The Effects of TENS, Heat, and Cold on the Pain Thresholds Induced by Mechanical Pressure in Healthy Volunteers

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▪ ABSTRACT

This study was aimed to test whether the administration of transcutaneous electrical neural stimulation (TENS), heat or cold alone, or the coadministration of TENS in combination with heat or with cold may alter the thresholds of the sensory (algosity) and the affective (unpleasantness) dimensions of experimental pain. Mechanical pain induced by a pressure algometer was applied to the tibial shaft of 180 healthy volunteers before and after random application of one of the six following modalities: sham-stimulation, cold, heat, TENS, combination of TENS + cold, or combination of TENS + heat. All modalities were applied in the same (L4) dermatome with the use of Thermotens (Mediseb Technologies Ltd., Hertzelia, Israel), a device which produces quantifiable combinations of thermal and electrical modalities separately or simultaneously. Only the combination of TENS + heat significantly elevated the thresholds of algosity (from 221 mmHg to 262 mmHg, $p < 0.01$) and of unpleasantness (from 134 ± 9 to 197 ± 9 mmHg; $p < 0.001$). These findings suggest that the coadministration of several physical modalities can be more efficacious in the treatment of pain than each modality alone. ▪

KEY WORDS: affective, pressure-pain, sensory, thermal stimulation.

INTRODUCTION

Physical modalities, such as thermal and electrical stimulation, have been utilized in the treatment of pain for many years. The application of hot packs, ice, and transcutaneous electrical nerve stimulation (TENS) are among the most commonly used modalities for the treatment of pain. TENS has been studied extensively in a considerable number of painful conditions with equivocal results (1). However, its proposed mechanism of action via the gate control theory is well known (2). In contrast, the scientific literature regarding the analgesic efficacy of thermal modalities has thus far been very limited, primarily due to the lack of devices through which quantifiable thermal stimuli can be applied (3). Furthermore, in spite of the frequent use of a variety of thermal modalities for pain

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control, their underlying analgesic mechanisms are not completely understood. The analgesic properties, relative usefulness of each modality in altering the different dimensions of the pain sensation, and possible advantage of simultaneous application of more than one modality (such as TENS in combination with heat) has not been explored.

The concept that pain has two distinctive dimensions, sensory and affective, is well known (4–9). Recently, Fields (10) has suggested the terms algosity and unpleasantness when referring to the two dimensions, respectively. The first has a specific quality, which allows it to be unequivocally identified as noxious. The second refers to a nonspecific sensory discrimination, which is not necessarily coupled with noxious stimuli. Using these terms, the present study was aimed to test the efficacy of sham TENS, TENS, heat or cold alone, TENS in combination with heat, or TENS in combination with cold in altering the threshold of the two pain dimensions. For that purpose, a pressure algometer was applied to produce an experimental model of mechanical pain in healthy volunteers and a device was used to induce the required thermal and electrical modalities, alone or in simultaneous combination, all in a quantifiable fashion.

MATERIALS AND METHODS

Subjects

The study population consisted of 180 healthy volunteers, 91 males and 89 females, aged 18–65 (mean 39.3, SEM ± 1.0). Inclusion in the study was contingent upon the margins of the tibial shaft being clearly palpable. All participants were required to sign a written informed consent. The study was approved by the Hospital's Helsinki Committee.

Apparatus

Pain stimulus was applied by using a manual pressure algometer with a 3-mm diameter paddle (algimeter; Med-Hako, Hamburg, Germany), which was pressed perpendicularly to the skin above the shaft of the tibial bone, halfway between the medial malleolus and the medial condyle. Pressure was increased by 20 mmHg per second by a trained investigator.

Thermotens (Mediseb Technologies Ltd., Hertzelia, Israel) is a new device that allows the use of thermal and electrical modalities alone or in variable combinations simultaneously, all in a quantifiable fashion. Because it is a computerized device, it allows the operator to control the following stimulation parameters: pulse amplitude, 0–75 v; pulse width, 20 μs–10 ms; pulse shape of any type of waveform; frequency range, 0.1–5000 Hz; temperature, −5 °C to +45 °C; temperature gradient, 40 °C/min. The computer has a wire connection to two probes, 5 cm in diameter each, which are attached to the skin with an elastic band. In the present experiment, the two probes were adjusted to provide the following six different types of stimulations: no stimulation (control); cold stimulation at 15 °C; heat stimulation at 39 °C; TENS at 100 Hz; 0.1 ms pulse duration; symmetric, biphasic waveform; tolerable intensity; TENS in combination with cold administered simultaneously; and TENS in simultaneous combination with heat. Parameters used in the combinations were identical to those given as separate stimulations. It has been our experience that at fixed intensity, TENS can be comfortable for some subjects and intolerable to others. Therefore, in the present study TENS intensity was adjusted individually. To avoid possible bias from the simultaneous administration of the thermal stimuli in the combination treatments, TENS intensity was adjusted first and the thermal stimuli were added immediately afterwards. All stimulations were applied for 20 min each.

Algosity and Unpleasantness Ratings

Explicit explanations and training were given to all subjects to ensure that they were capable of understanding the distinction between algosity and unpleasantness. Training consisted of increment of pressure applied to the tibial shaft of the nondominant leg. Participants were asked to say "now" when they first perceived either unpleasantness or algosity, and to define the dimension perceived. This was repeated in another site about 1 cm away for the other dimension. Subjects unable to make this distinction were excluded from the study. Unpleasantness and algosity thresholds were then determined via a steady increment of pressure in the dominant leg. The measurement shown on the algometer scale (measured by mmHg) was recorded as the threshold for each parameter.

Experimental Procedure

Upon signing a written informed consent, subjects were randomly assigned, in blocks of six, to receive one of the six possible treatments. There were 30 subjects in each group. Each participant was seated with the dominant leg raised and comfortably supported from below. The tibial shaft was palpated, and the midline between the medial malleolus and the medial condyle was marked with a 2 × 2 cm "+" sign, creating four corners. One corner was used to test one category only (such as, algosity threshold) and the opposite corner was used to test the other category. The two Thermotens probes were attached to the skin above the tibial bone, 10 cm apart from each other and equally distant from the center of the "+" sign (Fig. 1). Thus, both the algometer paddle and the two Thermotens probes were placed in one dermatome (L4). The algometer paddle was then placed in the two corners, and baseline measurements of the two categories were taken. Once baseline measurements were taken, a 20-min stimulation with the Thermotens was begun according to the preplanned parameters. The measurements were recorded in the same corners 20 min later while the stimulation was still in progress. All recordings were made by an investigator who was blinded to the type of stimulation applied.

Statistical Analysis

A mixed model analysis of variance (JMP; SAS Institute, Cary, NC) was performed to assess the differences between thresholds for each type of stimulation and the no-stimulation (control) condition. Preplanned contrasts were employed for specific comparisons. In particular, contrasts were used to adjust for differences in baseline levels within groups (net change from baseline levels). The data are presented as mean ± SEM. P was considered significant at the 0. 05 level.

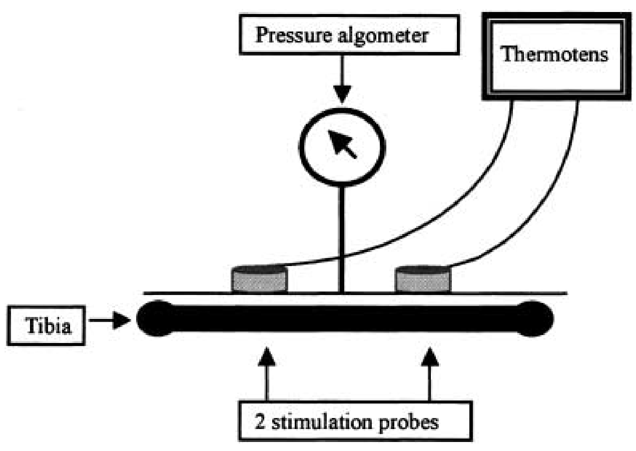

Figure1. Schematic illustration of the experimental procedure.

RESULTS

Subjects

All 180 screened subjects entered and completed the study. All subjects perceived the stimulations as nonpainful, and no one requested to discontinue the stimulation prematurely. The six groups (n = 30 per group) were not significantly different from each other with respect to their age, weight, or male/female ratio.

Threshold for Algosity

The mean threshold of algosity for the entire group was 243 ± 8 mmHg. No differences in thresholds were detected between the groups ($p = 0.29$). TENS in combination with heat produced the largest increase in the algosity threshold (from 221 mmHg at baseline to 262 mmHg following stimulation; $p < 0.01$; 18.5% change) (Table 1). TENS alone, heat alone, and cold alone also increased the thresholds, but not at a significant level. When compared with the other stimuli, the increase from baseline caused by TENS in combination with heat was significantly larger than those caused by TENS in combination with cold ($p < 0.05$) or those caused by no stimulation ($p = 0.04$) (Fig. 2A).

Threshold for Unpleasantness

The mean threshold of unpleasantness for the entire group was 153 ± 6 mmHg. No differences in thresholds between the groups were detected ($p = 0.56$). TENS alone, TENS in combination with cold, and TENS in combination with heat all increased the thresholds for unpleasantness (Table 1). However, the largest and the only significant increase was induced by TENS in combination with heat (from 134 ± 9 mmHg to 197 ± 9 mmHg; $p < 0.001$; 47% change). The increase from baseline induced

Table 1. Thresholds of Algosity and Unpleasantness Before and After Treatments (Mean ± SEM of mmHg)

	Algosity threshold			Unpleasantness threshold		
Stimulus	Before	After	P	Before	After	P
Control	284 ± 10	283 ± 10	0.93	172 ± 9	164 ± 9	0.53
Cold	231 ± 10	237 ± 10	0.69	162 ± 9	155 ± 9	0.62
Heat	221 ± 10	239 ± 10	0.23	149 ± 9	141 ± 9	0.49
TENS	252 ± 11	271 ± 11	0.21	158 ± 9	164 ± 9	0.62
TENS + Cold	249 ± 11	247 ± 11	0.91	146 ± 9	165 ± 9	0.15
TENS + Heat	221 ± 10	262 ± 10	< 0.01	134 ± 9	197 ± 9	< 0.001

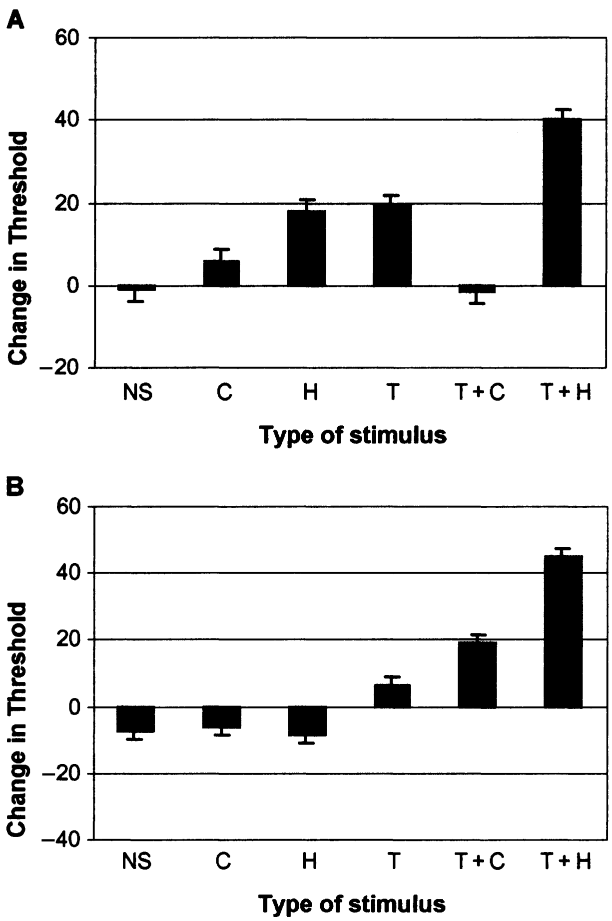

Figure 2. Change in thresholds of algosity and unpleasantness from baseline following treatments: NS, no stimulation (control); C, cold; H, heat; T, TENS; T + C, TENS + cold; T + H, TENS + heat. Data presented as Means ± SEM of mmHg; (A) algosity threshold (B) unpleasantness threshold.

by TENS + heat was significantly larger than that induced by no stimulation ($p = 0.003$), by TENS alone ($p = 0.03$), by cold alone ($p = 0.004$), or by heat alone ($p = 0.003$) (Fig. 2B).

DISCUSSION

The current study demonstrated: a) an experimental model of pressure-induced pain which allows a reliable testing of pain thresholds; b) an increase in unpleasantness and algosity thresholds if TENS is used in combination with heat, but not if TENS, heat, or cold are used alone or if TENS is used in combination with cold; and c) a dissociation of threshold of unpleasantness from that of algosity.

A handheld pressure algometer has been used in previous studies to measure pressure-pain threshold in both patients (11,12) and in healthy volunteers (13,14). The pressure algometer is easy to operate, produces little intraindividual variation, and allows the investigation of relatively small groups (14). In agreement with those studies, the repeated measures recorded in the control group of our study remained unchanged, indicating that the pressure algometer can be regarded as a reliable method for the study of mechanical pain threshold.

Despite the fact that TENS, heat, and cold are commonly used in the treatment of clinical pain (1,3), they failed to produce an effect when used separately in the present study. There ase several possible explanations for their lack of efficacy. First, the analgesic efficacy of these modalities, in general, is still questionable. TENS has been tested in a large variety of experimental and clinical painful conditions, but the results are equivocal. In contrast, the efficacy of heat and cold have not been studied scientifically, presumably due to the lack of quantifiable thermal devices, which allow the conductance of appropriately designed studies. Second, in clinical practice these modalities are usually applied directly onto the painful site while in the present study they were applied to an adjacent area within the same dermatome. This design might have reduced their effectiveness. This assumption is supported by the results of a recent study, in which vibration failed to reduce experimental thermal pain when applied to an adjacent area within the tested dermatome (15). A third explanation is related to the time of the intervention. In the present study all treatments were given prior to the painful stimulus, whereas in clinical conditions they are often used for the treatment of an existing pain. Thus, these findings may indicate that TENS, heat, and cold (at least at the stimulation parameters used in this study) do not reduce pain when applied preemptively.

In contrast to the single modalities or to the combination of TENS and cold which failed to attenuate the outcome measures, TENS in combination with heat significantly elevated the threshold of both unpleasantness and algosity. As we do not have a sufficient understanding of the underlying analgesic mechanisms of the two modalities, there is no clear explanation to this finding. Yet several possibilities can be raised. One explanation is that the elevation of thresholds induced by the combination of heat and TENS simply represents a synergistic effect of the two modalities. Each modality on its own was not powerful enough to produce a significant effect, but when administered simultaneously they produced an overt analgesic effect. A different explanation is related to the understanding that TENS reduces pain through the activation of large diameter afferent fibers. The activated Aβ fibers produce an inhibitory interaction with the small caliber fibers via the gate control theory (2) and possibly activate spinal δ opioid receptors (16). It is possible that heat enhances the effect of TENS by improving the conductivity in the Aβ fibers, especially, as the two stimuli were applied simultaneously and to the exact same area. In this case, the inhibitory effects of the Aβ fibers could have been facilitated. We do not have direct evidence to prove this possibility. However, it is well known that skin temperature has an effect on the results of routine conduction velocity studies (17). Lastly, treatment stimulations were given over 20 min and were still in progress when the second threshold measurements were done. It is possible that the different treatments, either alone or as combinations, may have caused different degrees of nonspecific effects such as distraction. This, however, can be true for any physical modality used in the treatment of existing pain.

The notion that the complexity of pain requires dissociation between its sensory and affective dimensions has recently gained increasing attention in the pain literature (9,10). Such dissociation has been previously demonstrated in models of experimental pain induced by contact heat, electric shock, ischemic exercise, and cold (8). Consistent with this are the results of the present study which show that, following an explanation of the concept and a short training period, healthy subjects can dissociate the threshold of unpleasantness from that of algosity. They further support the understanding that this dissociation is present in a large variety of painful somatic conditions. The fact that the threshold of unpleasantness is so much lower than that of algosity may indeed indicate that the first refers to a nonspecific sensory discrimination which is not necessarily coupled with noxious stimuli, while the second has a specific quality which allows it to be identified as noxious (10). Several pharmacologic (6,7) and psychologic (4,9) interventions have been shown to differentially modulate the sensory and the affective dimensions of pain. In all previous studies, only central manipulations, such as the administration of fentanyl (7) and hypnosis (9), have been used. In the present study, only peripheral manipulations were used, and in the case of TENS in combination with heat, the two dimensions were attenuated differentially (the elevation of unpleasantness threshold was 1.5 times larger than the elevation of algosity threshold). The fact that a peripheral manipulation can have such a differential effect may further support the concept according to which algosity and unpleasantness have different circuits (10).

Lastly, several caveats should be taken into account while interpreting the study results. First, although this was a randomized, controlled study, for obvious reasons the participants were not blinded to the applied modality. Second, due to lack of scientific information, some of the stimulation parameters (temperatures, duration of stimulation) were chosen arbitrarily. Third, only one type of experimental pain model was used in this study. Therefore, it is unclear if these results can be generalized beyond the specific modalities and application approaches used in the study.

In conclusion, TENS, heat, and cold are noninvasive, inexpensive, safe, and easy to use modalities that are extensively used in the treatment of acute and chronic pain conditions. While each modality alone might not produce sufficient analgesia, the present study shows that TENS in combination with heat significantly elevates thresholds of both the sensory and the affective dimensions of experimental mechanical pain. We therefore cautiously raise the possibility that this combination, or additional algorithms, may be more efficacious than

TENS, heat, or cold alone in the treatment of clinical pain.

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