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Original Article

Analgesic Effects of Transcutaneous Electrical Nerve Stimulation and Interferential Current on Experimental Ischemic Pain Models: Frequencies of 50 Hz and 100 Hz

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Abstract. [Purpose] This study compared the analgesic effects of transcutaneous electrical nerve stimulation (TENS) and interferential currents (IFC) on induced ischemic pain in healthy volunteers. [Subjects] The subjects were 36 volunteers (18 male, 18 female) without known pathology that could cause pain. Their mean age was 24.5±2.2 years. [Methods] A single-blind and parallel-group method was used. Subjects were randomly allocated to receive each 50 Hz TENS, 50 Hz IFC, 100 Hz TENS, and 100 Hz IFC. This study experimentally induced ischemic pain in otherwise pain-free subjects using a modified version of the submaximal effort tourniquet technique. Subjects completed twelve cycles of the ischemic-induced pain test. The primary outcome measure was the change in self-reported of pain intensity during one of four possible treatments. [Results] There were significant effects for Time, which were attributed to a significant reduction in pain intensity for all groups. There were no significant effects for groups or group-time interaction. The 50 Hz IFC treatment was more comfortable than the other treatments in the present study, and it is likely to be better accepted and tolerated by patients. [Conclusion] We conclude that there were no differences in the analgesic effects of the four treatments under the present experimental conditions. The 50 Hz IFC treatment is more comfortable than the other treatments.
Key words: Transcutaneous electrical nerve stimulation, Interferential current, Ischemic pain model

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INTRODUCTION

Electrical stimulation is a popular treatment used by physiotherapists for muscle strengthening, endurance, spasticity management, pain control, circulation promotion and edema control[1–5]. Transcutaneous electrical nerve stimulation (TENS) and interferential current (IFC) are widely used for relief of chronic and acute pain[6–9].

It is believed that IFC excites deep tissue and that TENS excites superficial tissue. TENS machines are usually relatively inexpensive, portable, battery operated devices, while IFC machines tend to be more expensive, are not portable, and require an electrical power source[10].

Experimental pain models provide a useful representation of clinical pain and make it possible to control variables such as pain intensity and duration. Clinical trials can be expensive and time consuming, while the intensity, location, and duration of clinical pain can be difficult to control. Experimental pain models can thus guide subsequent clinical trials, potentially saving time and money. Different experimental pain models exist utilizing different types of pain stimulus such as cold, mechanical, electrical, and ischemic pain[11].

The frequencies of 50 Hz and 100 Hz have a high analgesic effect[12–15]. Experimental pain models using the same frequencies for TENS and ICT analgesic effects have been compared, but the analgesic effects are unclear[16–18]. Thus far, there have been few studies that have compare the analgesic effects of TENS and IFC with these two frequencies.

The ischemic pain model is a method commonly used to validate analgesic effect. The modified version of the submaximum effort tourniquet technique (SETT) can cause pain that is similar to clinical pain[10, 19].

Therefore, this study used the ischemic pain model to compare the analgesic effects of 50 Hz TENS, 50 Hz IFC, 100 Hz TENS and 100 Hz IFC.

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SUBJECTS AND METHODS

The subjects were 36 university student volunteers (18 male, 18 female) without known pathology. Their mean age was 24.5 years (SD 2.2) (Table 1). All subjects who expressed interest in participating in the study were briefed on the experimental procedure (both verbally and in written form) and were screened for contraindications to the experimental procedure or electrotherapy. These contraindications included any illness or pathology such as peripheral vascular abnormalities, hypertension, hypotension, peripheral neuropathies, recent trauma, and menstruation problems. Subjects who were taking any medication or who were likely to take any medication during the period of study were excluded.

The investigator also checked each subject's nondominant arm for signs of previous trauma and recorded the subject's blood pressure from the nondominant arm (because the effectiveness of TENS and IFC is dependent on normally functioning nerves in the skin) using a sphygmomanometer.

Outcome measurements were recorded from the nondominant arm so that subjects could use the dominant arm when completing visual analog scales (VASs). All subjects who expressed an interest in the study met the criteria and agreed to participate. Subjects were required to sign a consent form and were reminded that they had the right to withdraw from the experiment at any time.

All subjects gave informed consent according to the methods outlined by Sahmyook University's institutional review board. This study protocol and procedures were also approved by Sahmyook University's ethics committees.

Each subject attended our research laboratory on four separate occasions with a 24-, 48-, or 72- to 96-hour interval between visits. During each visit, ischemic pain was induced over a 12-minute period using the SETT. Self-reported pain intensity was recorded at 1-minute intervals during the ischemic pain test using a VAS in which 0 cm represented "no pain" and 10 cm represented "worst pain imaginable". Analgesia was induced by one of four treatments: 50 Hz TENS, 50 Hz IFC, 100 Hz TENS or 100 Hz IFC.

At the end of the fourth testing session, participants were asked, "Which of the two modalities, if either, seemed more effective?" and "Which of the two modalities, if either, felt more comfortable?" The subjects were given the opportunity to comment.

During the SETT, a sphygmomanometer cuff is usually applied above the subject's elbow and inflated to 200 mm Hg. During pilot studies in our laboratory, we found that most subjects experienced widespread paresthesia in the arm rather than pain. Thus, we modified the SETT by applying the sphygmomanometer cuff to the forearm 5 cm below the elbow crease, because this placement of the sphygmomanometer cuff produced a dull aching pain that was localized to the area of the cuff in all subjects.

Before the start of the experiment, maximal grip force was determined using a dynamometer (Martin Vigorimeter*) fitted with a medium bulb. Seventy-five percent of the maximal grip force was calculated and identified on the dynamometer scale. Ischemic pain was induced in the following manner. Subjects raised their nondominant arm vertically above their head for 1 minute to decrease the volume of blood the limb. The sphygmomanometer cuff (15 cm in length) was then inflated to above 200 mmHg at a rate of 40 mmHg per second. Full cuff inflation was taken as time 0, and subjects rated the intensity of pain in their raised arm using the VAS. The forearm was then returned to rest in the horizontal position on a polystyrene box that was designed to support the forearm and hand without applying pressure to the sphygmomanometer cuff. This was to ensure an even distribution of pressure throughout the cuff. Subjects then performed 20 hand-gripping exercises at 75% of their maximal grip force for a period of one minute (squeeze for two seconds and rest for two seconds). Pain intensity was recorded on completion of these exercises and at one minute intervals for the remainder of the experiment. The cuff was deflated over a period of two minutes to allow the volume of blood to increase in the limb, and the final pain intensity rating was taken one minute after cuff deflation. No signs of trauma were observed in the arms of any subjects following the ischemic pain test[10, 19].

Table 1. General characteristics of the subjects

Variable	Mean±SD
Age (yr)	24.5±2.2
Height (cm)	170.3±12.5
Weight (kg)	64.7±15.3

SD, standard deviation

On each visit to the laboratory, subjects were randomly allocated to one of four treatments: 50 Hz TENS, 50 Hz IFC, 100 Hz TENS and 100 Hz IFC. All subjects received 22 minutes of uninterrupted treatment. A single-blind experimental approach was used whereby the subjects were not aware of which treatment they were being given. Four self-adhesive electrodes (each electrode 4.5 cm^2) were applied before the start of the experiment, and treatment was switched on 10 minutes and 40 seconds before the arm was raised above the head. Electrode sites were chosen to target afferents emerging from the ischemic area. We were concerned that afferents under the cuff might be unable to fire due to pressure block from the cuff. However, all subjects reported that they experienced a strong but comfortable electrical paresthesia, suggesting to us that afferents remained active.

Electrodes were applied in a quadripolar manner to the anterior and posterior aspects of each subjects' forearm so that electrical currents would intersect at the midpoint of the cuff. The distal electrode for channel A was attached to the anterior surface of the forearm 5 cm proximal to the first wrist crease. The distal electrode for channel B was attached to the posterior surface of the forearm directly beneath the distal electrode for channel A. Proximal electrodes were applied directly above the cuff. Subjects in the IFC group were told that to produce an effect, the intensity

Table 2. Pain intensity rating for treatments during the ischemic pain test

	Cuff Inflated	Handgrip Exercise Start	Handgrip Exercise End	Cuff Inflated						Cuff Deflating	Cuff Deflating	Cuff Deflated
	-20 s	0 min	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
	VAS 1	VAS 2	VAS 3	VAS 4	VAS 5	VAS 6	VAS 7	VAS 8	VAS 9	VAS 10	VAS 11	VAS 12
50 Hz TENS												
Mean±SD	0.4±0.8	1.5±1.2	2.4±1.8	2.8±1.6	3.4±1.6	4.0±1.6	4.1±1.7	4.5±1.8	4.8±1.9	5.1±2.2	2.6±2.3	1.3±2.0
50 Hz IFC												
Mean±SD	0.5±0.6	1.3±0.6	2.1±1.2	2.4±1.2	3.0±1.3	3.6±1.9	3.9±2.1	4.2±2.2	4.5±2.4	4.3±2.6	2.5±2.5	1.6±2.3
100 Hz TENS												
Mean±SD	0.3±0.3	1.3±0.5	2.2±0.9	2.5±1.1	2.9±1.4	3.6±1.5	3.7±1.3	3.9±1.4	4.1±1.6	3.9±1.9	2.2±1.8	1.4±1.2
100 Hz IFC												
Mean±SD	0.4±0.4	1.1±0.6	1.9±0.8	2.2±1.0	2.8±1.5	3.4±1.7	3.6±1.5	4.0±1.5	4.4±1.4	4.1±2.0	2.3±1.7	1.7±1.1

Values are expressed as the mean ±SD. TENS, transcutaneous electrical nerve stimulation; IFC, interferential currents; VAS, visual analog scale

of the stimulator must be maintained at a "strong but comfortable level" at all times. Initially, when the IFC device was switched on for the first time, the "comfortable level" was obtained by increasing the current amplitude so that the subjects reported either that the currents were uncomfortable or that the motor threshold had been reached. High analgesic effects of bursts at 50 Hz and 100 Hz generated by 4-kHz sinusoidal waves were applied[20, 21].

TENS is usually applied using a single-channel device via two electrodes. The TENS in our study was delivered via four electrodes using a dual-channel device in order to standardize the amount of current administered by the two modalities. Electrodes were applied to the anterior and posterior aspects of the each subjects's forearm in an identical manner to that for IFC. To minimize interference of currents from the two channels, both distal electrodes were attached to channel A of the TENS device, and both proximal electrodes were attached to channel B. The "comfortable level" was obtained using the same procedure as that described for IFC. The high analgesic effect of a 125-microsecond phase duration at a frequency of 50 Hz and a 200-microsecond phase duration at a frequency of 100 Hz were applied[20, 21].

All statistical analyses were performed using the SPSS version 19.0 software. Data were analyzed by calculating the change in pain intensity rating during the treatment between measurements. Treatment effects were determined by a two-way repeated measures analysis of variance (ANOVA) of the change in pain intensity during treatment for VAS ratings 4 through 9 and all VAS ratings.

RESULTS

After completing the four interventions, there were significant effects for time, which were attributed to a significant reduction in pain intensity during treatment, for VAS ratings 4 through 9 and all VAS ratings (VAS 1–12) ($p<0.05$). There were no significant effects for groups or group-time interaction in pain intensity during treatment for VAS ratings 4 through 9 and all VAS ratings. There were significant time effects that could be attributed to the increase in pain intensity in all groups during cuff inflation and hand-grip exercises (VAS 1–3) and a decrease in pain intensity immediately upon cuff deflation (VAS 10–12). This result means pain intensity was significantly increased by the treatment in all groups ($p<0.05$). But there was no significant difference between the groups (Table 2).

At the end of the fourth session, participants were asked which of the four types of intervention felt most comfortable. Twenty subjects (56%) reported that 50 Hz IFC was the most comfortable, six (17%) felt that 100 Hz-IFC was the most comfortable, six (17%) felt that 50 Hz TENS was the most comfortable, and four (10%) felt that 100 Hz TENS was the most comfortable.

At the end of the second session, participants were asked which modality felt more effective for pain relief. Nineteen subjects (53%) reported that 50 Hz IFC was the most effective, nine (25%) felt that 100 Hz IFC was the most effective, five (14%) felt that 50 Hz TENS was the most effective, and three (8%) felt that 100 Hz TENS was the most effective.

DISCUSSION

The effects of TENS and IFC stimulation at frequencies of 50 Hz and 100 Hz on pain relief were analyzed to investigate the usefulness of electrical stimulation on ischemic-induced pain.

In this study, pain intensity was significantly increased during treatment in all groups. But it was not significantly between the groups during the treatment.

Johnson and Tabasam used 100-Hz stimulation and found a greater effect with TENS than IFC in a cold pain model, but the difference between treatments was not significant. The measured difference was not statistically significant, but the study only had seven participants in each, group so the lack of significance could have been due to low statistical power[22]. With methods similar to this study, Shanahan et al. reported an experimental study using a crossover design with larger participant numbers. They found that TENS at a frequency of 100 Hz had a greater analgesic effect than premodulated IFC at a beat frequency of 100 Hz.

The balance of evidence thus indicates that IFC is less effective than TENS. Cheing and Hui-chan reported no significant difference between treatments in a heat pain model[23]. Johnson and Tabasam reported no significant difference between treatments in an ischemic pain model[20]. Johnson and Tabasam reported a statistically significant result, with 100 Hz TENS being more effective than premodulated 100 Hz IFC[23]. Ward et al. remarked that the controversy over the effect of pain relief between TENS and IFC resulted from lack of statistical power in published papers due to inadequate sample sizes[21].

Ward et al. found that the effects of TENS and IFC at 50 Hz on the pain threshold was significantly increased and that there was no significant difference between TENS and IFC in a cold pain model[21]. Johnson et al. found that higher frequencies of pulsed current (above 50 Hz) resulted in a lesser hypoalgesic effect[17]. The between-frequency differences in the study by Johnson et al. were not statistically significant, possibly due to a small sample size, but a downward trend was clearly evident above 40 Hz[17]. Ward et al. speculated that a short burst duration prevents or severely restricts multiple firing of sensory nerve fibers and instead produces one action potential per burst[21]. The hypoalgesic effects are thus equivalent to TENS. Thus 50 Hz IFC and 50 Hz TENS are equally effective in alleviating cold-induced pain in healthy subjects[21]. Therefore, in previous studies, there was a debate that not significant difference between the different types of electrical stimulation. However, analgesia was significantly increased during electrical stimulation. The results of our study were similar to those of previous studies and also showed a statistically significant difference between the different types of electrical stimulation, but analgesia was significantly increased during electrical stimulation in all groups.

Ward et al. reported that subjects experienced the most analgesia from electrical stimulation and the greatest comfort at a frequency of 50 Hz with IFC, as was the case in our study[21]. The current results and previous TENS and IFC comparative studies strengthen the conclusion drawn that low-duty-cycle, burst-modulated AC is more comfortable than conventional low-frequency pulsed current[21]. That 50 Hz IFC is an acceptable treatment is likely a consequence of the lesser discomfort.

We conclude that there were no differences in the analgesic effects of the four interventions under the present experimental conditions. However, 50 Hz IFC is more comfortable than other interventions and is likely to be better accepted and tolerated by patients. Further clinical investigation is warranted.

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