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Original Article

Effects of two different intensities of transcutaneous electrical nerve stimulation on pain thresholds of contralateral muscles in healthy subjects

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Abstract. [Purpose] This study aimed to investigate the differential effects of high-intensity and low-intensity transcutaneous electrical nerve stimulation on the contralateral side on the pain threshold in healthy subjects. [Subjects and Methods] Twenty-five healthy adults, volunteers received two intensity levels (motor-level, 1.5 times the muscle motor threshold; sensory-level, sensory threshold of the common peroneal nerve), for 30 s on separate days. Pressure pain threshold was recorded on the contralateral tibialis anterior and deltoid muscle before, during, and after stimulation. [Results] Motor-level stimulation significantly increased the pressure pain threshold at both muscle sites, while effects of sensory-level stimulation on pressure pain thresholds were significant only at the deltoid site. The percent change in pressure pain thresholds at both sites was significantly higher during motor-level stimulation. [Conclusion] Motor-level stimulation, applied unilaterally to one leg, produced immediate contralateral diffuse and segmental analgesic effects. This may be of therapeutic benefit in patients for whom transcutaneous electrical nerve stimulation cannot be directly used at the painful site.
Key words: Transcutaneous electrical nerve stimulation, Pressure pain threshold, Motor-level stimulation

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INTRODUCTION

Transcutaneous electrical nerve stimulation (TENS) is commonly used in the clinical management of chronic pain, such as for patients with low back pain and knee osteoarthritis[1–3)]. Typically for chronic pain management, TENS is applied to the peripheral site of the lesion, with the stimulation administered for at least 15 min[4–6)]. These general stimulation parameters produce a diffuse inhibition of pain, likely to be mediated by descending pain control pathways[7, 8)]. As well, a dose-response relationship of TENS on pain control has been reported, with stronger intensities of stimulation having a greater effect on pain relief[9)]. These reported effects of TENS on pain control could be of clinical benefit in the management of post-operative pain. Yet, TENS is seldom used after surgery as the required stimulation period is typically too long and the placement of electrodes on the surgical site difficult in the early period of post-operative rehabilitation. Therefore, the purpose of our study was to investigate the effects of short-duration, high-intensity and low-intensity TENS on pain thresholds in healthy adults, where pain thresholds were evaluated on the side contralateral to the TENS application.

SUBJECTS AND METHODS

Twenty-five healthy adults (16 males and 9 females; mean age, 24.5 ± 4.8 years) were recruited for the study. Participants were screened for relevant contraindications, injury or nerve damage to the upper and lower limbs, chronic illness, pregnancy, cardiac pacemaker, sensitivity to the TENS electrodes, current use of pain medication, skin conditions or impairments in skin sensation in the region of electrode placement. The methods and procedures for this study were approved by the institutional ethics committee of Kochi University. The study was conducted in compliance with the Declaration of Helsinki, and all participants provided written informed consent.

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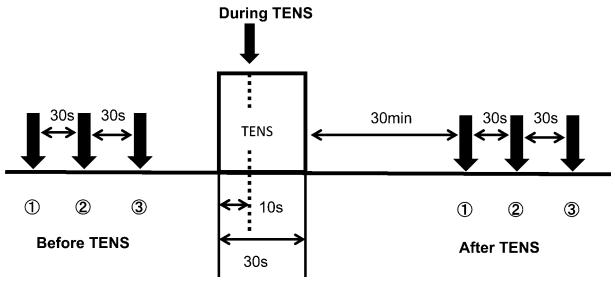

Fig. 1. Measurement protocol
Three PPT values were obtained, at 30 s intervals, before- and after-TENS application, with the average PPT of the three measures used in the analysis. A single PPT measurement was obtained during the 30 s duration of TENS application.

Table 1. Pressure pain threshold (PPT) of each time period of TENS application (unit: kPa)

	Motor-level	Sensory-level
(A) TA muscle site		
Before	248.8 ± 21.6	256.5 ± 22.1
During	329.4 ± 30.2* †	272.0 ± 18.6
After	260.3 ± 22.1	244.5 ± 20.7
(B) Deltoid muscle site		
Before	161.4 ± 21.7	174.2 ± 19.9
During	217.4 ± 24.2* †	200.6 ± 23.9* †
After	161.4 ± 18.4	171.6 ± 21.2

Mean ± SE; *, significant difference between during- and before-TENS; †, significant difference between during- and after-TENS ($p<0.05$)

Table 2. Percentage of change in PPT during TENS (unit: %)

	Motor-level	Sensory-level
TA	135.8 ± 8.0*	112.0 ± 5.9
Deltoid	147.2 ± 10.0*	116.3 ± 4.0

Mean±SE; *, $p<0.05$

TENS was administered using a NIHON KOHDEN unit (Nihon Kohden Corporation, Japan), using the following parameters of stimulation: 10 Hz frequency, 500 μs pulse width, 30 s stimulation duration. This stimulation was delivered at two intensity levels, a low intensity (sensory) level and a high intensity (motor) level. For the motor-level, the intensity of the stimulation was set at 1.5 times the motor threshold of the muscle, while for the sensory-level, the intensity was set at the sensory threshold of the common peroneal nerve. The two intensity levels of stimulation were administered on separate days, with participants randomly selecting the order of stimulation by drawing random numbers.

The TENS stimulation was applied to the peroneal nerve of the dominant leg, through two circular, self-adhesive electrodes (2.5 cm diameter; Vitrode D, NIHON KOHDEN, JAPAN), positioned on the head of the fibula and over the popliteal fossa. The effects of TENS stimulation on pain thresholds was measured using a pressure pain threshold (PPT) technique previously described in the literature[10, 11]. To determine the PPT, pressure was applied perpendicularly to the skin, at a rate of 50 kPa/s, using a flat, circular, 1 cm^2 probe tip. Therefore, the PPT reflects the pressure pain sensitivity of deeper tissues. A 100-point visual analog scale (VAS) was used to quantify the PPT, with anchors at '0', 'no pain', and '100', 'worst pain'. As the pressure was applied, participants were asked to rate the associated pain on the VAS. The VAS was considered to be an appropriate measure of the PPT based on findings by Kemp et al. who reported that even pressure stimulation below the pain threshold was consistently perceived and rated significantly higher than '0', 'no pain', on the VAS[12]. Ulrika et al. reported a VAS score between 30 and 40 to be representative of the PPT in healthy adults[13]. Based on these previous studies, the VAS score of 30 was set as a reference point, a priori, in our study, and participants were asked to push a button when they perceived the applied pressure to exceed this pain threshold. PPTs were assessed at two different sites on the non-dominant limbs: 1) the belly of the deltoid muscle of the upper limb, at a location 5 cm distal to the acromion, along the midline of the muscle, and 2) the tibialis anterior (TA) muscle of the lower limb, at a location 5 cm distal and 3 cm lateral to the tibial tuberosity, along the midline of the tibia. These two PPT sites provided information on the segmental (i.e., PPT of the TA) and non-segmental, or diffuse, (i.e., PPT of the deltoid muscle) effects of TENS. PPT was recorded before, during, and 30 min after the application of TENS (i.e., before-TENS, during-TENS, and after-TENS, respectively). Three PPT measurements, taken 30 s apart, were recorded before and after TENS, with the average of the three PPT values used for analysis; one PPT measurement was made during the 30 s application of TENS (Fig. 1). The PPT values were highly consistent, with calculated intra-class correlations of 0.94, for the deltoid muscle site, and 0.82, for the TA.

All participants completed the study protocol and all data points were included in the analysis. PPT results were expressed as a mean±SE. The percent change in PPT (%PPT) was calculated (i.e., (during-TENS/before-TENS) × 100) to compare the effects of the sensory-level and motor-level TENS. All statistical analyses were performed using SPSS 21.0 software. The level of significance was set at $p < 0.05$ for all tests.

RESULTS

PPT measures are reported in Table 1. There were no differences in baseline PPT measures (i.e., before-TENS) for the sensory-level and motor-level TENS conditions, both at the deltoid and the TA muscle sites. Motor-level TENS produced significant increases in the PPT at both the deltoid and TA muscle sites (i.e., segmental and diffuse effect), whereas sensory-level TENS increased the PPT only at the deltoid muscle site (i.e., diffuse effect only). The PPT at both muscle sites decreased immediately after stimulation for both levels of TENS application.

Percent changes in the PPT (%PPT) during TENS application are reported in Table 2. There were significant differences in %PPT for both the motor- and sensory-level TENS at both muscle sites, deltoid (motor level: 147.2% ± 10.0%, sensory level: 116.3% ± 4.0%) and TA (motor-level: 135.8% ± 8.0%, sensory-level: 112.0% ± 5.9%).

DISCUSSION

In this study, we investigated the immediate effect of two intensity levels of TENS application, motor-level and sensory-level, on the modulation of the PPT of the contralateral lower limb (i.e., segmental effect) and upper limb (i.e., diffuse effect). The most important outcome of this study was a finding of the segmental and diffuse effects of motor-level TENS, increasing the PPT at both deltoid and TA muscle sites. Motor-level TENS also produced a larger increase in the PPT (i.e., higher %PPT), compared to the sensory-level TENS intensity. These results are in agreement with findings from Claydon et al.[14] who reported high-intensity TENS stimulation to be of fundamental importance to effective dosage, regardless of the frequency of stimulation. To the best of our knowledge, no other studies have shown the immediate effects of high-intensity, motor-level, TENS application on the PPT at contralateral sites. Positive findings of the diffuse and segmental effects of motor-level TENS on contralateral PPTs provides evidence of the feasibility of including TENS as one component of an effective pain management strategy in the early post-operative phase of rehabilitation, and laying a foundation for a novel approach to pain management in physical therapy.

As motor-level TENS produced an increase in the PPT at both segmental and diffuse contralateral sites, it is reasonable to suppose that motor-level TENS activated a systemic pain modulating response, rather than only a local response. Animal studies have demonstrated a positive correlation between nociception (i.e., application of painful stimuli) and activation of diffuse noxious inhibitory controls (DNIC)[15]. In humans, Pud et al.[16] reported both a local (i.e., segmental) and diffuse effect of endogenous analgesia. For their noxious stimuli, Pud et al. asked subjects to immerse themselves into noxious cold water (1 ± 0.5 °C) for 30 s. In our study, we demonstrated that a 30 s of motor-level TENS was an effective stimulus to trigger a diffuse, pain analgesic, effect. The intensity of the motor-level TENS stimulus was a 'very strong' but subjectively still 'non-painful' stimulation (i.e., no participants withdrew from the painful stimulus), as used in previous studies[17]. We hypothesize that the intensity of the motor-level TENS was sufficient to activate a DNIC-like mechanism which contributed to the generalized increase in PPTs.

Exercise-induced hypoalgesia (EIH), using a variety of exercise modalities, has been reported to be effective in humans. Although many studies have used high-intensity exercise (e.g., aerobic exercise or exhaustive isometric exercise) to produce hypoalgesia[18–20], positive analgesic effects of low intensity exercise (i.e., hand grip or raising leg straight) have also been reported[21–23]. In the present study, motor-level TENS induced muscle contractions. Although it was not a voluntary contraction, this stimulus may have produced an EIH effect.

Changes in attention have been shown to modulate analgesia[24–26]. Placebo analgesia is activated by expectation and distraction of attention. In our study, it is possible that the TENS stimulation distracted attention away from the pressure point. However, analysis of this specific mechanism lies outside the scope of this study.

Researchers have investigated the analgesic effect of treating other sites. Lannersten et al. reported that, during voluntary contraction of the quadriceps at an intensity of 20% to 25% of maximal voluntary contraction, PPTs increased in both the contralateral quadriceps (i.e., segmental) and infraspinatus (i.e., diffuse) muscles, compared to baseline[27]. In our study, we demonstrated that these segmental and diffuse analgesic effects can be achieved even with a low intensity muscle contraction.

Sensory-level TENS increased the PPT only at the deltoid muscle site. The baseline PPT indicated a higher sensitivity of the deltoid to pressure, compared to the TA muscle. This result was consistent with previous studies[28, 29], with the higher sensitivity of the deltoid to effects of TENS contributing to the significance of PPT measures at this site only.

The limitations of our study must be considered in the interpretation of the outcomes. Foremost, participants in our study were healthy adults and, therefore, it is unclear whether similar results would be obtained in patients. Studies are needed to confirm our findings in clinical populations. As well, we did not measure PPTs on the ipsilateral side of stimulation and, therefore, comparisons to measured contralateral effects are not possible. Finally, the effects for only two levels of stimulation intensity were evaluated and, therefore, the 'most' effective intensity to achieve an analgesic effect cannot be determined.

In conclusion, our study provided evidence of the beneficial effects of motor-level TENS to produce an immediate and large increase in PPT, compared to sensory-level TENS. While additional research is required, outcomes of this study provide a foundation for a novel approach for post-operative pain management in physical therapy.

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