



Original Article

## Comparison of the pain-relieving effects of transcutaneous electrical nerve stimulation applied at the same dermatome levels as the site of pain in the wrist joint

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**Abstract.** [Purpose] The purpose of this study was to develop a proposal for an effective interventional option for therapeutic stimulation sites by comparing the pain-relieving effect of transcutaneous electrical nerve stimulation (TENS) applied to the same dermatome level of the contralateral sites of the dorsal wrist joint with the pain or the neck, or both sites simultaneously. [Subjects and Methods] A control was first established by triggering pain in the left dorsal wrist joints of adult females by using heat stimulation. Three interventions were then performed, comprising the TENS to the contralateral wrist joint (CW) and to the neck (N) at the same dermatome level as the site of pain, and the TENS to both CW and N simultaneously (CWN). Levels of pain and cerebral blood flow were also measured. [Results] The pain levels of three interventions were found to be significantly decreased compared with the control; however, no significant differences in the levels of pain were seen between any combinations of three interventions. Furthermore, no significant differences were seen between any interventions in terms of cerebral blood flow. [Conclusion] The results suggest that in order for TENS to be effective, it is necessary to make effective use of the dermatome.

**Key words:** Transcutaneous electrical nerve stimulation, Dermatome, Near-infrared spectroscopy

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### INTRODUCTION

Transcutaneous electrical nerve stimulation (TENS) is a useful physical therapy for pain-relief; however, the effects of this therapy are said to be influenced by the site of placement of the TENS stimulating electrodes<sup>1)</sup>. Furthermore, TENS applied to the site contralateral to the site of pain is reportedly effective in patients, including those with wounds or amputations, who are unable to receive direct stimulation to the site of their pain<sup>2-5)</sup>. However, much currently remains unclear about whether TENS applied to the site contralateral to the site of pain is effective. There are no published reports that discuss the effects of TENS applied simultaneously to the site contralateral to the site of pain and to the neck at the same dermatome level as the site of pain. Moreover, almost no current reports discuss the relationship between changes in pain and brain activity after TENS<sup>6)</sup>.

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30 sec	60 sec	5 min	60 sec	5 min	60 sec	5 min	60 min	20 sec
Rest (Baseline)	47 °C	Rest	47 °C	Rest	47 °C	Rest	47 °C	Rest

**Fig. 1.** Experimental protocol (single-epoch design)

After a baseline session of 30 seconds, a control was performed followed by three 60-second interventions (TENS to CW, N, and CWN). The rest between the control and the three interventions was 5 minutes. TENS was applied to CW, N, and CWN using 47 °C heat stimulation.

CW: Contralateral right dorsal wrist joint at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); N: Neck at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); CWN: Both CW and N simultaneously; 30 sec: Baseline session of 30 seconds; 60 sec: Control and three interventions were performed for 60 seconds; 5 min: Rest between control and three interventions; 20 sec: Rest at the end of all TENS interventions; 47 °C: 47 °C heat stimulation; TENS: transcutaneous electrical nerve stimulation

The purpose of this study was therefore to develop a proposal for more effective options for therapeutic stimulation sites by comparing the pain-relieving effects of TENS applied at either the contralateral dorsal wrist joint at the same dermatome level as the site of pain in the dorsal wrist joint or the neck at the same dermatome level as the site of pain in the dorsal wrist joint, or both sites simultaneously.

## SUBJECTS AND METHODS

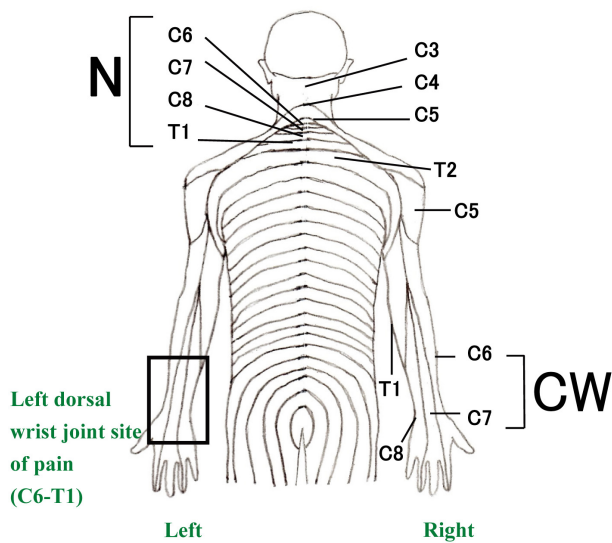
The subjects in this study were 15 healthy adult females (mean age:  $21.9 \pm 0.3$  [21–22] years) without any neurological or orthopedic disease in the four limbs or trunk. The Research Ethics Committee of Konan Women’s University approved this study (12203) to be conducted, and all subjects gave their informed consent to participate after receiving a full explanation of the study’s purpose and methods.

The design for this study was set as a single session of heat stimulation during measurement based on the single-epoch design of Koyama et al.<sup>7)</sup> (Fig. 1). The study protocol involved 30 seconds of rest at baseline, followed by a control of 60 seconds of heat stimulation with 47 °C conductive heat from a Peltier device using a pain thermometer (UDH-201; Unique Medical Co., Ltd., Tokyo, Japan) to produce quantitative pain in advance in the left dorsal wrist joint. Next, to achieve pain-relief, a total of three different types of TENS were applied randomly. These three TENS interventions were: TENS applied to the contralateral right dorsal wrist joint at the same dermatome level as the site of pain in the left dorsal wrist joint (CW), TENS applied to the neck at the same dermatome level as the site of pain in the left dorsal wrist joint (N), and TENS applied to both CW and N simultaneously (CWN). Five minutes of rest was scheduled before each TENS intervention, and 20 seconds of rest was scheduled at the end after completion of all TENS interventions. CW was performed on a rectangular site measuring 10 cm horizontally and 5 cm vertically, established on the skin on the dorsum of the right wrist joint at the same dermatome level as the site of pain in the left dorsal wrist joint. The myelomere levels of this dermatome were C6, C7, C8 and T1. Meanwhile, N was the location on the neck at the same levels of C6, C7, C8 and T1 associated with the site of pain in the left wrist joint (Fig. 2).

TENS was performed using an electrostimulator (ES-520; Ito Co., Ltd., Tokyo, Japan) for 60 seconds at a frequency of about 15 Hz<sup>8, 9)</sup> and a wavelength of 200  $\mu$ s, which can trigger the release of large quantities of hormones including endorphins, enkephalins,  $\beta$ -endorphin and dynorphins, which are opioid peptides. The intensity of TENS was set at the threshold of pain for CW based on diffuse noxious inhibitory controls (DNIC)<sup>10, 11)</sup>, and at a comfortable intensity for N based on gate control theory<sup>12)</sup>.

To determine the therapeutic effect, a visual analogue scale (VAS) was used for pain evaluation. To evaluate brain activity on the basis of blood flow measurements of the primary somatosensory cortex and prefrontal cortex mainly in accordance with the 10–20 system, a device based on near-infrared spectroscopy (LABNIRS; Shimadzu Corporation, Kyoto, Japan) was used for the control, CW, N and CWN to measure all 44 channels. Indices used were oxygenated hemoglobin (oxy-Hb) at 10, 30 and 60 seconds after starting each stimulation session of CW, N and CWN. Numeric values obtained were tallied and calculated as means.

The effect size (mean oxy-Hb during task – mean oxy-Hb at rest/standard deviation at rest) of the value obtained for each channel was also calculated. This effect size was used in statistical processing. One-way analysis of variance was used for comparisons by condition, and Tukey’s post-hoc test was used for multiple comparisons. The level of statistical significance was set at <0.05.



**Fig. 2.** CW and N placements of TENS electrodes for a site of pain in the left dorsal wrist joint

CW: Contralateral right dorsal wrist joint at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); N: Neck at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); TENS: transcutaneous electrical nerve stimulation

**Table 1.** VAS comparison of TENS between the control and each site (n=15)

	Control	CW	N	CWN
VAS	41.1 ± 20.8	27.2 ± 16.1*	27.4 ± 19.2*	27.5 ± 17.7*

\*Significant difference compared with the control,  $p < 0.05$  (Tukey's post-hoc test)

One-way analysis of variance ( $F=4.491$ ,  $df=3.56$ ,  $p < 0.05$ )

VAS: Pain rating scale (from 0 to 100). Zero was defined as no pain and 100 was defined as the worst imaginable pain; CW: Contralateral right dorsal wrist joint at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); N: Neck at the same dermatome level as the site of pain in the left dorsal wrist joint (C6–T1); CWN: Both CW and N simultaneously; VAS: visual analogue scale; TENS: transcutaneous electrical nerve stimulation

## RESULTS

The mean intensity of TENS in CW at the DNIC-based threshold of pain was  $9.9 \pm 4.7$  mA (4–21.5 mA), and in N at a gate control theory-based comfortable intensity was  $28.1 \pm 8.6$  mA (13.5–40 mA). The levels of pain measured by VAS after CW, N and CWN were  $27.2 \pm 16.1$ ,  $27.4 \pm 19.2$  and  $27.5 \pm 17.7$ , respectively, which were significantly reduced levels compared with  $41.1 \pm 20.8$  for the control (Table 1). Multiple comparisons of post-intervention levels of pain measured by VAS between the three interventions (CW, N and CWN) revealed no significant difference between any of the combinations.

Furthermore, in comparing the cerebral blood flow in a total of 44 channels, mainly of the primary somatosensory cortex and prefrontal cortex between the control, CW, N and CWN interventions (all 10, 30 and 60 seconds after starting stimulation), no significant difference was seen in any of the interventions.

## DISCUSSION

The application of TENS to CW, N, and both CW and N simultaneously resulted in significantly decreased VAS scores compared with the control. TENS applied to CW could therefore trigger a pain-relieving effect. This suggests that TENS applied N could be effective in patients whose site of impairment cannot be treated directly due to an amputation, wound or other reason. Although the elements of DNIC and gate control theory were taken into account in CW and N, respectively, the lack of a difference between the three interventions also suggests that TENS applied to a site at the same dermatome level as the site of pain, a common factor in all three interventions, could be effective. On the other hand, no significant differences were seen between all four interventions in terms of the pain-relieving effect of TENS on cerebral blood flow at all 44 measured sites. This lack of change in the measured primary somatosensory cortex and prefrontal cortex suggests that a pain-relieving effect may be triggered via another cerebral limbic system<sup>13</sup>.

Platon et al.<sup>14</sup> compared the pain-relieving effects of pharmacotherapy and TENS in postoperative induced abortion patients and reported that electrical stimulation with TENS applied to the skin area at the same dermatome as the myelomere level innervating the uterus was equally as effective as pharmacotherapy. In an animal experiment involving the application of noxious stimuli, Garrison et al.<sup>15</sup> suggested that when electrode stimulation at the site perceiving pain is interrupted, the effects of this electrical stimulation can still be obtained by placing the electrodes at the contralateral dermatome. The above shows that reports exist that describe a significant pain-relieving effect as a result of placing electrodes with consideration to dermatomes, indicating the same tendency as that discovered in the present study using dermatomes. As for the significance of applying stimulation to sites of pain that cannot be directly stimulated, electrical stimulation has long been a mainstream method of stimulating sites of pain (spontaneous pain, tenderness), but few studies involving electrical stimulation to sites

including the periphery of the site of pain and dermatomes have been performed. Symptoms of acute trauma and complex regional pain syndrome including allodynia, phantom limb pain and post-herpetic neuralgia have a history of difficulties because the affected site often cannot be treated. We therefore investigated if other effective analgesic treatment sites exist besides the affected site in conditions such as phantom limb pain and reflex sympathetic dystrophy. Our accumulated research indicates that it is important to make effective use of other sites including contralateral dermatomes and trunk dermatomes. Contralateral stimulation has been described in studies that recorded brain activity at the site of brain response to pain stimuli in both the contralateral and ipsilateral cerebral hemispheres using magnetoencephalography<sup>16–18</sup>. Because it is possible to record equivalent current dipoles that respond to unilateral electrical stimulation in the somatosensory cortexes of both the contralateral and ipsilateral cerebral hemispheres, applying stimulation to a site contralateral to the site of pain (for example, when pain is in the left wrist joint, stimulation applied to the right wrist joint could stimulate the somatosensory cortex of the right cerebral hemisphere responding to pain in the left wrist joint) could stimulate the ipsilateral hemisphere responding to the site of pain and thereby be a useful intervention.

A possible limitation to the present study was the somewhat unclear exact anatomical and physiological bases for the input path of stimulation and the pain-relieving mechanism in TENS applied to the site contralateral to the site of pain, to another dermatome at the same level, or to both sites simultaneously. Reported mechanisms are those based on gate control theory, endogenous opioid peptides, the descending pain modulatory system, and DNIC. However, without a treatment protocol systematized according to site of treatment, symptoms and other factors, TENS therapy has a history of being practiced on the basis of trial and error. Moving forward, it will be vital to continue exploring clues to elucidate the therapeutic effects of TENS through collaboration between clinical and basic research investigations.

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