Changes in the Current Perception Threshold (CPT) Due to Artificial High Concentration CO₂ Water Warm Bathing

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I INTRODUCTION

It is very important to give heat therapy to patients with painful chronic musculoskeletal diseases in order to remove or relieve pain\(^1\). However, it is difficult to objectively evaluate the intensity of pain and is also difficult to objectively and quantitatively evaluate the efficacy of treatments for pain\(^2\). Although the artificial CO\(_2\) warm water is effective for relieving pain, only a few reports have been made on the mechanism of its action. Further, the heat therapy has been reported to relieve pain by elevating a pain perception threshold. However, the presence of common points has not yet been determined between the CO\(_2\) water warm bathing and the heat therapy.

The present study was carried out to elucidate the mechanism involved in the removal of pain by the artificial CO\(_2\) water warm bathing by determining the threshold of nerve fibers (A\(_\beta\), A\(_\delta\), and C) using equipment for current perception threshold (CPT)\(^3\). In healthy adult women, CPT was determined at 35, 38, and 41°C and compared with that in the control group receiving the tap water warm bathing\(^4\). The results are reported here with discussion.

II Materials and Methods

Thirteen healthy women without sensory disturbance (mean age: 24.1±3.9 years) and 11 such women (23.4±3.3 years) were assigned to the artificial CO\(_2\) water warm bathing and warm tap water bathing groups, respectively. The artificial high concentration CO\(_2\) warm water was prepared using MRE-SPA manufactured by Mitsubishi Rayon Co., Ltd. The concentration of carbonic acid gas in this water was maintained at around 1,000ppm. During the measurement of CPT\(^5\), the CPT equipment (Neurometer\(^\text{TM}\) manufactured by Neurotron Co, Ltd.) was placed so that the data display screen could not be seen by the subjects. The subjects sat comfortably from the start to the completion of the experiment. Prior to the start of the experiment, the procedure of testing was informed to the subjects and after their consent to participation in the experiment was obtained, CPT was measured by the double-blind forced selection method.

The temperature of bathing water was set at 35, 38, and 41°C. CPT was measured in the index finger of the left hand. It was measured before and after whole body bathing without right hand at each temperature in a room maintained at a temperature of 23-25°C\(^6\).

During the experiment, body temperature was measured at 1-min intervals using a deep body thermometer (CORETEMP\(^\text{TM}\) CTM-205 manufactured by Terumo Corporation). In addition, surface skin temperature, tissue blood flow, blood pressure, and pulse were measured. During bathing at each temperature, the subject in a sitting position placed the area distal to the middle part of the left upper arm into the warm water (Fig. 1). The duration of bathing was set at 15 min, and the above parameters were measured for a total of 30 min including 5 min before bathing and 10 min after the completion of bathing. Changes of deep body thermometer, surface skin temperature, tissue blood flow, blood pressure, and pulse were determined as changes from the mean value before bathing (this
changes in CPT due to Conc CO₂ warm bathing

being considered 0) and shown graphically. The significance of differences was determined by the paired t-test. The level of significance was set at p < 0.05.

III Results

1. Changes of surface skin temperature (Fig. 2)

At a water temperature of 35°C, the surface skin temperature showed no change in the index finger and upper arm. At 38°C, it was significantly higher in the index finger and upper arm in the CO₂ group than in the tap water group. At 41°C, it showed a significant increase in both the tap water and CO₂ groups. The surface skin temperature in the upper arm, which was not immersed in the warm water, was higher in the CO₂ group than in the tap water group during bathing. However, after the completion of bathing, it decreased rapidly in the CO₂ group and became lower than in the tap water group.

On the other hand, the surface skin temperature in the index finger was slightly higher in the CO₂ group. Further, in the CO₂ group, it showed a marked decrease after the completion of bathing at 35°C, but subsequently improved gradually.

2. Changes of the deep body thermometer (Fig. 3)

There was little difference of the deep body thermometer changes between the chest and the upper arm. Briefly, it increased gradually with time according to the temperature of bathing water. In the CO₂ group, it increased rapidly from 5-7 min after the start of bathing at 41°C and showed a 1°C or more increase immediately before the completion of bathing. There was no clear difference between 35°C and 38°C.

3. Changes of tissue blood flow (Fig. 4)
Fig. 2 Comparison of changes in the surface skin temperature

Fig. 3 Changes of the deep body thermometer

Fig. 4 Changes of the tissue blood flow volume

Fig. 5 Changes of the blood pressure and the pulse rate
At a temperature of 35°C, the tissue blood flow showed no particular change in the upper arm and index finger in the tap water group, while it showed a gradual decrease during bathing in the CO₂ group. At 38°C, the tissue blood flow showed no change in the index finger, but increased in the upper arm after the start of bathing and decreased rapidly with time after the completion of bathing in the tap water group. It showed a significant increase until 1-min after the completion of bathing. In the CO₂ group, the tissue blood flow showed a significant increase in the upper arm and index finger after the start of bathing. At 41°C, the tissue blood flow showed a rapid increase in the upper arm and index finger after the start of bathing in both the tap water and CO₂ groups. It was still higher than the values before bathing at 10 min after bathing, showing a significant increase in both groups. Comparison of both groups showed that the tissue blood flow was significantly higher in the CO₂ group than in the tap water group from several minutes after the start of bathing.

In the CO₂ group, it was always higher throughout the 15-min bathing period, but showed a rapid decrease after the completion of bathing.

4. Changes of the blood pressure and the pulse rate (Fig. 5)

The blood pressure showed no significant change at 35, 38, and 41°C in the tap water group, although it occasionally showed a slight decrease during bathing. In the CO₂ group, however, marked hypotension was noted from immediately after the start of bathing at 35, 38, and 41°C and the degree of hypotension showed little temperature-related difference. During bathing, the systolic and diastolic pressure showed a maximum decrease of about 30mmHg.

The pulse rate showed no significant temperature-related difference in the tap water group. In the CO₂ group, it showed no change at 35 and 38°C, but increased with time at 41°C.

5. CPT

Table 1 shows the changes in the mean CPT before and after bathing at 35, 38 and 41°C. As shown in the table, at 35°C, there was little changes in the CPT of 2000Hz Aβ fibers, 250Hz Aδ fibers, and 5Hz C fibers in the tap water and CO₂ groups. At 38°C as well as 35°C, the CPT of Aβ, Aδ, and C fibers showed little changes in the

<table>
<thead>
<tr>
<th>Water temperature 35°C</th>
<th>38°C</th>
<th>41°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tap water</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before bathing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>After bathing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aβ (2000Hz)</td>
<td>182.7±39.3</td>
<td>181.5±36.7</td>
</tr>
<tr>
<td>Aδ (250Hz)</td>
<td>66.7±20.1</td>
<td>67.1±22.9</td>
</tr>
<tr>
<td>C (5Hz)</td>
<td>42.3±10.8</td>
<td>42.7±12.4</td>
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<tr>
<td><strong>CO₂ water</strong></td>
<td></td>
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<tr>
<td>Before bathing</td>
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<tr>
<td>After bathing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aβ (2000Hz)</td>
<td>181.6±59.5</td>
<td>203.1±48.8</td>
</tr>
<tr>
<td>Aδ (250Hz)</td>
<td>58.8±22.2</td>
<td>67.5±25.8</td>
</tr>
<tr>
<td>C (5Hz)</td>
<td>47.6±22.0</td>
<td>36.4±20.7</td>
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</tbody>
</table>
two groups. However, at 41°C, the CPT of C fibers increased from 44.4±7.7 to 50.6±9.7 in the tap water group and from 40.2±23.9 to 53.2±15.5 in the CO₂ water, with a significant difference (p<0.05), while it showed no change at 35 and 38°C.

IV Discussion
1. Changes of the surface skin temperature and the deep body thermometer

According to the changes in the surface skin temperature and the deep body thermometer, the water temperature of 35°C approximating to the body temperature acted as an insensible temperature, inducing no body temperature rise. At 38°C, the body temperature was higher in the CO₂ group than in the tap water group, presumably because heat was incorporated more easily into the body from the warm water due to the vasodilator effect of CO₂ water. At 41°C, the temperature increased in both the tap water and CO₂ groups.

In the CO₂ group, this was presumably because heat was introduced rapidly into the body due to the vasodilator effect of warm CO₂ water.

After the completion of bathing, the temperature decreased more rapidly in the CO₂ group presumably because of more rapid heat radiation due to vasodilation. Therefore, it is important to prevent a temperature fall due to heat radiation by taking measures to retain heat from immediately after the completion of CO₂ bathing.

2. Changes of the tissue blood flow

The tissue blood flow as well as the surface skin temperature was significantly higher in the CO₂ group than in the tap water group at a water temperature of 38°C. It is considered from this result that not only temperature but also the vasodilator effect of CO₂ is related to the increase of blood flow. At 41°C, the tissue blood flow increased in both the tap water and CO₂ groups. This result suggests that the CO₂ warm water improves various symptoms by vasodilation plus thermotherapy and plays some role in relieving pain by improving circulation and metabolism. Furthermore, the tissue blood flow did not return to the pretreatment value immediately after the completion of bathing, but remained increased for a while. So, it is suggested that the improvement of circulation is maintained and the efficacy of the CO₂ water warm bathing continues for a period of time after the completion of bathing.

The tissue blood flow decreased during bathing at 35°C in the CO₂ group, presumably because the blood pressure or pulse rate remained unchanged despite vasodilation, resulting in insufficient blood circulation in blood vessels.

3. Changes of the blood pressure and the pulse rate

Since the blood pressure was lower in the CO₂ group than in the tap water group even at a temperature of 35°C, CO₂ water was found to have a vasodilator effect even when its temperature was low. Almost the same blood pressure changes were observed at 38 and 41°C. These results suggest that sufficient hypotension may be achieved by the vasodilator effect of CO₂ in the temperature range of 35 to 41°C, even if there is no beneficial effect of temperature. However, attention should always be paid to blood
pressure when the CO₂ water warm bathing is applied clinically⁸), because the blood pressure decreased by almost 30 mmHg in the present study, although the subjects were healthy women.

The load of the heart is usually reduced when peripheral vascular resistance is decreased by vasodilation. However, the heart rate also increases at 41°C, so attention should be paid to the load of the heart in warm CO₂ bathing. However, it may be sure that the CO₂ warm water makes a greater contribution than the tap warm water to the improvement of tissue metabolism because it has the advantages of vasodilation and increase of circulatory blood flow.

4. Bathing time and temperature

In the preliminary experiment, CPT did not tend to increase during 10-min bathing even at 41°C, so the duration of bathing was prolonged to 15 min. As a result, CPT showed a change compared with that during the 10-min bathing, so at least 15 min were considered necessary to obtain the efficacy of bathing. However, the CPT of A δ fibers was not influenced even when the bathing time was prolonged to 15 min. The CPT of A β fibers was not influenced either. Therefore, 15-min whole body warm water bathing may be appropriate for an elevation in the CPT of C fibers⁹).

Since the water temperature of 35°C is an insensible temperature, the results of the experiment at this temperature were used as the control for comparison. The temperature of 41°C is a comfortable bathing temperature, so the temperature of bathing at home is usually set at around it. At 35°C, the surface skin temperature, tissue blood flow, and CPT showed little changes, so bathing was considered ineffective at this temperature¹⁰). At 38°C, the skin surface temperature and tissue blood flow showed no significant increase in the tap water group, but increased significantly in the CO₂ group. So, CO₂ bathing at this temperature was considered effective for improving metabolism and relieving pain. CO₂ bathing at 41°C was expected to markedly improve metabolism. In addition, the CPT of C fibers increased at this temperature, suggesting its usefulness for relieving pain derived from the C fibers, including so-called secondary pain and dull pain. Based on these results, the CO₂ water warm bathing under these conditions is considered to be an effective topical thermotherapy for reliving pain. Clinically, the efficacy of the CO₂ water warm bathing may be increased when it is given under these conditions.

Based on these results, the CO₂ water warm bathing is expected to relieve pain by vasodilation at 35°C and by removing pain substance by improving tissue circulation at 38°C. At 41°C, pain may be removed more markedly by the synergistic effect of circulatory improvement and an elevation in the perception threshold of C fibers.

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References


