Effects of Hot Water Baths Containing Carbon Dioxide and 3-Octylphthalide on Work-Related Chronic Shoulder-Neck Muscle Pain

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Abstract. The purpose of this study was to investigate the effects of enhancement of systemic circulation due to repetitive hot water bathing on work-related chronic shoulder-neck muscle pain. Eight female office workers reporting chronic shoulder-neck muscle pain used a bath additive, KYN, while they took baths at home for 2 weeks and then took baths without KYN for another 2 weeks. KYN contained CO2 generators and 3-octylphthalide that produced final concentrations of 100 ppm and 3 ppm in 150 L bath water, respectively. The effects of KYN were evaluated during and after the use of KYN using a visual analog scale (VAS), fatigue scores, muscle hardness, near-infrared spectroscopy (NIRS), and the pressure pain threshold (PPT). During the use of KYN, VAS significantly decreased (p<0.05), as did fatigue score III expressing “sense of physical discomfort” (p<0.01) and muscle hardness (p<0.01). These indices expressed increases during the next 2 weeks of hot water baths without KYN. In conclusion, the effects of repetitive use of KYN were clarified by subjective and physiological parameters on work-related chronic shoulder-neck pain, and they could be ascribed to cumulative immediate enhancement of systemic circulation. Further studies are necessary to clarify the correlations among parameters and underlying mechanisms.

Key words: Trapezius, Pain, Bath

INTRODUCTION

The incidence of chronic shoulder-neck pain has been increasing recently in industrial societies as revealed in The National Livelihood Survey by the Health, Labor, and Welfare Ministry of Japan. These shoulder-neck symptoms are generally classified into symptomatic and essential groups, with and without etiological factors such as orthopedics and medical disorders. Essential shoulder-neck pain is considered to develop and be exacerbated by corresponding muscle fatigue and hindered microcirculation due to repetitive tension of the shoulder-neck muscles1, 2). Increases in both mental and physical stresses because of the recent increase in the popularity of information technology devices and the modification of the workplace environment are thought to be predominantly responsible for the increase in shoulder-neck problems.

Various kinds of coping methods for chronic shoulder-neck pain have been reported. For example, trophotherapy and pharmacotherapy3), physical therapy using massage4), acupuncture, and moxibustion or electrotherapy treatment5). Balneotherapy, which is a commonly used thermotherapy, has good prospects as a useful treatment for essential chronic shoulder-neck pain, because it has an underlying effect on the systemic circulation6). However, the physiological effects
and mechanisms of the treatment by specific spas or hot baths have not been elucidated sufficiently with regard to chronic shoulder-neck muscle pain. We hypothesized that active enhancement of systemic circulation by hot water baths, which are commonly used daily at home in Japan, containing enhancing agents could contribute to the improvement of chronic shoulder-neck pain.

The effects of CO2 and 3-octylphthalide on blood vessels, as well as the safety of the vasodilators, have previously been examined. CO2 hot water bathing has a positive effect on circulation\(^7-10\). The positive effect on dermal blood flow of a 38°C bath at relatively low concentrations of CO\(_2\) (60–150 ppm)\(^11\), and an increase in deep tissue temperature have been reported\(^12\). These reports also indicated the enhancing effect of CO\(_2\) on systemic circulation and a mechanism involving the intake of calcium ions into the endoplasmic reticulum in smooth muscle cells contributing to the dilatation of blood vessels has been suggested\(^10\). In addition, 3-octylphthalide, which is a synthetic analog of the active ingredient, 3-alkylphthalide, in the common Chinese drug Sen-kyu, has a positive effect on the dilatation of blood vessels. 3-octylphthalide has been reported to be a calcium antagonist in smooth muscle cells\(^13,14\), and hot baths containing 3 ppm of 3-octylphthalide have a positive effect on human dermal blood flow\(^15\). We investigated the combined effect of CO\(_2\) and 3-octylphthalide in hot water baths on systemic circulation. To facilitate daily home use, we prepared a bath additive, KYN, containing CO\(_2\) generators and 3-octylphthalide. As parenthetic information, both active ingredients are commercially available and officially approved under the Pharmaceutical Law of the Health, Labor, and Welfare Ministry of Japan under the quasi-drug category.

To evaluate chronic shoulder-neck pain and the usefulness of the KYN treatment on it, some physiological parameters of muscle tension, blood circulation, and pain intensity were used. With regard to muscle tension, previous studies have measured muscle hardness using various types of devices to identify the level of tension in the trapezius, because the hardness is thought to be closely related to the subjective symptoms\(^16\). For blood circulation analysis, direct measurement of dynamic flow using Laser-Doppler flowmetry\(^5,17\) and non-invasive measurement of total hemoglobin volume and tissue oxygen saturation using near-infrared spectroscopy (NIRS) have been reported\(^18\). To quantify pain intensity, the relationship between subjective symptoms and pressure pain has previously been used\(^19\). Based on these previous studies, we evaluated muscle hardness, NIRS, and pressure pain as physiological indices in addition to using a visual analog scale (VAS) and fatigue scores as subjective indices.

The purpose of this study was to investigate the effect of passive circulation enhancement induced by hot water baths containing blood circulation enhancers on chronic shoulder-neck pain. In this study, we evaluated subjective and physiological parameters during treatment and in a follow-up period.

**METHODS**

**Subjects**

Eight female office workers with a mean (range) age of 30.8 ± 4.5 (25–38) yr, body weight of 52.1 ± 7.4 (44–65) kg, height of 1.58 ± 0.06 (1.50–1.68) m, and BMI of 21.0 ± 3.0 (19.0–28.1) participated in this study. All subjects reported conscious chronic shoulder-neck muscle pain for more than the last six months. All subjects were fully informed of the nature and possible risks of the procedures and provided their written consent before this study. This study was conducted under the supervision of occupational physicians with considerations in accordance with the Declaration of Helsinki.

**Preparation and measurements**

The bath additive, KYN, was comprised of fumaric acid and carbonates. The concentration of CO\(_2\) was adjusted to approximately 100 ppm in 150 L of 40°C bath water (not lower than 100 ppm for 1 h) using an expandable ion analyzer EA940 with Model 95-02 CO\(_2\) electrode (Orion Research Inc. Boston, MA, USA) calibrated with 0.1 M sodium bicarbonate standard solution (Orion Research Inc.). KYN also contained 0.45 g of 3-octylphthalide with an adjusted concentration of 3.0 ppm in 150 L water. Emulsifiers (Emulgen 306P, 409P, and Nikkol GO-440) were used to dissolve 3-octylphthalide. All ingredients used in KYN were of quality levels approved by the relevant authorities for cosmetics and quasi-drugs.

The protocol is shown in Fig. 1. The test period was 4 weeks. All subjects used KYN on a daily basis at home during the first two weeks and then
they took baths without KYN for the next two weeks. During the test period, use of other bath additives was prohibited. Measurements were conducted on days 0 (before use), 7, 14 (during KYN use), and 28 (at the end of the follow-up period). The effect of KYN was analyzed by comparing the data from days 0, 7, and 14. Data from days 14 and 28 were compared to evaluate changes during the period of bathing without the use of KYN. VAS of perceived shoulder-neck muscle pain and fatigue scores as subjective indices20, 21), as well as muscle hardness by tactile sensor, total hemoglobin volume (t-Hb) and oxygen saturation (StO 2) by NIRS, and pressure pain threshold (PPT) by algesiometer as physiological parameters were measured during the test period. In addition, the improvement of shoulder-neck muscle pain during the use of KYN was evaluated.

Subjective evaluation of shoulder-neck muscle pain was determined by a 100-mm VAS. The left end of the scale (0) meant no-pain and the right end (100) meant the most severe pain imaginable. Improvement was evaluated using a 5-criteria score (5: markedly improved, 4: improved, 3: slightly improved, 2: not changed, and 1: exacerbated) by self-rating of the symptom on days 7 and 14 and compared to that on day 0. Fatigue feelings were evaluated by the fatigue scores, which were developed by The Institute for Science of Labour of Japan to investigate industrial labor and hygiene20). The fatigue scores (min; 0, max; 30) were determined by a questionnaire containing 3 categories regarding “sleepiness and lethargy feeling” (I), “difficulty in concentration” (II), and “sense of physical discomfort” (III), each of which had 10 questions.

Muscle hardness was determined using a tactile sensor system, which could evaluate the elasticity of surface layer muscles, such as the trapezius, in a non-invasive manner22). The tactile sensor system was assembled using a specific ceramic vibrator [thickness: 5 mm, width: 10 mm, length: 30 mm, composition: Pb(Zr/Ti)O3/ vibration frequency: 63 KHz] according to a method described previously22). Points for the measurements were determined at the mid-point between the cervical vertebra (C7) and the acromion on both sides of the trapezius muscle to ensure the same location was used each time. The hardness was represented by the average of 10 measurements at each position.

NIRS spectra were recorded to evaluate oxygenated (Oxy-Hb) and deoxygenated hemoglobin volume (Deoxy-Hb) in the trapezius using PSA-IIIN (Biomedical Science, Kanazawa, Japan). Total oxygen volume (t-Hb) and tissue oxygen saturation (StO 2) were automatically calculated from these values according to a method described previously23). The point for the measurement was determined as the mid-point between C7 and the acromion on both sides of the trapezius muscle. The recording was conducted for 5 min and an average was calculated from the values recorded every 5 seconds.

PPT examination was performed by an algesiometer (Igarashi Medical Corp. Tokyo, Japan). After the operator had asked the subject to say “yes” at the time the patient felt pressure pain, the operator increased the pressure at a rate of 1 kgf/cm²/sec. PPT was determined as the pressure when the subject said “yes”. The point for the measurement was determined on both sides of the trapezius muscle (mid-point between C7 and the acromion). Pressure pain was measured after all the other measurements were done, because it was
thought to hinder the measurements of muscle hardness and NIRS.

All data are presented as median values with maximum and minimum values or means ± SD. To clarify the efficacy of KYN, data obtained at days 0, 7, and 14 were analyzed by repeated-measures ANOVA for each variable. In cases where significance was detected, multiple comparison was performed with the Student-Newman-Keuls test. To clarify changes during the latter 2 weeks without KYN use, data between day 14 and day 28 were analyzed by the paired t-test or Wilcoxon’s signed rank test. Statistical significance was set to p<0.05.

results

KYN was used on average 12.8 ± 2.1 times (range; 8–14) during the 2 weeks by the 8 subjects (91.4 ± 15.0%). No noteworthy events such as hospital visits or use of medication were reported by the 8 subjects throughout the test period.

Changes in subjective and physiological parameters are shown in Table 1. Median VAS of subjective shoulder-neck muscle pain decreased during the 2 weeks of KYN use. Significance was detected between days 0 and 14 (p<0.05). On the contrary, the value increased during the follow-up period, though the difference between days 14 and 28 was not significant.

A high ratio of improvement in shoulder-neck pain is shown in Table 2. Most of the subjects (7/8) felt more than “slight improvement” after 7 days of use and they felt progress in the improvement after another 7 days of use.

Total fatigue score consisting of physical and mental fatigue feelings decreased during KYN use and then increased during the follow-up period, though the changes were not significant. Median fatigue score I, representing sleepiness and lethargy feeling, decreased during the use of KYN. Similarly, median fatigue score II, representing difficulty in concentration, and score III, representing sense of physical discomfort, decreased during the first two weeks. Significant decreases from day 0 were detected in score III at day 7 and day 14 (p<0.05, p<0.01), while no significant differences were found in scores I and II. All three scores increased during the follow-up period, but not significantly.

Muscle hardness recorded using a tactile sensor system decreased drastically during the 2 weeks of KYN use. Significant changes from day 0 were found on the right trapezius at days 7 and 14 (p<0.05, p<0.01) and on the left trapezius at days 14 (p<0.05), respectively. However, muscle hardness increased during the following 2 weeks, though

<table>
<thead>
<tr>
<th>Items / Day</th>
<th>0</th>
<th>7</th>
<th>14</th>
<th>28</th>
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<tbody>
<tr>
<td>VAS</td>
<td>0.68 (0.54–0.78)</td>
<td>0.66 (0.13–0.93)</td>
<td>0.43 (0.05–0.73)*</td>
<td>0.67 (0.18–0.91)</td>
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<tr>
<td>Fatigue score</td>
<td>Total</td>
<td>I</td>
<td>II</td>
<td>III</td>
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<tr>
<td></td>
<td>9 (3–22)</td>
<td>4 (1–13)</td>
<td>3 (1–9)</td>
<td>7 (2–14)</td>
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<td></td>
<td>4 (2–8)</td>
<td>2 (0–7)</td>
<td>1 (0–7)</td>
<td>3 (0–7)</td>
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<tr>
<td></td>
<td>2 (0–8)</td>
<td>1 (0–4)</td>
<td>0 (0–3)</td>
<td>1 (0–4)</td>
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<tr>
<td></td>
<td>3 (1–6)</td>
<td>2 (1–2)*</td>
<td>1 (1–3)**</td>
<td>2 (1–4)</td>
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<tr>
<td>Muscle hardness (Hz)</td>
<td>Right</td>
<td>–640 ± 106</td>
<td>–754 ± 117*</td>
<td>–745 ± 50**</td>
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<td></td>
<td>Left</td>
<td>–601 ± 115</td>
<td>–725 ± 131</td>
<td>–752 ± 152*</td>
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<tr>
<td>StO2 (%)</td>
<td>Right</td>
<td>67.2 ± 3.4</td>
<td>68.3 ± 2.0</td>
<td>67.5 ± 2.1</td>
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<td></td>
<td>Left</td>
<td>70.5 ± 2.2</td>
<td>71.0 ± 2.5</td>
<td>71.2 ± 2.0</td>
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<tr>
<td>t-Hb (mg/cm³)</td>
<td>Right</td>
<td>364 ± 101</td>
<td>410 ± 106</td>
<td>414 ± 98</td>
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<td></td>
<td>Left</td>
<td>422 ± 81</td>
<td>421 ± 98</td>
<td>395 ± 79</td>
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<tr>
<td>PPT (kgf)</td>
<td>Right</td>
<td>2.3 ± 0.7</td>
<td>1.8 ± 0.7</td>
<td>1.8 ± 0.5</td>
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<td></td>
<td>Left</td>
<td>1.9 ± 0.4</td>
<td>1.7 ± 0.6</td>
<td>1.8 ± 0.5</td>
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*p<0.05, **p<0.01.

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<thead>
<tr>
<th>Table 1. Changes in subjective and physiological parameters during two weeks use of KYN and the following two weeks without KYN</th>
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<tr>
<td>Items / Day</td>
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<td>----------------</td>
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<tr>
<td>VAS</td>
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<td>Fatigue score</td>
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<td>Muscle hardness (Hz)</td>
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<td>t-Hb (mg/cm³)</td>
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* p<0.05, ** p<0.01.

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<th>Table 2. Improvement of shoulder-neck muscle pain during use of KYN</th>
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<td>Day 7</td>
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<td>Markedly improved</td>
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<tr>
<td>Improved</td>
</tr>
<tr>
<td>Slightly improved</td>
</tr>
<tr>
<td>Not changed</td>
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<tr>
<td>Exacerbated</td>
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significance was not detected.

The stationary values of t-Hb and StO₂ as well as PPT did not change drastically during KYN use or during the follow-up period, while a slight decrease in PPT was found throughout the test period.

**DISCUSSION**

Subjects reporting chronic shoulder-neck muscle pain used KYN, which contained vasodilation ingredients, for 2 weeks and were followed-up for a further 2 weeks. We evaluated subjective and physiological parameters during the test period.

VAS is a common and reliable scale of subjective symptoms, which was developed to evaluate the strength of perceived pain[24]. In this study, VAS scores improved slightly during the first 7 days and improved markedly during the next 7 days. The improvement rate increased in a manner consistent with the change of VAS.

Fatigue scores were developed to evaluate work-related fatigue from a physical and mental point of view[20]. The scores were composed of 3 categories: sleepiness and lethargy feeling (I), difficulty in concentration (II), and sense of physical discomfort (III). Fatigue score III decreased significantly during 2 weeks of KYN use and increased again during the following 2 weeks after the use of KYN. Scores I and II expressed almost the same changes as score III, though significance was not detected. In other words, the ratio of these scores, which describe the quality of fatigue feeling, did not change drastically either during the use of KYN or during the whole test period. Consequently, 2 weeks use of KYN drastically ameliorated physical fatigue feelings and psychological fatigue feelings, while they are important factors for muscle fatigue[25]. Physical and psychological feelings of fatigue could have contributed to the reduction of VAS of shoulder-neck pain, though the mechanisms were not clear.

Studies regarding the relationship between muscle hardness and shoulder-neck pain have been reported[16, 26]. Though some previous papers revealed that muscle hardness of the upper trapezius increased according to the development of subjective feelings during visual display terminal (VDT) work[16, 27], the relationship between the muscle hardness and chronic shoulder-neck symptoms were not analyzed fully. Measurements were made using a tactile sensor to resemble the feeling by human fingers in the appreciation of muscle tension rather than other types of hardness meters, because it was less affected by elastic characters of the skin surface[28]. Some previous studies proved the application of tactile sensors were useful to evaluate muscle hardness of cardiac, trapezius, and latissimus dorsi muscle as a non-invasive method[29]. Thus, the change of hardness over time could reflect the change of stationary strength of tension in the upper trapezius during the test period.

The upper trapezius muscle hardness decreased during 2 weeks of KYN use and increased during the following 2 weeks after KYN use. This result suggests that muscle tension due to chronic shoulder-neck pain drastically decreased with the repetitive use of KYN and increased again after the cessation of use of KYN. A drastic decrease in muscle tension was found during the first 7 days, which was obviously faster than the decrease in VAS of shoulder-neck pain. The early term relaxation of the upper trapezius muscle might have been caused by accumulation of enhancement of muscle metabolism immediately after bathing due to the active enhancement of systemic circulation by CO₂ and 3-octylphthalide in addition to the daily hot bath. Furthermore, the decrease by 150 Hz in average muscle hardness during 2 weeks of KYN use was thought to be large enough to be perceived by self-palpation in several of the subjects in this study.

NIRS spectroscopy is commonly used to evaluate tissue oxygen saturation and total hemoglobin volume non-invasively[23, 29]. Though the effect of trophotherapy on the upper trapezius was studied using venous occlusion methods[3], the relationship between systemic circulation in the upper trapezius and perceived shoulder-neck pain is unclear. In this study, NIRS was measured to evaluate stationary t-Hb and StO₂ in the upper trapezius.

During the test period, neither index showed changes dependent on the use of KYN, indicating that the effect of KYN was not evident on the stationary t-Hb or StO₂ values. However, additive circulation enhancement by KYN was conceivable immediately after bathing, because the enhancement of circulation immediately after bathing due to the daily hot bath has been revealed by previous studies[7, 8, 11]. The resulting decrease in muscle hardness in this study was possibly the result of the cumulative effect of the immediate
enhancement of systemic circulation. However, dynamic blood circulation was not examined directly in this study because of the limitations of stationary NIRS. In spite of difficulties in the application of direct methods such as laser-Doppler flowmetry in the hot bath experimental settings, direct measurement will be necessary in future studies, in one way or another, to investigate the detailed mechanisms.

Pain indices have been applied to evaluate chronic muscle problems and delayed onset muscle soreness (DOMS). Studies on the relationship between pressure pain threshold (PPT) and chronic shoulder-neck pain have been reported\(^{19, 30}\). Moreover, the effects of some treatments on shoulder-neck pain have been revealed from the viewpoint of the pain indices. Some studies have demonstrated lower PPT in subjects with shoulder-neck pain compared with healthy controls\(^{19, 31}\).

The simultaneous evaluation of pain, especially of pressure pain was thought to be necessary to investigate chronic shoulder-neck muscle pain. Measurement of PPT at the center of the upper trapezius was selected in this study. As a result, PPT showed no remarkable changes during the 2 weeks of KYN use, though a slight decrease was noted throughout the test period and the VAS of shoulder-neck pain improved with repetitive use of KYN. PPT may reflect the reception of mechanical (pressure) stimuli at facias, indicating that physiological and pathological alteration of the muscle and other periphery tissues was involved\(^{32}\). Thus, a possible reason explaining the difference between these previous studies and the present results is that muscle hardness decreased markedly during the treatment during the 2 weeks of the KYN use. The decrease in muscle hardness may facilitate abatement of pressure to the surrounding tissue due to the increase in distortion, decreasing peripheral nerve stimulation.

Moreover, possible plastic changes in the spinal cord and superior nerve center have recently been reported to be involved in the mechanisms of chronic muscle pain including shoulder-neck pain\(^{33, 34}\). Though physiological alteration of muscle due to KYN treatment may affect the sensory nerve system, such an alteration might need a longer time than the range of this study. Thus, further studies are necessary to clarify the relationship between subjective evaluation of shoulder-neck pain and PPT, and to understand the underlying pain mechanisms.

A great number of the recent increase in cases of work-related chronic shoulder-neck pain may have been the result of increased tension and fatigue of corresponding muscles. Thus, we investigated the hypothesis that active enhancement of systemic circulation by KYN in addition to usual hot water baths could affect chronic shoulder-neck pain. Perceived shoulder-neck pain improved gradually with repetitive use of KYN during 14 days. Moreover, drastic reduction of muscle hardness was detected at a relatively early stage, which might have contributed to the reduction of VAS of shoulder-neck pain. Our results suggest that the application of balneotherapy treatment was useful in the case of essential shoulder-neck pain, a condition which could be caused by hindered microcirculation. This treatment by bath additives including CO\(_2\) and 3-octylphthalide is sustainable, because it is easy to use, affordable, and above all safe. Therefore, the possibility of a useful household treatment to prevent and improve chronic shoulder-neck pain was indicated.

ACKNOWLEDGEMENTS

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