Concentric Electrodes for Producing Acupuncture-Like Anesthetic Effects

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We designed concentric electrodes composed of a center electrode and an outer ring electrode. Electrical stimulation with two sets of such electrodes for 15 min as conditioning stimuli was given to the left hand of 35 adult subjects to induce acupuncture-like anesthetic effects. The effects immediately after the conditioning were compared between stimulation through a pair of center electrodes alone at 3 Hz (conditioning 1) and simultaneous stimulation of 3 Hz through a pair of center electrodes and 100 Hz through a pair of outer ring electrodes (conditioning 2). In conditioning 2, modulating effects of 100 Hz stimuli through a pair of outer ring electrodes made it possible to increase the voltage strength of 3 Hz stimuli through a pair of center electrodes with maintaining the minimum perception of pricking sensation. In both conditioning procedures, muscle twitching was not accompanied. It was found that the respective stimulating current thresholds for faint touch sensation and also for pricking sensation at the right forearm could be elevated significantly more by conditioning 2 (1.54 and 1.40 times) than by conditioning 1 (1.20 and 1.14 times).

Low frequency electrical cutaneous stimulation evoking muscle twitch elevates the threshold of pain sensation like acupuncture anesthesia (Andersson and Holmgren 1975; Hans and Terenius 1982). Generally, muscle twitching for a certain period is a necessary condition for alleviating pain sensation (Andersson et al. 1973, 1977; Chiang et al. 1973), suggesting that muscle twitching is a variable to determine the electrical strength to induce acupuncture anesthesia with acupuncture needles. Muscle twitching induced by electrical stimulation with needle electrodes brings about pain sensation. Instead of stimulating muscles with needle electrodes, low frequency cutaneous stimulation as a conditioning for a certain period could alleviate pain sensation on the test cutaneous area. In studies on acupuncture anesthesia, the strong stimulation that subjects could barely tolerate has been used (Andersson et al. 1973, 1977; Chiang et al. 1973; Andersson and Holmgren 1976; Hyodo and Kitade 1984). In order to reduce pain sensation induced by electrical stimulation, we have devised a new type of
concentric electrodes equipped with a center electrode and an outer ring one. The new electrode had made it feasible to elevate sensory threshold for electrical stimulation on the test cutaneous area without muscle twitch.

METHODS

Experiments were performed on 35 healthy adult volunteers with written consent, 6 males and 29 females, aged from 18 to 21 years. They had no significant medical history and did not take any medicine throughout the period of the experiment.

The subjects lied back on a bed in a sound-proof laboratory. They were asked to discriminate the intensity of electrical stimulation by its quality and graduations; faint touch and pricking sensation (Table 1).

A 2 mm square silver plate was fixed on an acupuncture point, "Xiemen", of the palmar side of the right forearm with electrode paste (Elefix; Nihon-Kohden Co., Tokyo) using surgical tape (Fig. 1). Rectangular pulses of 0.2 msec duration with constant current at a frequency of 5 Hz were delivered through an isolator (SS-1025; Nihon-Kohden Co.) from an electronic stimulator (SEN-3201; Nihon-Kohden Co.). The intensity of stimulus was below 50 mA. The threshold current for eliciting faint touch or pricking sensation was determined as an average of two values obtained by slowly increasing and decreasing the current intensity. It usually took about 30 sec for the detection of each threshold.

The difference of thresholds before and after conditioning stimulation of the left arm was analyzed. For excluding daily differences of those threshold values, the changing ratio of the threshold value after the conditioning divided by that before it was calculated.

The conditioning stimuli were applied on the dorsal aspect of the left forearm, Hoku and Waiguan (Fig. 3) with two sets of the new electrodes (Fig. 2). Hoku and Waiguan are the acupuncture points of traditional Chinese medicine. Two types of conditioning were used. First, a pair of center electrodes were used for the stimulation and secondly, those combined with a pair of outer ring electrodes. A series of the experiments was performed

<table>
<thead>
<tr>
<th>Table 1. Sensory category table for test stimulation</th>
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</thead>
<tbody>
<tr>
<td>1. Faint touch sensation (Grade 1)</td>
</tr>
<tr>
<td>2. Pricking sensation (Grade 2)</td>
</tr>
<tr>
<td>3. Stabbing pain</td>
</tr>
<tr>
<td>4. Strong pain</td>
</tr>
<tr>
<td>5. Unbearable pain</td>
</tr>
</tbody>
</table>

In the current intensities producing 3, 4 and 5, muscle twitching was accompanied.

![Fig. 1. Stimulus points used for determining test threshold currents on the palmar side part of the right forearm. A black square represents a silver electrode (2 mm square for test stimuli) and a large white square a silver indifferent electrode (5×4 cm²).](image)
using the following two conditioning stimuli.

**Conditioning 1 with single electrodes (a pair of center electrodes)**

Biphasic electrical pulses of 3 Hz with variable voltage (Fig. 4A) generated by a specially constructed stimulator (Neuro-Medical, Osaka) were delivered through a pair of center electrodes at Hoku and Waiguan. The subject was asked to describe the strength of stimulation using the category listed on Table 2 and then the threshold voltage for pricking sensation was determined.

**Conditioning 2 with double electrodes (a pair of concentric electrodes and a pair of outer ring electrodes)**

The experiment was performed more than one week after the conditioning 1. First, the threshold for pricking sensation induced by biphasic 3 Hz stimuli was determined through a pair of center electrodes and secondly, the threshold for tingling sensation induced by biphasic 100 Hz stimuli was determined through a pair of outer ring electrodes. Muscle twitching was never observed during the stimulation. The strength for eliciting muscle twitch was high enough to induce burning pain. Thirdly, the experiment was performed with simultaneous stimulation of 3 Hz and 100 Hz stimuli. Additional stimuli of 100 Hz
The consequences under conditioning 1 with a pair of center electrodes

As is clearly seen in Table 3, immediately after the conditioning 1 at 3 Hz for 15 min through a pair of center electrodes at “Hoku” and “Waiguan”, the mean threshold values for the two grades of sensation at right “Xiemen” showed significant elevations, respectively (p < 0.05, paired t-test). These elevating effects of conditioning 1 on both threshold values are seen also as the values of the changing ratio.
The consequences in conditioning 2 with a pair of center electrodes and a pair of outer ring electrodes

The respective mean threshold currents before the conditioning 2 for inducing sensation of faint touch and that of pricking at right "Xiemen" are shown in Table 3.

The minimum voltage for pricking sensation (grade 2) with only a pair of center electrodes was 66.81 ± 15.72 V. The minimum voltage for pricking sensation (grade 2) modulated with a pair of outer ring electrodes at 100 Hz was 87.27 ± 20.53 V. This increase was statistically significant (p < 0.05) and yet we could not observe muscle twitching.

Immediately after the conditioning 2 at 3 Hz with a pair of center electrodes and at 100 Hz with a pair of outer ring electrodes, the test threshold values for the two grades of sensation were elevated significantly, as is shown in Table 3 (p < 0.05, paired t-test). These anesthetic effects are shown also as increments of the changing ratio.

Correlations and daily differences concerning the test threshold values

Correlations between the test threshold currents for faint touch sensation and those for pricking sensation (grade 2) before the conditioning in 35 subjects were fairly good; r = 0.768 (p < 0.01, before conditioning 1) and r = 0.690 (p < 0.01, before conditioning 2). Similar respective correlations between the threshold values in the single electrodes session and those in the double electrodes session conducted more than a week later were not significant (p > 0.05), probably due to daily differences.

<table>
<thead>
<tr>
<th>Conditioning No.</th>
<th>Sensation grade</th>
<th>Threshold value before conditioning (a, mA)</th>
<th>Threshold value after conditioning (b, mA)</th>
<th>Changing ratio of the respective threshold values (paired b/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Faint touch</td>
<td>16.96 ± 4.40</td>
<td>19.96 ± 4.40*</td>
<td>1.20 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>sensation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Pricking</td>
<td>28.90 ± 6.63</td>
<td>32.87 ± 6.76*</td>
<td>1.14 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>sensation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Faint touch</td>
<td>18.94 ± 8.01</td>
<td>26.41 ± 8.79*</td>
<td>1.54 ± 0.65</td>
</tr>
<tr>
<td></td>
<td>sensation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pricking</td>
<td>28.20 ± 8.43</td>
<td>37.18 ± 9.19*</td>
<td>1.41 ± 0.58</td>
</tr>
<tr>
<td></td>
<td>sensation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± S.D.
*p < 0.05 (paired t-test, b vs. a)
Comparisons of the acupuncture-like anesthetic effects between conditioning 1 and 2

For excluding daily differences of the test values, the changing ratios after the conditioning were compared between conditioning 1 and 2. As is seen Table 3, statistical examination (paired t-test) revealed that the conditioning 2 using concentric electrodes is significantly more effective for elevating the electrical thresholds of both faint touch sensation and pricking sensation than the conditioning 1 (p < 0.05). The usefulness of our designed concentric electrodes is clearly seen in the present finding.

Discussion

In acupuncture anesthesia, a rhythmic stimulation for a certain period through needle electrodes was usually given to the subject (Andersson et al. 1973; Toda 1978; Hyodo and Kitade 1984). Clinicians try to stimulate with the strongest but tolerable electrical current, though pain perception is unpleasant for patients. Muscle twitch response of the subject to stimulation assists clinicians in determining the intensity of electrical stimulation. It has been insisted that afferent impulses initiated by muscle twitch are necessary for attaining acupuncture anesthesia (Andersson et al. 1977; Hyodo and Kitade 1984). Nevertheless, afferent impulses for another modality of sensation may be capable for alleviating pain. In the present study, we demonstrated that electrical cutaneous stimulation without muscle twitching on one-side hand can alleviate pain on the opposite-side arm.

Using newly devised concentric electrodes composed of a center electrode and an outer ring one, we could increase the voltage of 3 Hz stimuli through a pair of center electrodes by simultaneously adding 100 Hz stimuli through a pair of outer ring electrodes without inducing muscle twitching. Consequently, the pair of concentric electrodes were found to be more useful to elevate the sensory thresholds not only for faint sensation but for cutaneous pricking sensation on the opposite-side arm than only a pair of center electrodes.

A tentative explanation for this result may be such that electric stimuli given through a pair of center electrodes at 3 Hz can be increased in voltage without strengthening pricking perception and also without muscle twitching. The augmentation of afferent impulses evoked by the strengthened 3 Hz stimuli and their depressive effect on the impulses for pain conduction in the spinal cord and/or the brain can be assumed as a main cause. Furthermore, the effect obtained by 100 Hz stimuli through a pair of outer ring electrodes may be added algebraically to that by 3 Hz stimuli through a pair of center electrodes. However, 100 Hz stimulation is known to have anesthetic action to the same skin area or the homolateral dermatome region but not to the contralateral limbs, differently from 3 Hz stimulation (Melzack and Wall 1965; Andersson and Holmgren 1978;
Therefore, a simple summation effect of 100 Hz stimulation through a pair of outer ring electrodes would not be probable.

Acknowledgments

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References