Influence of Dynamic Foot Exercise and a Warm-water Footbath on Arterial Distensibility

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Abstract

Introduction: Prevention of the onset of cardio/cerebrovascular diseases, which represent circulatory system diseases, is now emphasized. It requires ensuring good arterial distensibility, which has been demonstrated to be reduced by life environments such as the lack of exercise or overnutrition but improved by aerobic exercise. Even if implementation of such exercises is possible, it increases the risks of the frail elderly with declined cardiopulmonary function and those with other diseases. This study aimed to focus on plantar flexion and dorsiflexion exercises of the ankles as a type of effective, low-load exercise that can induce dynamic stimulation associated with increased blood flow, using muscle pumping of the triceps surae and footbath, which could potentially increase overall blood flow via hyperthermic action. We then investigate the benefits of the combined effects of these two exercises on arterial distensibility.

Methods: We selected 25 physically and mentally healthy adult men and women (17 men and eight women; mean ± SD age, 25.7 ± 3.3 years) as study subjects.

All the 25 subjects performed each of three exercises, namely footbath, ankle exercise, and ankle exercise in footbath, in a sitting position for 15 minutes. Ankle-brachial index (ABI), brachial-ankle pulse wave velocity (PWV), systolic blood pressure, diastolic blood pressure, and heart rate were measured using form PWV/ABI before and after the exercise for the evaluation of arterial distensibility.

Results: No significant differences were observed in the PWVs, ABIs, systolic/diastolic blood pressures, and heart rates before and after exercise in the footbath and exercise groups. However, for the footbath exercise group, a significant reduction in PWV was observed from before to after exercise.

Discussion: In this study, we focused our attention on the ankle exercise in footbath as a low-load exercise that could improve arterial distensibility. The results indicated a significant reduction in PWV, an index used to show the level of arterial distensibility, only for the footbath exercise group, which performed the combination of ankle exercise and footbath. We can infer that the improvement of arterial distensibility is attributed to the synergistic effect of the muscle pump and hyperthermic actions, which result in further increases and facilitation of cardiac output.

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Conclusions: This study demonstrated that the ankle exercise in footbath was beneficial for the improvement of arterial distensibility.

Keywords: Footbath, Ankle exercise, Arterial distensibility

I  INTRODUCTION

In recent years, the gross national medical expenditure has been steadily increasing. Medical cost incurred from circulatory system diseases is the highest of all, accounting for 20.8% of the total cost. This is nearly twice the medical cost incurred from neoplasms, which account for the second highest expense. Thus, prevention of the onset of cardio/cerebrovascular diseases, which represent circulatory system diseases, is now emphasized. It requires ensuring good arterial distensibility, which has been demonstrated to be reduced by life environments such as the lack of exercise or overnutrition but improved by aerobic exercise. Therefore, aerobic exercise has been reported as a preventive method for the onset and recurrence of cardio/cerebrovascular diseases. Moreover, arterial distensibility was reported to diminish with decrease in the amount of physical activities, suggesting that these two factors are related. The intensity of aerobic exercise is believed to be effective when the exercise is performed at 50% of the maximal oxygen uptake (4-5 metabolic equivalents [METs]) for more than 30 minutes. In clinical practice, however, many subjects are not fit to perform dynamic, moderate-load modes of exercise. Even if implementation of such exercises is possible, it increases the risks of the frail elderly with declined cardiopulmonary function and those with other diseases. Therefore, we believe that investigating the range of exercise intensity that improves arterial distensibility, that is, the effect of low-load exercise on arterial distensibility, is required for establishing individualized prescription of exercise with optimum benefit and safe intensity.

Improvement of arterial distensibility has been reported to result from exercise-induced changes in blood-flow volume and the increase in flow-mediated dilatation as the shear stress level increases. Therefore, simple exercise is deemed not very effective in improving arterial distensibility. Meanwhile, muscle pumping of the triceps surae has been indicated to be effective in increasing stroke volume and muscle blood flow, and enhancing the degree of its effects on arterial distensibility. Accordingly, this study aimed to focus on plantar flexion and dorsiflexion exercises of the ankles as a type of effective, low-load exercise that can induce dynamic stimulation associated with increased blood flow, using muscle pumping of the triceps surae and footbath, which could potentially increase overall blood flow via hyperthermic action. We then investigate the benefits of the combined effects of these two exercises on arterial distensibility.

II  MATERIALS AND METHODS

1. Target Subjects

We selected 25 physically and mentally healthy adult men and women (17 men and eight
women; mean ± SD age, 25.7 ± 3.3 years) as study subjects (Table 1). In this study, a healthy person was defined as one who does not sustain certain chronic diseases or have any issues with activities of daily living.

2. Methods

All the 25 subjects performed each of three exercises, namely footbath (footbath group), ankle exercise (exercise group), and ankle exercise in footbath (footbath exercise group), in a sitting position for 15 minutes on different days in an environment with an average room temperature of 24.2°C and average relative humidity of 44%. The average temperature of the footbath was 42.5°C. The ankle exercise was performed at a speed of 50 times/min using a metronome (Figures 1 and 2). In our preliminary study, the expired gas analysis showed that the metabolic equivalents for footbath, ankle exercise, and footbath exercise were 1.36, 1.89, and 1.54 METs, respectively. Ankle-brachial index (ABI), brachial-ankle pulse wave velocity (PWV), systolic blood pressure, diastolic blood pressure, and heart rate were measured using form PWV/ABI© (OMRON COLIN Co., Ltd.) before and after the exercise for the evaluation of arterial distensibility. The pre-exercise measurements were performed in a recumbent position after the subjects had the opportunity to rest sufficiently in a quiet room with a stable temperature. Ten minutes after the subjects performed the exercise, the post-exercise measurements were performed in a recumbent position under the same environment used for

Table 1  Characteristics of the study subjects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Male/female</td>
<td>17/8</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>25.7 ± 3.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.6 ± 9.4</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.5 ± 10.2</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.5 ± 2.5</td>
</tr>
</tbody>
</table>

BMI, body mass index

Fig. 1 and 2  Ankle exercise in foot bath is the combination of foot bath and ankle exercise.
The arrow indicates the direction of motion of the ankle joint.
the pre-exercise measurements. The intraclass correlation coefficient of OMRON COLIN Co., Ltd. form PWV/ABI®, which was reviewed in advance, was higher than 0.85, confirming its high intrarater and interrater reliabilities. This study adopted an analysis method by obtaining the bilateral average of the PWVs, ABIs, systolic blood pressures, and diastolic blood pressures, and by using a paired t test with a significance level of less than 5%.

3. Ethical Considerations

This study was conducted after securing approval from the hospital ethics review committee and after obtaining consent from the subjects, to whom a full explanation the research content had been provided.

III RESULTS

No significant differences were observed in the PWVs, ABIs, systolic/diastolic blood pressures, and heart rates before and after exercise in the footbath and exercise groups. However, for the footbath exercise group, a significant reduction in PWV (p < 0.05) was observed from before to after exercise (Table 2).

IV DISCUSSION

In this study, we focused our attention on the ankle exercise in footbath as a low-load exercise that could improve arterial distensibility. The results indicated a significant reduction in PWV, an index used to show the level of arterial distensibility, only for the footbath exercise group, which performed the combination of ankle exercise and footbath. Aerobic exercise has been reported to not only modify the risk factors of arteriosclerosis but also reduce PWV, an arterial stiffness index, via a direct effect on vascular function. Apart from the improvement of arterial distensibility due to increased vascular elasticity as a contributing factor to decreased PWV, a seemingly lowered PWV has been indicated to be observed under low-blood-pressure conditions or conditions with declined measurement accuracy of arterial pressure in the lower extremities with an ABI below 0.95. In this study, however, no statistically significant differences in blood pressure and ABI were observed before and after the footbath exercise. These results suggest that the declined PWV observed in this study can be attributed to the improvement of arterial distensibility due to the increased vascular elasticity. Improvement of arterial distensibility has been reported to occur because of the mechanism that involves the application of shear stress to arterial walls (vascular endothelium) with increased blood flow, inducing the production and release of nitric oxide (NO) as a vasodilator substance. Thus, the ankle exercise in this study expands the cardiac output by increasing venous return using the muscle pump action of the triceps surae, which is called the second heart. Moreover, footbath is associated with hyperthermic action and increases the cardiac output as the peripheral vasodilator action reduces the preload and afterload on the heart. As a result, owing to the repeated shear stress with the increased blood flow volume caused by the exercise and footbath, the production and release of NO from vascular endothelium increases. We believe this led to
Table 2  Changes in brachial artery hemodynamics from before to after training and detraining

<table>
<thead>
<tr>
<th></th>
<th>Foot bath</th>
<th></th>
<th>Exercise</th>
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<th>Foot-bath exercise</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
<td>Follow-up</td>
</tr>
<tr>
<td>Brachial-ankle PWV (cm/s)</td>
<td>1154.2 ± 132</td>
<td>1132.1 ± 99.5</td>
<td>1146.6 ± 93.6</td>
<td>1122.2 ± 113.7</td>
<td>1151.3 ± 120.1</td>
<td>1090.7 ± 110.8*</td>
</tr>
<tr>
<td>Ankle brachial index</td>
<td>1.11 ± 0.1</td>
<td>1.10 ± 0.1</td>
<td>1.14 ± 0.1</td>
<td>1.09 ± 0.1</td>
<td>1.09 ± 0.1</td>
<td>1.09 ± 0.1</td>
</tr>
<tr>
<td>Systolic BP (mm Hg)</td>
<td>114.9 ± 8.5</td>
<td>112.6 ± 7.4</td>
<td>114.6 ± 8.5</td>
<td>113.9 ± 7.5</td>
<td>112.8 ± 8.3</td>
<td>112.9 ± 6.7</td>
</tr>
<tr>
<td>Diastolic BP (mm Hg)</td>
<td>64.8 ± 7.5</td>
<td>62.9 ± 6.6</td>
<td>65.4 ± 6.8</td>
<td>64.5 ± 6.9</td>
<td>64.2 ± 5.9</td>
<td>62.2 ± 6.0</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>64.9 ± 8.5</td>
<td>66.1 ± 9.7</td>
<td>64.8 ± 8.5</td>
<td>64.3 ± 9.1</td>
<td>63.0 ± 9.0</td>
<td>63.7 ± 8.3</td>
</tr>
</tbody>
</table>

Results are shown as mean ± SD. The p values indicate significant differences between the baseline and follow-up values (paired t test). PWV, pulse wave velocity; BP, blood pressure
*p < 0.05, versus baseline values in the foot-bath exercise group
the declined PWV, that is, the improvement of arterial distensibility.

As recommended in the guidelines\(^1\), Goto et al.\(^9\) reported that no effects of aerobic exercises with low intensity (25% of maximal oxygen uptake, 2 METs) and high intensity (75% of maximal oxygen uptake, 6 METs) were observed, whereas improvement of arterial distensibility was observed in aerobic exercise with moderate intensity (50% of maximal oxygen uptake, 4 METs). Moreover, Matsuda et al.\(^10\) mentioned that athletes who continued aerobic exercise training with high intensity to participate in competitive sports showed greater arterial distensibility than general subjects. This means that the extent of exercise effectiveness on arterial distensibility is related to both the amount and intensity of exercise. This study also showed that no improvement of arterial distensibility was observed for one low-load exercise of either footbath or the ankle exercise, similar to the results in the previous study\(^5\) and the recommendations in the guidelines\(^1\). Meanwhile, despite being a low-load exercise, the footbath exercise achieved improvement of arterial distensibility. These results indicate that the improvement of arterial distensibility does not necessarily depend on the intensity of exercise. We can infer that the improvement of arterial distensibility is attributed to the synergistic effect of the muscle pump and hyperthermic actions, which result in further increases and facilitation of cardiac output. The limitations of this study include small sample size, Verification of immediate effect, and Measurement of cardiac output is a lack.

V CONCLUSIONS

This study demonstrated that the ankle exercise in footbath was beneficial for the improvement of arterial distensibility. We believe that this exercise would play a role in preventing the onset and recurrence of cardio/cerebrovascular diseases in frail elderly people and those with other diseases.

Conflict of Interest

No potential conflicts of interest were disclosed.

References


