1. Introduction

Intramuscular pressure rises in response to static exercise. Because of this, muscle blood flow is inhibited when force production level increases. This results in an accumulation of metabolites and an increase in muscular sympathetic nerve activity, resulting in an increase in muscle vascular resistance and blood pressure. The larger the muscle mass involved, the more prominent the blood pressure elevation during static exercise becomes (Seals, 1993). It is also reported that the larger the muscle thickness, the higher the intramuscular pressure becomes (Sejersted, et al., 1984). It is known that muscle mass has an influence on the circulatory system.

In static handgrip exercise with incremental load, blood pressure elevation arising from load increase becomes precipitous at and above a certain load and deviates from the straight-line load-BP relationship established when the load is smaller; which is to say that the strength-BP response relationship is not
always linear in static muscular contraction. Kagaya, et al., called this critical load BPcrit (the critical load for notable blood pressure elevation) (2001) and suggests that it reflects the muscular metabolic condition which has changed through exercise. In other words, in the process of static handgrip exercise with incremental load, muscular sympathetic nerve activity is enhanced due to a decrease in intramuscular pH at and above a certain load (Victor, et al. 1997), which results in a sharp rise in blood pressure.

BPcrit is reported to decline with advancing age (Kagaya, et al., 2001); the older one becomes, the smaller the absolute load that causes a sharp rise in blood pressure is. This is considered to be related to age-associated changes of the metabolic condition of active muscle and of functional characteristics of the artery. In addition, skeletal muscle mass decreases (Miyatani et al. 2000) and, what is more, exertion capacity decreases (Yue, et al., 1999) with advancing age. While it is known that, in the body of the same individual, an increase in active muscle groups and active limbs causes blood pressure elevation during exercise (Mitchell, et al., 1980), how the quantity of the muscle mass of a certain muscle in different individuals is related to blood pressure response during exercise has not yet been reported. It is considered important for elderly people to maintain skeletal muscle mass, which is the basis of physical activity, and to prevent a decrease in strength in order to maintain or improve quality of life. To reveal how this is related to blood pressure response during exercise is significant in terms of exercise performance safety. It is, therefore, necessary to clarify how blood pressure during exercise responds to various different quantities of muscle mass. Because blood pressure response occurs in relation to relative intensity (% MVC) (Lewis, et al., 1984), those who have a large amount of muscle mass and high MVC (maximal voluntary contraction), compared with those who do not, should perform exercise without blood pressure elevation if the exercise is at a constant absolute load.

Based on the hypothesis that the larger the muscle mass one has, the higher the critical load required to produce a sharp rise in blood pressure, this study has aimed to clarify the relationship between blood pressure response during static exercise and the muscle mass of active muscle for elderly women.

2. Methods

2.1. Study subjects

In this study, subjects were 66 female residents in a rural area in Ibaraki Prefecture, aged between 60 and 81 years of age, were examined. The purpose and procedures of this study and potential accompanying risks were explained to 150 women, and written informed consent was obtained from willing subjects prior to the commencement of the study. After undergoing medical checkups, all subjects performed static handgrip exercise in order to obtain a BPcrit. Ultimately, BPcrit for 114 of 150 subjects was obtained. Those who were on a stable dose of antihypertensive medication for the treatment of hypertension were excluded from the study, and the data of the remaining 66 subjects was used for analysis. A comparison of age groups was conducted between the group including subjects in their 60’s (48 subjects aged 60-69) and the group including subjects in their 70’s (17 subjects aged 70-79).

2.2. Protocol

The exercise used for this study was the static handgrip exercise with incremental load (Kagaya, et al., 2001). After a 3-minute rest in a supine position with elbow joint in the fully extended position and shoulder joint abducted to 90 degrees, the participant performed a 30-second static handgrip exercise with the dominant right hand repeatedly with a 30-second rest interval between each exercise set. A hand-ergometer (Meiko-sha, Co.) was used for the handgrip exercise, in which the participant was required to grasp the grip of a weight that was suspended by a chain and pulley and to raise it 2 cm and hold it up. A weight was used as load: 1 kgw for the first exercise measurement, 2 kgw for the second measurement, and the weight was increased by 2kgw from the third exercise measurement on. Exercise was terminated at the point where a notable blood pressure elevation that deviated from the load-BP relationship was observed. During the static handgrip exercise, the participant was instructed to maintain as normal a respiration rate as possible without stopping breathing. More than two investigators observed each participant’s general condition, including breathing, during the experiment and paid adequate attention to the safe conduct of the experiment.
systolic blood pressure rose to over 200 mmHg or the participant complained of muscle fatigue, exercise was terminated even if a notable blood pressure elevation was not observed, and their data was excluded from the analysis.

2.3. Measurement of blood pressure and estimation of BPcrit

A non-invasive serial blood pressure monitor (Finapress, Ohmeda) was used for blood pressure measurement. A finger cuff was placed around the participant’s contralateral middle phalanx, and blood pressure was measured continuously from the rest period preceding the commencement of exercise. A signal from the potentiometer attached in the hand-ergometer pulley indicating the beginning and ending of an exercise, and the analog blood pressure waveform were A/D converted at 400Hz sampling rate simultaneously (MacLab 8S, AD Instruments).

SBP (systolic blood pressure) and DBP (diastolic blood pressure) at rest and during exercise were calculated by analysis software. Blood pressure at each load was obtained by averaging 5 beats of SBP and DBP immediately before the ending of each 30-second static handgrip exercise.

BPcrit was obtained following the method used by Kagaya, et al. (2001) as shown in Figure 1. That is, regarding SBP at low load, the load-BP relationship was determined and its regression line was referred to as L1. Regarding SBP at high load, also, the load-BP relationship was determined and its regression line was referred to as L2. The intersection of these two regression lines was determined and the load (kgw) at said point was referred to as BPcrit. The reproducibility of BPcrit measurement was confirmed by experiment (n=16) prior to this study: no significant differences were observed between the first measurement (9.8±1.9kgw, mean±SD) and the second measurement (10.3±1.8kgw); the correlation coefficient was \( r=0.572 \) \( (p<0.01) \) (Kagaya, et al., 2000); and the variation coefficient of two measurements was 10.5±5.4% mean±SD.

2.4. Measurement of muscle thickness and grip strength

Muscle thickness of the forearm muscle group was measured by a B-mode ultrasound apparatus (Echo camera SSD-500, Aloka). Following the method used by Abe, et al. (1994), forearm length was measured by measuring the length from the radiale to the ulnar styloid process with a steel tape measure when the participant was in a standing position with the arms hanging naturally at the participant’s sides. Forearm circumference was measured at a point that was 30% of the forearm length in a direction away from the radiale, and an ultrasound image of the forearm flexor at the same point was obtained. Muscle thickness was measured on the obtained ultrasound image. Muscle volume of the forearm muscle group was estimated by using an estimation formula based on the anthropometric data (Miyatani, et al. 2000).

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MV = 4.095H - 0.851W + 30.424C + 0.526 (MT)^2 - 1020.66
\]

Where, \( MV \) is muscle volume \( (\text{cm}^3) \); \( H \) is height \( (\text{cm}) \); \( W \) is weight \( (\text{kg}) \); \( C \) is forearm circumference \( (\text{cm}) \); \( MT \) is forearm muscle thickness \( (\text{cm}) \); \( FAL \) is forearm length \( (\text{cm}) \).

Grip strength was measured by grip dynamometer by measuring the right and left hand grip strength twice each and averaging the higher recorded strength of each hand.
2.5. Statistics

The measurement result of each parameter was presented as a mean value±SEM. Paired t-test was applied to the comparison of mean values of two groups. Pearson’s correlation coefficient was used for an examination of the correlation of parameters. Statistical significance was set at $p<0.05$.

3. Results

BPcrit significantly decreased with advancing age ($r=-0.263$, $p<0.05$). BPcrit for subjects in their 60s was 8.7±0.4kgw (n=48), and 8.0±0.6kgw(n=17) for subjects in their 70s. While grip strength significantly decreased with advancing age ($r=0.297$, $p<0.05$), no significant correlation between grip strength and BPcrit was observed. BPcrit that was normalized by grip strength was 37.9±1.8%MVC, regardless of participant age. Compared with slope 1, which was the slope of L1 obtained from the relationship between the load at and below BPcrit and blood pressure, slope 2, which was the slope of L2 obtained from the relationship between the load at and above BPcrit and blood pressure, showed a significantly high value ($p<0.001$, Figure 2). Neither slope 1 nor slope 2 showed any significant correlation to age and grip strength. Slope2, however, showed a tendency to increase with advancing age ($r=0.241$, $p=0.051$). The difference between slope 1 and slope 2 showed a significant increase with advancing age ($r=0.255$, $p<0.05$).

Neither forearm muscle thickness nor muscle mass showed any significant relation to BPcrit or BPcrit that was normalized by grip strength. As for the relationship between slope 2 in the load-BP relationship and forearm muscle thickness and muscle mass, slope 2 showed no significant relation to muscle thickness; however, it showed a significant relation to muscle mass ($r=-0.244$, $p<0.05$, Figure 3). This shows that the more muscle mass increased, the more significantly slope 2 decreased.

4. Discussion

This study examined the relationship between blood pressure response during static handgrip exercise and the muscle mass of the forearm flexor in elderly women. The results showed no significant relation between BPcrit and forearm muscle thickness and muscle volume. It is, therefore, possible that muscle thickness and the muscle mass of active muscle are not factors in the determination of BPcrit in elderly women during static handgrip exercise. Notable blood pressure elevation at and above BPcrit has been thought to be a reflection of a change in
the muscular metabolic condition (Boushell, et al., Grassi, et al., 1999) and a change of sympathetic nerve activity (Saito, et al., 1986, 1993) in response to an increase in exercise intensity, and this load shows a significant positive correlation to the intensity of increase in deoxygenated hemoglobin concentration in muscle (Kagaya, et al. 2000). The difference between slope 1, the slope of L1 obtained from the relationship between load at and below BPcrit and blood pressure, and slope 2, the slope of L2 obtained from relationship between load at and above BPcrit and blood pressure, significantly increased with advancing age ($r=0.255$, $p<0.05$). This was attributable to the upward tendency of slope 2 with advancing age ($r=0.241$, $p<0.051$). This suggests that the difference of blood pressure response to exercise with low load at and below BPcrit and to exercise with high load at and above BPcrit becomes increasingly large with advancing age.

Regarding the slope of blood pressure elevation in the response to load increase, slope 2 is significantly greater than slope 1 ($p<0.001$). While no significant relationship between forearm muscle mass and slope 1 was revealed, a negative correlation between muscle mass and slope 2, in which slope 2 decreased as muscle mass increased, was observed ($r=-0.244$, $p<0.05$). This suggests that, during exercise with a low load at and below BPcrit, muscle mass does not affect blood pressure response and that, during exercise with a high load, the larger the muscle mass is, the more blood pressure elevation is prevented. This seems to be because blood pressure elevation is prevented, since the larger the muscle mass is, the higher the maximum muscle strength is and the lower the relative strength of incremental load is (Lind and McNicol, 1967). Meanwhile, MacDougall, et al., (1992), who have similarly examined the relationship between skeletal muscle mass and blood pressure response for active muscle and exercises, which are different from those used in this study, have reported that a cross sectional area of femoral muscle shows no significant relation to blood pressure values in 85% MVC leg press and that, regarding blood pressure response, muscle mass is an independent factor. That the results obtained by MacDougall, et al.(1992), suggest a view different from this study seems to be related to the fact that muscle sympathetic nerve activity, which regulates peripheral vascular resistance, varies according to the type of active muscle and the type of exercise. For example, regarding static exercise with a constant relative intensity more than 33%MVC, the handgrip exercise, which is used in this study, is reported to induce a greater sympathetic nerve activity in comparison with plantar flexion exercise does (Saito, 1995). Moreover, the maximum value of blood pressure response during static exercise varies according to the active muscle group, and increases in large muscle groups, such as the leg, to a greater degree than in smaller muscle groups, such as finger; in short, the larger the active muscle mass is, the higher the said value becomes (Mitchell, et al., 1980). A significant negative correlation between blood pressure elevation and forearm muscle mass was observed with a load at and above BPcrit, which corresponds to about 38% MVC, while the relative value of BPcrit for the leg muscle group may be different from that for the forearm muscle group. Moreover, the threshold of muscle sympathetic nerve activity increase strongly depends on the tempo of and muscle contraction and relaxation with respect to exercise duration (Seals and Victor, 1991, Saito, et al., 1993). Regarding exercises which use muscle groups other than the forearm muscle group and regarding dynamic exercise, therefore, further examination is needed, in addition to this study.

This study was based on the hypothesis that the larger the muscle mass is, the higher the load required to generate notable blood pressure elevation. The results of experiment, however, show that the larger the muscle mass was, the smaller the increase in blood pressure that occurred during high intensity exercise. This suggests that blood pressure elevation was suppressed because the larger the forearm muscle mass was, the higher the maximum muscle strength became and the lower the relative intensity of load became. With a small pennation angle (Yamaguchi, et al., 1990), the forearm muscle group is similar in form to parallel muscle. Forearm muscle mass is small compared with other limb muscles (Miyatani et al. 2000). It is, therefore, possible that an increase in the intramuscular pressure of the forearm muscle group at the time of exertion is small compared with those muscle groups, such as the femoral and calf muscles, which have more pennate muscles and greater muscle mass. Consequently, regarding the forearm muscle group, muscle mass increase within the range of the forearm muscle mass for ordinary elderly females may not be attributable to blood
pressure elevation during exercise.

From the above discussion, it has been clarified that the difference in the forearm muscle mass of elderly females does not affect blood pressure response during static handgrip exercise with a load at and below BPCrit, and that the larger the forearm muscle mass is, the smaller the blood pressure elevation during high-intensity static handgrip exercise with a load at and above BPCrit becomes. In other words, the maintenance of skeletal muscle mass in elderly individuals does not affect blood pressure elevation during static exercise with a low load but tends to suppress blood pressure elevation during exercise with a high load. It is, therefore, supposed that duration of static handgrip exercise with a low load is affected by factors excluding muscle mass, while duration of exercise with a high load is affected by muscle mass. This suggests that the prevention of muscle strength decrease through the maintenance of skeletal muscle mass not only prevents muscular and skeletal functional decline but also contributes to the prevention of rapid blood pressure elevation during exercise.

5. Summary

This study has examined the relationships between blood pressure response during static exercise and the muscle mass of active muscle in elderly females. 66 elderly female subjects (aged 60-81) in a supine position underwent 30-second static handgrip exercise repetitions at 30-second intervals. Exercise was terminated when a sharp rise in blood pressure was observed. BPCrit, the critical load for notable blood pressure elevation, was the intersection of two regression lines (L1, L2 in order of increasing load), which were obtained from the load-BP relationship. Anterior forearm muscle thickness was measured by B-mode ultrasound apparatus. The examination results are as follows:

1) BPCrit for subjects in their 60s was 8.7±0.4kgw and 8.0±0.6kgw for subjects in their 70s. BPCrit significantly decreased with advancing age (r=-0.263, p<0.05). Slope 1 and slope 2, which were the slopes of L1 and L2, respectively, showed no significant correlation to age. The difference between slope 1 and slope 2, however, increased significantly with advancing age (r=0.255, p<0.05).

2) Neither muscle thickness nor estimated forearm muscle mass showed any significant relation to BPCrit and slope 1. This has proved that the muscle mass of active muscle is not determining factor for BPCrit and that it does not affect blood pressure response during exercise with intensity at and below BPCrit.

3) Forearm muscle mass showed a significant positive relationship with slope 2 (r=-0.244, p<0.05). This has revealed that the greater the forearm muscle mass is, the more preventable blood pressure elevation during static handgrip exercise is.

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References


