS is classified into low-frequency and high-frequency types according to the stimulation parameters. Both types of TENS cause hypoalgesia by releasing endogenous opioids in the central nervous system. Although high-frequency TENS is instantaneously effective, its analgesic effect is not maintained after the stimulation is stopped. Conversely, low-frequency TENS is not instantaneously effective, but its analgesic effect is maintained after the stimulation is stopped. Low-frequency stimulation of a relatively high intensity affects the motor neurons of muscles. Several studies have shown that TENS is effective at reducing pain and improving physical function[1–3)], including the management of low back pain.

Low back pain (LBP) is a worldwide problem and is one of the most frequent causes of movement limitation in highly industrialized countries[4)]. The most commonly cited risk factors of LBP include rapid and repetitive workplace motion patterns, insufficient recovery time, heavy lifting and other forceful manual exertions, non-neutral body postures, mechanical pressure, and vibration[5)]. LBP includes discogenic pain, facet pain, and muscle pain, which is most commonly observed in clinical practice[6)]. Muscles are the most common site of nociception. The afferent fibers which transmit nociceptive impulses in the muscles are thin myelinated fibers (A delta) or unmyelinated fibers (C fibers) that mediate pain[7)]. The development and application of TENS are based on the gate control theory of pain[7)]. In addition, muscle fatigue can ultimately contribute to LBP through its effect on the neuromuscular mechanism[6)]. Many studies have shown that patients with LBP exhibit excessive fatigability in their back extensor muscles[6, 8)], as demonstrated by the results of lower back endurance tests[8, 9)]. In addition, many studies have been performed on the effect of TENS on LBP due to muscle fatigue[1–3)]. These studies were based on gate control theory and opiate theory. However, it is still unclear whether the effect of TENS on muscle fatigue alleviates LBP. The purpose of this study was to determine the effect of TENS on erector spinae muscle fatigue after an isometric trunk extension exercise.

METHODS

Ten healthy male volunteers (22.3 ± 1.2 years) with no previous history of LBP or physical disabilities were recruited for our study. All the subjects were informed about the purpose and procedure of the study and provided their

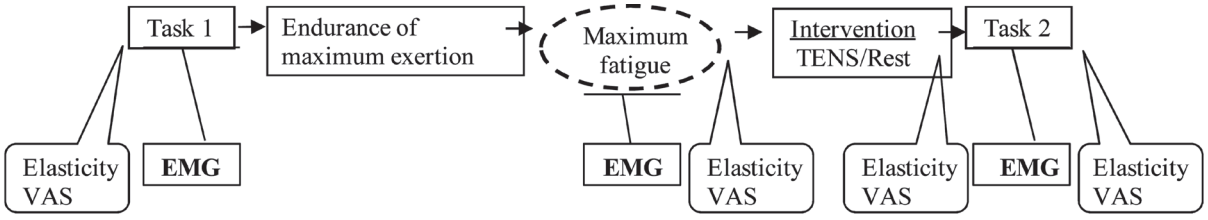

Fig. 1. Schema of the study procedure

Table 1. The characteristics of the subjects

	Study group (n=5)	Control group (n=5)
Age (years)	22.0 ± 0.7	22.6 ± 1.5
Height (cm)	170.0 ± 4.3	170.2 ± 3.1
Weight (kg)	63.0 ± 3.4	62.6 ± 4.1

informed consent to participation. Subjects were classified into 2 groups (study group and control group), each comprised of 5 individuals. Individuals in the study group received low-frequency TENS, whereas those in the control group were rested (Table 1).

Our study followed the order presented in Figure 1. First, each subject's perception of fatigue intensity was measured using a 100-mm visual analog scale (VAS; 0, no fatigue; 100, worst possible fatigue). Muscle elasticity was measured using a PEK-1 (Imoto Co., Japan), and 3 measurements were obtained for each muscle. To determine muscle activity and endurance of fatigue, each subject was asked to perform 15 of maximum isometric exertions (Task I [TI]). Electromyography (EMG) of the middle 3 seconds of 5 seconds of 1st, 4th, 8th, 12th, and 15th maximal contractions was recorded. For the task, the subjects were positioned prone on a couch, with the iliac crest aligned with the couch edge. The lower body was stabilized by placing straps over the hips, knees, and ankles. The subjects placed their hands on their forehead, and their heads were placed in a neutral position looking downward in a horizontal position. EMG (Power Lab/30 series AD instruments Co.) was used to record signals from 4 surface EMG channels. After cleaning the skin with alcohol, 2 electrodes (S&ME Co, Japan) were placed bilaterally on the right longissimus thoracis (LTh-R) and left longissimus thoracis (LTh-L) at the Th10 level 4 cm lateral to the tips of the spinous processes, and on the right iliocostalis lumborum (ILL-R) and left iliocostalis lumborum (ILL-L) at the L3 level 5 cm lateral to the tips of the spinous processes. A ground electrode was attached to the left wrist of each subject.

For maximum exertion, the subjects were asked to maintain their bodies in an unsupported position for as long as possible. Immediately afterward, the muscle activities of both groups were recorded by EMG to evaluate fatigue. Muscle fatigue was defined as "maximum fatigue" (MF), and muscle elasticity and VAS were measured.

After MF, the subjects in the study group received TENS, whereas the subjects in the control group were rested for 5 min. The subjects in the study group were asked to rest in a prone position, and TENS was administered using an ES-420 (ITO Co., Tokyo, Japan) with a pulse duration of 100 ms and a frequency of 4 Hz at the maximum intensity that the subjects could tolerate. Two channels of 4 large self-adhesive electrodes (diameter: 5 cm) from dual channels were placed bilaterally over the lower back at the 12th thoracic vertebra and on the 5th lumbar vertebra. Both the electrodes were placed 4 cm lateral to the tips of the spinous processes. After this intervention, muscle elasticity and VAS were measured in each group.

Finally, to evaluate muscle activity and the effect of TENS, maximum isometric exertion was again performed 15 times (Task II [TII]) and EMG was recorded as in TI. Muscle elasticity and VAS were measured after TII. During the study, subjects wore comfortable clothes such as shorts and T-shirts.

The integrated values of EMG were measured and stored in a computer for analysis at a later time. The first EMG measure of TI was set as 100% of volume muscle activity (%VMA), and subsequent measures of TI ($TI_{4,8,12,15}$), MF, and TII ($TII_{1,4,8,12,15}$) were expressed relative to TI_1 and compared with TI_1. The mean of 3 measured scores of muscle elasticity for each muscle was analyzed.

Wilcoxon's test was used to compare the %VMA values of the 4th, 8th, 12th, and 15th trials with those of the first trial of each task, and to compare the %VMA of the same trials in TI and TII. Wilcoxon's test was also used to compare the muscle elasticity and VAS before and after each intervention before and after both tasks. All the significance levels were chosen as 0.05 and SPSS 17.0 was used to perform the analyses.

RESULTS

Muscle elasticity values are shown in Table 2. There were no significant differences in muscle elasticity between the control and study groups. In the study group, the muscle elasticity of the LTh-R after TENS (before TII) was significantly higher than that before TENS (after MF). Moreover, muscle elasticity of the LTh-L and ILL-R after TI (after MF) was significantly higher than that before TI, and ILL-R after TII was significantly higher than that before TII. In the control group, the muscle elasticity of the LTh-R, LTh-L, and ILL-R after TI (after MF) was significantly higher than that before TI. Moreover, the muscle elasticity of the LTh-R

Table 2. Muscle elasticity scores

	Before TI	After MF	Before TII	After TII
Study group				
LTh-R	55.7 ± 2.3	55.7 ± 2.3	59.0 ± 3.5*	58.9 ± 4.6
LTh-L	56.5 ± 2.6	60.1 ± 4.5*	60.2 ± 4.5	61.1 ± 4.4
ILL-R	47.6 ± 3.4	52.7 ± 4.4*	52.0 ± 4.5	54.9 ± 5.7
ILL-L	51.3 ± 5.3	56.2 ± 4.9	55.3 ± 5.8	56.2 ± 5.5*
Control group				
LTh-R	56.2 ± 1.6	58.7 ± 2.6*	58.0 ± 2.7	59.7 ± 2.2*
LTh-L	56.9 ± 2.2	59.7 ± 0.9*	59.8 ± 2.6	59.5 ± 3.5
ILL-R	49.3 ± 3.2	53.3 ± 4.5*	53.3 ± 4.7	56.6 ± 2.6
ILL-L	49.5 ± 2.6	53.3 ± 3.9	53.5 ± 3.4	53.8 ± 5.6

* Differences significant at the 0.05 level.

Table 3. VAS scores

	Before TI	After MF	Before TII	After TII
Study group	2.8 ± 5.6	88.2 ± 5.6*	34.6 ± 13.1*	90.6 ± 10.6*
Control group	7.5 ± 4.8	81.2 ± 16.8*	37.8 ± 11.7*	86.8 ± 6.6*

* Differences significant at the 0.05 level.

Table 4. %VMA of study group in TaskI and TaskII, and MF

		Time					
Muscle / task		1	4	8	12	15	MF
LTh-R	TI	100	101.4 ± 32.0	85.7 ± 39.5	80.3 ± 39.2	67.2 ± 27.4*	69.0 ± 31.4
	TII	92.9 ± 37.4	107.4 ± 49.5	90.3 ± 46.5	81.9 ± 40.2	74.4 ± 40.6	
LTh-L	TI	100	110.7 ± 42.3	85.5 ± 21.7	77.1 ± 18.2*	67.9 ± 14.1*	65.1 ± 23.2
	TII	93.4 ± 32.6	105.4 ± 29.6	84.3 ± 32.7	78.1 ± 27.0	71.9 ± 22.2*	
ILL-R	TI	100	107.3 ± 27.3	89.6 ± 20.4	75.9 ± 24.7	64.7 ± 12.4*	63.2 ± 19.3
	TII	87.4 ± 19.2	89.9 ± 53.7	70.7 ± 43.3	59.3 ± 34.2*	65.7 ± 49.0	
ILL-L	TI	100	97.6 ± 18.8	74.8 ± 21.3*	67.4 ± 21.5*	63.8 ± 18.2*	63.3 ± 19.1
	TII	63.3 ± 19.1	95.1 ± 28.1*	77.4 ± 31.5	67.8 ± 30.2	61.2 ± 19.8*	

* Differences significant at the 0.05 level.

after TII was significantly higher than that before TII for.

The VAS scores are shown in Table 3. There were no significant differences in VAS scores between the study and control groups. For both the groups, VAS scores before the task were significantly higher than those after the task during both TI and TII. Moreover, VAS scores significantly decreased after the intervention in both the groups.

The %VMA values for each task are presented in Tables 4, 5. There were no significant differences in %VMA between the study and control groups. For the study group in TI, significant decreases in %VMA were observed in TI_{15} of the LTh-R, TI_{12} and TI_{15} of the LTh-L, TI_{15} of the ILL-R, and $TI_{8, 12, 15}$ of the ILL-L compared to TI_1 of the respective muscles. In TII, significant decreases in %VMA were observed in TII_{15} of the LTh-L, TII_{12} of the ILL-R, TII_{15} of the ILL-L compared to TII_1 of the respective muscles. In addition, %VMA of TII_4 of the ILL-L was significantly higher than that of TII_1. No significant differences were observed between TI and TII in the study group (Table 4). In TI of the control group, significant decreases in %VMA were observed in TI_{12} and TI_{15} of the LTh-R, $TI_{8,12,15}$ of the LTh-L, and TI_{12} and TI_{15} of the ILL-L as compared to TI_1 of the respective muscles. In TII of the control group, %VMA significantly decreased for TII_8 and TI_{12} of the LTh-R, TII_{12} of the LTh-L, and TI_{15} of the ILL-L as compared to TII_1 of the respective muscles. Comparison of TI and TII values showed that %VMA of the LTh-L of TII_1 was significantly lower than that of TI_1. Similarly, %VMA of the ILL-R and ILL-L of TII_4 were significantly lower than their respective values for TI_4 (Table 5).

DISCUSSION

In this study, although there were no significant differences in %VMA between the 2 groups, there were different characteristics of %VMA in each group. We found that in

Table 5. %VMA of study group in TaskI and TaskII, and MF

Muscle / task		Time 1	4	8	12	15	MF
LTh-R	TI	100	142.4 ± 58.0	96.7 ± 22.9	66.9 ± 8.2*	72.6 ± 14.7*	74.9 ± 9.8
	TII	86.4 ± 9.0	86.6 ± 11.0	73.9 ± 11.5*	69.9 ± 5.0*	72.9 ± 21.6	
LTh-L	TI	100	100.3 ± 25.6	76.6 ± 6.9*	67.3 ± 6.1*	74.2 ± 14.8*	67.0 ± 14.7
	TII	83.8 ± 8.9	82.8 ± 13.8	77.7 ± 12.6	63.0 ± 12.7*	70.6 ± 23.7	
ILL-R	TI	100	123.0 ± 44.1	89.1 ± 22.1	77.1 ± 29.9	82.7 ± 20.4*	74.0 ± 21.0
	TII	98.5 ± 15.2	95.0 ± 21.5	84.6 ± 23.4	78.8 ± 18.3*	71.4 ± 31.4	
ILL-L	TI	100	121.6 ± 62.5	89.4 ± 16.0	74.8 ± 12.1*	70.5 ± 15.6*	70.0 ± 18.7
	TII	88.1 ± 19.8	93.3 ± 24.3	82.4 ± 28.0	75.3 ± 15.9	62.7 ± 23.6*	

* Differences significant at the 0.05 level.

the study group, the significant decrease in %VMA of the LTh-R, LTh-L, and ILL-L during TII began later than in TI. In the control group, the %VMA of LTh-L of TII_1 was signnnificantly lower than that of TI_1, and similarly, %VMA of ILL-R and ILL-L of TII_4 were significantly lower than their respective values for TI_4. Thus, the width of the decrease in TII of the control group was smaller than that of the study group. Muscle fatigue occurs when the muscle tissue cannot meet the metabolic needs of the contractile elements because of insufficient oxygen and blood supply, local depletion of metabolic substrates, or alterations in electrolyte concentrations[10, 11]. TENS normalizes this and has the same effect as normal voluntary muscle contraction in causing a temporary increase in muscle metabolism in terms of increasing oxygen content, local blood flow, muscle temperature, and muscle-pumping action and restructuring the responsible ions during the electrical impulse. This results in an increase in muscle fiber excitability, muscle contraction effectiveness, and muscle regeneration[12]. Therefore, we suspect that in our study, muscle fatigue was delayed in the study group because of the effect of TENS.

We examined the first and fourth trials of TI and TII in both groups. We found that the fourth trial had a larger value of %VMA than that of the first trial for all muscles in TI in both groups. TII of the study group exhibited the same tendency as TI. Conversely, for the control group, we observed significant decreases in %VMA of the LTh-L during TII_1 as compared to TI_1, and of the ILL-R and ILL-L during TII_4 as compared to TI_4. The degree of muscular contraction is altered by the discharge frequency, number of motor units, and the synchronicity of the activity timing of each motor unit. In the case of voluntary movement, according to the size principle, the motor unit with the smaller action potential is activated first, and then the motor unit with the larger action potential gradually participates in the activity. Therefore, in this study during TI of both groups and during TII of the study group, we consider that the number of excited motor units increased, and the larger motor units participated in activity in the fourth trial rather than in the first trial of each task. This would explain why %VMA increased significantly in the fourth trial. However, in TII of the control group, we consider that muscle activity increase generated by the motor unit was inhibited, and the discharge frequency increase was inhibited by muscle fatigue. Moreover, %VMA in TII became smaller than that in TI. In TII of the study group, we consider that the physiologic fatigue reduction mentioned above was induced by TENS; thus, %VMA was not decreased. In contrast, muscle activity increased as observed in TI.

We also measured VAS and muscle elasticity. VAS is a measure of mental fatigue, and PEK-1 measures muscle elasticity. There were no differences in mental fatigue and muscle elasticity between the study and control groups. Conversely, there were differences in %VMA in both the groups. Therefore, we believe that TENS electronically influenced the nervous system to prevent muscle fatigue during the isometric trunk extension exercise.

Several studies have shown that TENS for 15–20 min is effective at reducing pain[1–3]; however, in the present study, we administered TENS for only 5 min. However, we believe that positive effects such as the normalization of muscle activity in muscle fatigue after high-strength isometric contraction were induced more rapidly by TENS than analgesic effects.

It is often said that repetition of the movements of lift and trunk anteflexion and the decline of the muscular endurance of the isometric trunk extensors are related to LBP[5, 6]. In addition, isometric contraction of trunk extensor muscles are often repeated during lifting movements and transportation. Therefore, the task in this research was designed to simulate conditions that can cause LBP. We believe that this task was useful for determining the influence of TENS on muscle fatigue caused by short-term isometric contraction of the type that causes LBP and other diseases.

This study had several limitations. First, the number of participants was small. Second, in this study, the control group might have recovered after the rest. Our task used high-frequency short-term isometric contraction, and the muscle fatigue induced by this protocol may not have been sufficient. The differences between the groups might become more apparent by additional repetitions of this task.

ACKNOWLEDGEMENTS

The authors are grateful to everyone at the Sakamoto Laboratory for their critical review and assistance with this manuscript.

REFERENCES

1) Chou R, Huffman LH: Nonpharmacologic therapies for acute and chronic low back pain: a review of the evidence for an American Pain Society/ American College of Physicians clinical practice guideline. Ann Intern Med, 2007, 147: 492–504. [Medline]
2) Pop T, Austrup H, Preuss R, et al.: Effect of TENS on pain relief in patients with degenerative disc disease in lumbosacral spine. Ortop Traumatol Rehabil, 2010, 12: 289–300. [Medline]
3) Warke K, Al-Smadi J, Baxter D, et al.: Efficacy of transcutaneous electric nerve stimulation (tens) for chronic low-back pain in a multiple sclerosis population: a randomized, placebo-controlled clinical trial. Clin J Pain, 2006, 22: 812–819. [Medline] [CrossRef]
4) Charłusz M, Gasztych J, Irzmanski R, et al.: Comparative analysis of analgesic efficacy of selected physiotherapy methods in low back pain patients. Ortop Traumatol Rehabil, 2010, 12: 225–236. [Medline]
5) Punnett L, Pruss-Utun A, Nelson DI, et al.: Estimating the global burden of low back pain attributable to combined occupational exposures. Am J Ind Med, 2005, 48: 459–469. [Medline] [CrossRef]
6) Kankaanpää M, Taimela S, Airaksinen O, et al.: The Efficacy of active rehabilitation in chronic low back pain. Effect on pain intensity, self-experienced disability, and lumbar fatigability. Spine, 1999, 24: 1034–1042. [Medline] [CrossRef]
7) Cailliet R: Low Back Pain Syndrome. 5th ed. Philadelphia: Fa Davis Co, 1995, pp144−160, 310−313.
8) Niitsu M, Michizaki A, Endo A, et al.: Muscle hardness measurement by using ultrasound elastography: a feasibility study. Acta Radiol, 2011, 52: 99–105. [Medline] [CrossRef]
9) Coorevits PL, Danneels LA, Ramon H, et al.: Statistical modelling of fatigue-related electromyographic median frequency characteristics of back and hip muscles during a standardized isometric back extension test. J Electromyogr Kinesiol, 2005, 15: 444–451. [Medline] [CrossRef]
10) Eble OS, Jonas IE, Kappert HF: Transcutaneous electrical nerve stimulation (TENS): its short-term and long-term effects on the masticatory muscles. J Orofac Orthop, 2000, 61: 100–111. [Medline] [CrossRef]
11) Low J: Ann Reed.: Electrotherapy explained principles and practice. 2nd ed. London: Butterworth-Heinemann Ltd, 1995, pp44–84.
12) David A.: Winter.: Biomechanics and motor control of human movement. 3rd ed. New Jersey: John Wiley and Sons, 2005, pp229–257.