Oxygen Saturation and Hemoglobin Level in the Muscles of Hypertensive Patients during Exercise in Water

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Abstract. To clarify whether exercise therapy in a water environment is appropriate therapy for hypertensive patients, we investigated oxygen saturation and hemoglobin level in the vastus medialis muscle using a laser tissue blood oxygen monitor. Seven hypertensive patients (52 to 77 years of age, hypertensive group) and five healthy volunteers (44 to 69 years of aged, control group) participated in this study. Subjects maintained resting postures for about 5 minutes each in a standing position, a sitting position on a chair, a lying position out of water, and a position in water below the navel and to the chest level. Subjects performed flexion/extension movement of the knee joint (30 times/min) in and out of water. Oxygen saturation level (SaO2), oxygenated hemoglobin level (HbO2), deoxygenated hemoglobin level (HbD), and total tissue hemoglobin level (HbT) were measured in the muscle tissue. Blood pressure (BP) and pulse rate (PR) were monitored simultaneously. In the hypertensive group, SaO2 in muscle tissue in water was significantly increased compared with that in a standing position out of water (p<0.05), and returned to the level in the control group. HbD in the hypertensive group was significantly reduced in the position in water to the chest level compared to that in a standing position (p<0.05). In both groups, the ratios of HbD and HbO2 (O2/D ratio) was significantly increased in water environment compared with that out of water (p<0.05). The O2/D ratio, which indicates oxygenation within the tissue, increased during exercise in water in the hypertensive group. This study demonstrated that oxygen saturation in the muscles of the hypertensive group was lower than that in controls out of water, but the level was increased in water. Our findings suggest that water provides a good exercise environment for hypertensive patients from the perspective of oxygen saturation in hypertensive muscle tissue.

Key words: hypertension, water-based exercise, vastus medialis muscle, blood hemodynamics

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Water-based exercise to enhance physical endurance is widely used for physical therapy such as muscle strengthening and range of motion for orthopedic patients. It is a preferable method that enables systemic relaxation or muscle strengthening by changing movement direction or by regulating the water-level. Movement in water is characterized by buoyancy, water pressure and water resistance. Non-weight-bearing exercise, progressive resistance training, balance training and relaxation are carried out while taking advantage of these characteristics of movement in water.

Elderly patients with neuromuscular disease prefer water exercise for physical therapy. Many elderly patients with neuromuscular disease have medical complications such as hypertension, heart disease, or diabetes. Among these, hypertension is one of the most common diseases. Well controlled hypertensive patients are advised to perform mild exercise, such as water exercise, because it is
well known that moderate exercise reduces blood pressure in patient with mild hypertension\(^2\). Several authors had reported the positive mechanism of water exercise to treat hypertension from the perspective of cardiovascular circulation\(^3,4\). However, little is known about peripheral conditions, such as oxygen saturation, hemoglobin level within the muscle tissue in hypertensive patients under the condition of water exercise.

Hypertension is characterized by elevated peripheral resistance and is accompanied by a variety of peripheral circulatory changes\(^5\). It is known that excessive exercise, in the condition of peripheral blood flow dysfunction, induces peripheral vasoconstriction causing arterial blood pressure to rise\(^6\). Furthermore, Mitu et al.\(^7\) reported that heart failure induced peripheral vascular remodeling causing deterioration of skeletal muscle condition such as muscle atrophy, reduction of type I fibers and a relative increase in type IIb fibers.

We suppose that these peripheral conditions are crucial to determining the appropriate load to apply to muscular tissue in hypertensive patients in order to treat their neuromuscular disease effectively. This study investigated the effect of immersion on the blood hemodynamics in the tissue by directly examining the immersed muscle at rest and during exercise to clarify whether water immersion is an appropriate environment for exercise therapy in patients with hypertension.

### Methods

#### Subjects

Seven outpatients (5 males and 2 females) with mild hypertension, who were receiving conservative therapy for lumbar canal stenosis or osteoarthritis of knee joints, participated in this study. However, these neuromuscular diseases did not severity which affected the present measurement results. All mild hypertensive patients met the WHO (World Health Organization) criteria for hypertension. One patient was administered angiotensin II antagonist but the remaining subjects were not. Patients gave written informed consent to participate in the study as controls (Table 1). There was no significant difference in body height, body weight, or body fat percentage between two groups.

#### Measurement method

The subjects maintained a resting state for about 5 minutes each in a standing position, sitting position on a chair (sitting position), supine position (lying position) out of water, below the navel level in water (navel position) and below the chest level in water (chest position) with the water temperature being 30°C and the room temperature 24°C. The flexion-extension exercise of the right knee joint was performed in a standing position each 30 times/min for three minute at the chest position in water, followed by the standing position after a resting interval of 5 minutes, then the same sequence of exercise was performed out of water (Fig. 1). The rhythm of the motion was coordinated by a metronome.

Data of Oxygen saturation (SaO\(_2\)), oxygenated hemoglobin level (HbO\(_2\)), deoxygenated hemoglobin level (HbD), and total tissue hemoglobin level (HbT) were obtained with a waterproof laser tissue blood oxygen monitor (BOM-L1TR, OMEGAWAVE; Tokyo) set at the distal portion of the right vastus medialis muscle, at the thickest part. This equipment uses the wavelength of infrared light to determine the hemodynamics of tissue such as brain or muscle. SaO\(_2\), HbO\(_2\), HbD, and HbT in the muscle tissue were measured over time. The ratios of HbD and HbO\(_2\) (O/D ratio) before and after the exercise were calculated to determine the oxygenation level within the muscle tissue. O/D ratio shows a change of oxygen supply/consumption in order to examine the oxygen reserve in the muscle tissue. O/D ratio in the resting position was measured in the standing position out of water and chest position in water. Two probes were set a constant distance of 30 mm between the light transmitting probe and the light receiving probe. Pulse oximeter (pulse oximeter handy 100, Kimura) probe was set on the right second finger, and pulse rate (PR) was measured throughout the study. Blood pressure (BP) was recorded in the right arm both in and out of water, and the cuff arm was supported at heart level.

The subjects waited at rest for about 2 minutes in each posture until the measurement value stabilized, then measurements were obtained per second over a 3-minute period (Fig. 1). The mean measurement value was calculated as the representative value for each posture.

#### Statistical analysis

Data are shown as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used and when a significant F ratio was found, post-hoc Fisher’s
protected least significant differences (PLSD) test was performed on each variable. Differences in mean changes were compared between groups using the Mann-Whitney U test. Change in $O_2/D$ ratio or BP between measurements in water and that out of water was compared using paired t-test. Change in $O_2/D$ ratio at rest was compared between the standing position and chest position in or out of water. Analysis was performed using StatView-J version 4.5 software, and the criterion for significance was set at the 0.05 level.

**Results**

**Differences in BP and PR between in and out of water**

Systolic BP of the hypertensive group (157.1 ± 16.1 mmHg) was significantly larger than that of control group (131.2 ± 9.5 mmHg) out of water (p<0.05). In both groups, the Systolic BP under water significantly decreased (hypertensive group; navel position: 153.4 ± 21.3 mmHg, NS, chest position: 138.6 ± 22.5 mmHg, p<0.05, control group; navel position: 120.7 ± 6.7 mmHg, NS, chest position: 114.0 ± 7.2 mmHg, p<0.05) in comparison with that out of water, while diastolic BP of the hypertensive group remained virtually unchanged (hypertensive group; out of water: 79.1 ± 12.5 mmHg, navel position: 74.8 ± 11.1 mmHg, chest position: 69.0 ± 10.7 mmHg). The diastolic BP of the control group in the navel position: 114.0 ± 7.2 mmHg, p<0.05) in comparison with that out of water (83.3 ± 6.5 mmHg). The diastolic BP under control group was not significant difference between the two groups.

PR in water and out of water did not significantly differ between two groups. In both group, PR in water tend to decrease compared with that out of water. With exercise, PR was slightly higher out of water than that in water (Table 2).

**Changes in SaO₂, HbO₂, HbD, HbT in the muscle tissue**

Changes in each parameter of both groups are shown in Table 2. The SaO₂, HbO₂, HbD, and HbT in the muscle tissue in water and out of water did not significantly differ between hypertensive and control groups.

There were no significant differences in SaO₂ between in water and out of water in the control group in any posture. In the hypertensive group, SaO₂ tend to be a low value in the standing and sitting position out of water compared with that in the control group. SaO₂ during exercise and in either the navel or chest position in water was significantly increased in comparison with that in the standing position out of water (F=2.667, df=8, p<0.05), and returned to the level in the control group level.

HbO₂ did not show any changes based on each posture in either group, and there was no significant difference observed in HbO₂ during exercise.

HbD in the sitting position or lying position was reduced compared with that in the standing position in both groups. In the hypertensive group, HbD in chest position was significantly reduced compared to that in the standing position in water (F=1.490, df=8, p<0.05). HbD during exercise was more increased out of water than in water in the hypertensive group.

HbT remained virtually unchanged in the control group. In the hypertensive group, HbT in the standing, sitting and lying position in water were decreased compared with those out of water.

**Changes in O₂/D ratio in the muscle tissue**

Changes in the $O_2/D$ ratio of both groups during rest...
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and exercise are shown in Table 3. The O$_2$/D ratio was significantly increased in the water compared to that out of water in both groups (p<0.05 or p<0.01). The O$_2$/D ratio in both group increased during exercise. In the hypertensive group, the O$_2$/D ratio during exercise in water was significantly higher than that out of water (p<0.05).

### Discussion

As exercise therapy for hypertensive patients, walking and jogging are widely utilized for promoting general health and building physical strength by maintaining and improving the systemic stamina and endurance$^8$. Water-based exercise for patients with hypertension reduced the diastolic blood pressure and pulse rate, which may be favorable from the perspective of circulatory dynamics$^6$. Swimming exercise for mild hypertension was also described to reduce blood pressure in the early stage of hypertension$^9$. However, there is a report that exercise therapy may not be appropriate for patients with hypertension, because there was no significant change in blood pressure between rest and submaximal exercise in a hypertensive individual$^{11}$. Hypertensive patients with abnormal vascular wall or excessive load on the heart should perform exercise in water very carefully$^{12}$. Concerning treatment for neuromuscular disease, it was reported that short-term water-based exercise only improved aerobic fitness in elderly patients and did not improve muscle strength, endurance, or flexibility$^{13}$. Whether exercise in the water environment is appropriate for patients with hypertension remains controversial.

This study provides the first report of oxygen saturation and blood hemodynamics in the tissue of muscle under water. The SaO$_2$ was relatively maintained at all postures in the control group. In the hypertensive group, SaO$_2$ in water were improved compared to that in the control group level.

### Table 2. Changes in the measured parameters of each group in or out of water

<table>
<thead>
<tr>
<th></th>
<th>Out of water</th>
<th>In water</th>
<th>Out of water</th>
<th>In water</th>
<th>Out of water</th>
<th>In water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standing</td>
<td>Sitting</td>
<td>Lying</td>
<td>Navel</td>
<td>Chest</td>
<td>Exercise</td>
</tr>
<tr>
<td>SaO$_2$</td>
<td>C.G</td>
<td>57.7 ± 5.2</td>
<td>59.2 ± 4.0</td>
<td>63.6 ± 2.8</td>
<td>60.9 ± 4.1</td>
<td>62.0 ± 5.1</td>
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<tr>
<td></td>
<td>H.G</td>
<td>53.1 ± 7.9</td>
<td>57.0 ± 4.8</td>
<td>61.9 ± 3.3</td>
<td>61.3 ± 2.8*</td>
<td>63.9 ± 3.0*</td>
</tr>
<tr>
<td>HbO$_2$</td>
<td>C.G</td>
<td>12.5 ± 12.3</td>
<td>11.9 ± 10.0</td>
<td>12.1 ± 0.9</td>
<td>14.8 ± 3.2</td>
<td>13.9 ± 2.2</td>
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<tr>
<td></td>
<td>H.G</td>
<td>11.5 ± 15.0</td>
<td>11.7 ± 4.2</td>
<td>11.8 ± 17.2</td>
<td>12.1 ± 3.1</td>
<td>12.1 ± 2.9</td>
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<tr>
<td>HbD</td>
<td>C.G</td>
<td>9.4 ± 2.4</td>
<td>8.3 ± 1.8</td>
<td>7.0 ± 1.4</td>
<td>9.7 ± 2.3</td>
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<tr>
<td></td>
<td>H.G</td>
<td>9.6 ± 3.5</td>
<td>8.6 ± 2.9</td>
<td>7.3 ± 1.3</td>
<td>7.6 ± 1.8</td>
<td>6.8 ± 1.7*</td>
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<tr>
<td>HbT</td>
<td>C.G</td>
<td>21.9 ± 3.4</td>
<td>20.3 ± 2.7</td>
<td>19.1 ± 2.2</td>
<td>24.5 ± 5.8</td>
<td>22.7 ± 3.9</td>
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<tr>
<td></td>
<td>H.G</td>
<td>21.0 ± 8.4</td>
<td>20.3 ± 6.9</td>
<td>19.1 ± 2.7</td>
<td>19.7 ± 4.7</td>
<td>18.9 ± 4.5</td>
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<tr>
<td>PR</td>
<td>C.G</td>
<td>77.0 ± 15.0</td>
<td>74.8 ± 14.0</td>
<td>70.4 ± 14.7</td>
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<tr>
<td></td>
<td>H.G</td>
<td>75.9 ± 17.9</td>
<td>72.9 ± 14.6</td>
<td>68.6 ± 14.7</td>
<td>68.3 ± 12.5</td>
<td>66.4 ± 12.3</td>
</tr>
</tbody>
</table>

Values are mean ± SD. SaO$_2$: Oxygen saturation, HbO$_2$: oxygenated hemoglobin level, HbD: deoxygenated hemoglobin level, HbT: total tissue hemoglobin level and PR: pulse rate. C.G: control group. H.G: hypertensive group. The measured parameters in water and out of water did not significantly differ between two groups. *p<0.05 (compared with values in standing position of H.G).

<table>
<thead>
<tr>
<th></th>
<th>Out of water</th>
<th>In water</th>
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<tbody>
<tr>
<td>Control group</td>
<td>Rest</td>
<td>1.37 ± 0.31</td>
</tr>
<tr>
<td></td>
<td>Exercise</td>
<td>1.53 ± 0.30</td>
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<tr>
<td>Hypertensive group</td>
<td>Rest</td>
<td>1.17 ± 0.24</td>
</tr>
<tr>
<td></td>
<td>Exercise</td>
<td>1.44 ± 0.45</td>
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</table>

Values are mean ± SD. **p<0.01, *p<0.05 (compared with out of water).
control groups. These results suggest that water immersion is an appropriate environment for patients with hypertension as well as healthy volunteers.

Furthermore, we calculated the \( \frac{O_2}{D} \) ratio, which was assumed to estimate of oxygen supply/consumption, to determine the oxygen reserve in the muscle tissue. If the \( \frac{O_2}{D} \) ratio were increased in water, this would indicate that oxygen supply in the muscle tissue was increased, suggesting that the water environment is suitable for exercise. In this study, the \( \frac{O_2}{D} \) ratio under water was significantly higher than that out of water in the hypertensive group. In addition, mild exercise load significantly increased the \( \frac{O_2}{D} \) ratio. These results were supported by Hagberg’s report that low load exercise for patients with hypertension had a more antihypertensive effect than that with a higher load\(^{14}\). Our findings suggest that water immersion is an appropriate environment for exercise therapy for patients with hypertension. However, this study was performed using partial load, so further examination at various exercise loads will be necessary.

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**References**