Thermotherapy is widely used in diverse forms in patient rehabilitation or sports medicine. Thermotherapy is divided into superficial heat (heat, infrared rays, paraffin bath, liquid, whirlpool bath) therapy and deep heat (ultrasonic wave, short wave, microwave) therapy based on heat penetration depths after heat application. In particular, superficial heat such as hot packs is one of the most widely used methods among chronic musculoskeletal system disease patients because it has advantages such as easy handling, low costs, non-invasive application.

Superficial heat is mainly applied to relieve pain and muscle spasm. Physiological reactions to heat raise tissue temperatures, increase blood flow rates through vasodilatation in local applied sites, increase the physical change and metabolic activity of collagenic tissues, relieve muscle spasm, change nerve reactions, and change musculoskeletal system activities. In particular, muscle strength and endurance decrease in the musculoskeletal system so that the viscoelasticity of connective tissues increases. In addition, thermal stimulation changes nerve reactions to raise pain thresholds, change nerve conduction velocity, and affect muscle spindle firing rates. According to a previous study, when superficial heat was applied to chronic low back pain patients for two hours, the muscle activity of erector spinae muscle decreased and pain was relieved. Another previous study indicated that thermotherapy combined with stretching exercises changed muscles' stretching force thereby causing significant changes in the active and passive ranges of motion of the joints. Despite that thermotherapy has diverse physiological reactions and advantages, most previous studies have focused on its effects on pain relief and muscle relaxation. However, there is a lack of research on the specific effects of thermotherapy on muscle activity and isometric contractile force.

This study has investigated the effect of isometric contractile force and muscle activity applying superficial heat according to the time from the biceps brachii muscle. In this study, 20 university students participants without musculoskeletal and neurological disorders were divided into four groups: 5 minutes, 10 minutes, 20 minutes, and 30 minutes. The skin temperature, contractile force, and muscle activity were measured before and after applying the hot pack to each group. The results showed that the mean skin temperature increased with the application time, and the isometric contractile force and muscle activity were significantly different between the groups. These results suggest that thermotherapy can affect muscle activity and isometric contractile force, which may lead to improved muscle function and pain relief. Further research is needed to explore the optimal application time and temperature for maximizing muscle activity and contractile force.
except for some have focused on pain relief and muscle tone relief and studies of changes in skin temperatures, isometric contractile force, and muscle activity in relation to the time of application after the application of thermotherapy are insufficient. Therefore, the purpose of the present study was to apply heat to the biceps brachii muscle for different lengths of time and examine resultant changes in skin temperature and related changes in isometric contractile force and muscle activity.

METHODS

Subjects

The subjects of the study were a total of 20 healthy males without any peripheral vascular disease or musculoskeletal system disease. The study was conducted from May 11 to May 18, 2012. Before conducting the experiment, the purpose and method of the study were explained in detail to the subjects and voluntary agreement to participated in the present study was obtained from the subjects. All subjects underwent the experiment in the same measuring room and had an adapting time of at least 10 minutes before measurement. The indoor humidity in the measuring room was maintained in a range of 50~60%, and the indoor temperatures were maintained in a range of 24~27℃.

Measuring Instrument and Method

Application of heat

Electric hot packs of which the temperature is maintained at 65℃ when they are in contact with human bodies were evenly put into tight contact with the brachial region of each subject in a supine position by bending the hot packs round. The hot packs were applied for 10 minutes, 20 minutes, or 30 minutes.

Skin temperature measurement

Digital thermometers and wire sensors(Center-306, thermolog, Korea) were used to measure skin temperatures. The wire sensors and digital thermometers which are skin temperature measuring instruments were connected to a PC loaded with a thermolog computer lingking program that can record and analyze temperatures at intervals of one second during measuring time when they were used. Skin temperatures were measured by placing the end of the wire sensors which are heat detectors on the center region of the biceps brachii muscle(11).

Isometric contractile force measurement

Maximum voluntary isometric contractile force was measured using an MP150(BIOPAC System Inc, CA, USA) system, a mechanomyography amplifier, and a dynamometer(TSD121C, BIOPAC System Inc, CA, USA) in which a wrist cuff is connected to a fixed rope. The analog signals coming from the instruments were converted into digital data by the MP150 system. The sampling rate of the dynamometer (TSD121C) was set to 125Hz and the cut-off frequency of the, low pass filter was set to 5Hz. As a measuring posture, the subject was instructed to sit on the experimental chair maintaining the trunk upright. The maximum voluntary isometric contractile force of the right biceps brachii muscle which is the major hand side by instructing the subject to pull upward, the cuff connected to the dynamometer(TSD121C) while maintaining 90° flexion of the elbow joint and supination of the fore arm with the upper arm in tight contact with the trunk(12).

Measurement and Analysis of Electromyogram (EMG) Signals

To measure the muscle activity of the biceps brachii muscle, a surface EMG system(Bagnoli EMG system, Delsys Inc., USA) was used. The recording electrode was attached to the muscle belly of the biceps brachii muscle and the earth electrode was attached to a close region where the electrode would not disturb movements. To measure the muscle activity, when the subject felt maximum comfort, maximal voluntary isometric contraction(MVIC) of the biceps brachii muscle was induced based on the manual muscle strength test posture of the muscle and the data values were linearly filtered for five seconds. Then, the average value of the data values for three seconds was measured excluding those for the first one second and the last one second, The signal sampling rate was set to 1024Hz and the measurement frequency band filter of the Bagnoli EMG system with a frequency bandwidth of 20~450Hz and a 60Hz notch filter were used. The collected EMG signals were stored and analyzed using the Acquisition and Analysis Software(Delsys, USA) program by analyzing the root mean square(RMS)(13).

To analyze the median frequency(MDF), the frequency spectrum of the stored EMG signals was obtained from 1,000 signals for one second and FFT(fast fourier transformation) was repeatedly analyzed using a window length of one second and a window overlap of 0.5 seconds.
Data Analysis

In the present study, the SPSS 18.0 program was used for statistical analysis. For the experimental results, the means and standard deviations of all measured values were obtained. For each measurement variable, average values before the application of thermotherapy were set as base lines and paired t-tests were conducted for each measurement item for different lengths of the time of the application of thermotherapy to examine statistical significance. The statistical significance level was set to $\alpha = 0.05$.

RESULTS

Comparison of General Characteristics of the Subjects

The total number of study subjects who participated in the present study was 20. Their mean age was 22.10±1.21 years, their mean height was 167.76±5.16cm, and their average weight was 65.12±7.3kg (Table 1).

<table>
<thead>
<tr>
<th>Type of lung disease</th>
<th>Division</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age(years)</td>
<td>22.10±1.21</td>
<td></td>
</tr>
<tr>
<td>Height(cm)</td>
<td>167.76±5.16</td>
<td></td>
</tr>
<tr>
<td>Weight(kg)</td>
<td>65.12±7.23</td>
<td></td>
</tr>
</tbody>
</table>

Changes in Skin Temperature in Relation to the Length of Time of the Application of Heat

Compared to the base line 33.38±0.70℃, the skin temperatures increased to 36.90±0.46℃ when heat was applied for 5 minutes, to 38.24±0.49℃ when heat was applied for 10 minutes, and to 38.63±0.30℃ when heat was applied for 20 minutes, and to 39.15±0.63℃ when heat was applied for 30 minutes. Compared to the base line, there were statistically significant differences at all lengths of time of application ($p<0.001$) (Table 2).

<table>
<thead>
<tr>
<th>Division(n=20)</th>
<th>Skin temperature(℃)</th>
<th>Isometric contractile force(㎏)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base line</td>
<td>33.38±0.70</td>
<td>45.27±9.44</td>
</tr>
<tr>
<td>Heat 5 min</td>
<td>36.90±0.46***</td>
<td>46.65±9.49</td>
</tr>
<tr>
<td>Heat 10 min</td>
<td>38.24±0.49***</td>
<td>44.78±11.03</td>
</tr>
<tr>
<td>Heat 20 min</td>
<td>38.63±0.30***</td>
<td>43.79±11.12</td>
</tr>
<tr>
<td>Heat 30 min</td>
<td>39.15±0.63***</td>
<td>40.50±9.38***</td>
</tr>
</tbody>
</table>

Values are mean±SD, ***$p<0.001$

Changes the Isometric Contractile Force, Muscle Activity, and Median Frequency in Relation to the Length of Time of Application of Heat

Compared to the base line 45.27±9.44kg, the isometric contractile force increased to 46.65±9.49kg when heat was applied for 5 minutes but decreased to 44.78±11.03kg when heat was applied for 10 minutes, to 43.79±11.12kg when heat was applied for 20 minutes, and to 40.50±9.38kg when heat was applied for 30 minutes. Compared to the base line, statistically significant differences were shown when heat was applied for at least 30 minutes ($p<0.001$) (Table 3).

Compared to the base line 0.54±0.10mV, the muscle activity increased to 0.57±0.10mV when heat was applied for 5 minutes but decreased to 0.47±0.09mV when heat was applied for 30 minutes. Statistically significant differences were

<table>
<thead>
<tr>
<th>Division(n=20)</th>
<th>Isometric contractile force(kg)</th>
<th>Muscle activity(mV)</th>
<th>Median frequency(㎐)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base line</td>
<td>45.27±9.44</td>
<td>0.54±0.10</td>
<td>66.53±5.76</td>
</tr>
<tr>
<td>Heat 5 min</td>
<td>46.65±9.49</td>
<td>0.57±0.10</td>
<td>72.89±8.64**</td>
</tr>
<tr>
<td>Heat 10 min</td>
<td>44.78±11.03</td>
<td>0.50±0.10</td>
<td>64.58±4.54</td>
</tr>
<tr>
<td>Heat 20 min</td>
<td>43.79±11.12</td>
<td>0.49±0.09**</td>
<td>60.71±5.22**</td>
</tr>
<tr>
<td>Heat 30 min</td>
<td>40.50±9.38***</td>
<td>0.47±0.09***</td>
<td>60.85±3.97**</td>
</tr>
</tbody>
</table>

Values are mean±SD, *$p<.05$, **$p<.01$, ***$p<.001$
shown when heat was applied for 5 minutes, 10 minutes (p<.05), 20 minutes (p<.01), and 30 minutes (p<.001) respectively (Table 3).

Compared to the base line 66.53±5.76Hz, the median frequency increased to 72.89±8.64Hz when heat was applied for 5 minutes but decreased to 64.58±4.54Hz when heat was applied for 10 minutes, to 60.71±5.22Hz when heat was applied for 20 minutes, and to 60.85±3.97Hz when heat was applied for 30 minutes. Compared to the base line, statistically significant differences were shown when heat was applied for 5 minutes (p<.01), 20 minutes (p<.01), and 30 minutes (p<.01) respectively (Table 3).

DISCUSSION

In the present study, superficial heat was applied to the biceps brachii muscle for different lengths of time and changes in skin temperatures and resultant changes in muscle activity were examined. According to the results of the study, compared to the base line 33.38±0.70℃, the skin temperatures increased to 36.90±0.46℃ when heat was applied for 5 minutes, to 38.24±0.49℃ when heat was applied for 10 minutes, to 38.63±0.30℃ when heat was applied for 20 minutes, and to 39.15±0.63℃ when heat was applied for 30 minutes.

According to a study conducted by Petrofsky et al., when a 49℃ hot pack wrapped by four layers of towels were applied to the skin for 30 minutes, the tissue temperature increased from 33℃ to 39℃(14). Myrer et al. measured actual deep muscle temperatures after applying hot cloth and reported that the temperatures of the 1㎝ and 3㎝ deep triceps brachii muscles increased from 34∼36℃ to 37∼38℃ when hot cloth was applied for 15 minutes similarly to the results of the present study(15).

In the present study, compared to the base line 45.27±9.44kg, the isometric contractile force increased to 46.65±9.49kg when heat was applied for 5 minutes but decreased to 44.78±11.03kg when heat was applied for 10 minutes, to 43.79±11.12kg when heat was applied for 20 minutes, and to 40.50±9.38kg when heat was applied for 30 minutes. Compared to the base line, statistically significant differences were shown when heat was applied for 5 minutes (p<.01), 10 minutes (p<.05), 20 minutes (p<.01), and 30 minutes (p<.01). In a study conducted by Lewis et al., when hot packs maintained at 40℃ were applied to chronic low back pain patients’ erector spinae muscle for two hours, whereas the muscle activity increased statistically significantly compared to the control group, the value of maximum voluntary isometric contractile force decreased although the difference was not statistically significant(16). According to a study conducted by Chia et al., when the brachial skin temperature was 16.7℃, the muscle activity was 0.22 mV and isometric contractile force was 36.1Kg similarly to the results of the present study(17).

Compared to the base line 0.54±0.10mV, the muscle activity increased to 0.57±0.10mV when heat was applied for 5 minutes but decreased to 0.50±0.10mV when heat was applied for 10 minutes, to 0.49±0.09 mV when heat was applied for 20 minutes, and to 0.47 ±0.09mV when heat was applied for 30 minutes. Compared to the base line, statistically significant differences were shown when heat was applied for 5 minutes, 10 minutes (p<.05), 20 minutes (p<.01), and 30 minutes (p<.001) respectively. According to a study conducted by Pereira, when microwaves were applied to the biceps brachii muscle for 16 minutes, compared to the control group, the isometric contractile force and muscle activity of the biceps brachii muscle decreased but the value of the median frequency increased(18). This result should be because, when muscle temperatures rise, vasodilatation occurs(19) and blood flows and nutrition supply to the muscle increase so that motor units’ firing rates for muscle contraction increase making muscle contraction more efficient(20). In the present study, compared to the base line 66.53±5.76Hz, the median frequency of muscle contraction increased to 72.89±8.64Hz when heat was applied for 5 minutes but decreased to 64.58±4.54Hz when heat was applied for 10 minutes, to 60.71±5.22Hz when heat was applied for 20 minutes, and to 60.85±3.97Hz when heat was applied for 30 minutes. Compared to the base line, statistically significant differences were shown when heat was applied for 5 minutes (p<.01), 10 minutes (p<.05), 20 minutes (p<.01), and 30 minutes (p<.01) respectively.

Based on the present study, theories of previous studies could be identified to some extent. However, additional studies on the effects in relation to the lengths of time of application of heat should be conducted with diverse patients. This author hopes that diverse methods including superficial heat and contrast bath can be developed, studied, and applied in clinics.

CONCLUSION

The purpose of the present study was to apply heat
to the biceps brachii muscle for different lengths of time and examine resultant changes in skin temperature and related changes in isometric contractile force and muscle activity. Skin temperatures changed rapidly when heat was applied for 5 minutes but the amplitude of changes decreased over time (p < .001). Isometric contractile force was the largest when heat was applied for 5 minutes and the smallest when heat was applied for 30 minutes (p < .001). The muscle activity was the highest when heat was applied for 5 minutes (p < .05) and the lowest when heat was applied for 30 minutes (p < .001). The median frequency was the highest when heat was applied for 5 minutes (p < .01) and the lowest when heat was applied for 20 minutes (p < .001).

Based on the results of the present study, it could be seen that thermotherapy for muscle strength improvement should be the most effective when it is applied for 5 minutes. However, since the present study was conducted with healthy adults, later studies should be conducted with diverse patients.

REFERENCES

1. Prentice WE, Therapeutic Modalities in Sports Medicine. 1999(fourth ed); WCB/McGraw–Hill, Boston, USA.