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Acute effects of static passive stretching without voluntary contraction of skeletal muscles on arterial stiffness in elderly lacking exercise habits

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Abstract Stretching exercises conducted by oneself, herein referred to as self-stretching exercises, improve arterial stiffness in healthy people. Such exercises include voluntary contraction of peripheral muscles in addition to stretching of target muscles. However, the effects of static passive stretching without voluntary contraction of skeletal muscles on arterial stiffness remain unknown. In addition, it is important to verify the effects of stretching in the elderly lacking exercise habits with advanced arterial stiffness. Therefore, the purpose of the present study was to verify the acute effects of static passive stretching, without voluntary contraction of skeletal muscles, on the cardio-ankle vascular index (CAVI) in elderly individuals lacking exercise habits. The present study followed a pretest-posttest design without a control group. Twenty-nine elderly individuals (mean age, 77.8 ± 7.0 years; 24 female) recruited at an orthopedic clinic participated in the present study. The participants were subjected to static passive stretching of the neck, trunk, and extremities for 40 min by the same physical therapist. Stretching involved the shoulder flexors/extensors, elbow flexors/extensors, wrist palmar flexors/dorsal flexors, hip flexors/extensors/adductors, knee flexors/extensors, ankle plantar flexors/dorsal flexors, neck muscles, and trunk muscles. The CAVI (Rt, Lt, Ave), ankle-brachial index (ABI), blood pressure, and pulse rate were assessed before and after stretching. After stretching, both CAVI (Lt, Ave) and pulse rate were significantly decreased. In contrast, no significant changes in CAVI (Rt), ABI, or blood pressure were observed. The key new finding of the present study was that static passive stretching without voluntary contraction of skeletal muscles acutely improved the CAVI in elderly individuals lacking exercise habits.

Keywords : CAVI, arterial stiffness, stretching, elderly, orthopedics

Introduction

Arterial stiffness is a hallmark of aging⁽¹⁾ and a risk factor for cardiovascular events^(2,3). Physical inactivity accelerates the progression of arterial stiffness with advancing age^(4,5), while habitual aerobic exercise reduces arterial stiffness in young and elderly subjects⁽⁶⁻⁸⁾. In addition, Gando et al.⁽⁹⁾ reported that the longer time spent in light physical activity was associated with attenuation of arterial stiffness in the elderly. This previous study suggests that abundant low-intensity physical activity attenuates arterial stiffness, similarly to performing aerobic exercise in elderly people.

Recently, previous studies indicate that stretching exercise, a low intensity exercise, attenuates pulse wave ve-

locity (PWV) and the cardio-ankle vascular index (CAVI), which are indicators of arterial stiffness. A single round of self-administered muscle stretching exercise involving the entire body for 40 min reduced femoral-ankle and brachial-ankle PWV in healthy young subjects⁽¹⁰⁾. In addition, a 4-week self-stretching exercise intervention involving the entire body improved CAVI and brachial-ankle PWV in healthy middle-aged men⁽¹¹⁾. Moreover, a 13-week self-stretching exercise intervention involving the entire body resulted in a significant increase in carotid artery compliance via wave reflection magnitude in healthy middle-aged and elderly individuals⁽¹²⁾. These studies indicate that self-stretching exercises have the acute and chronic effects of improving the indicators of arterial stiffness in healthy people. Self-stretching exercises include voluntary contraction of other muscles in addition to stretching of target muscles. Some patients with pain or disabilities

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may not be able to perform self-stretching exercises with voluntary contraction of skeletal muscles. Therefore, it is meaningful to examine the effects of static passive stretching without voluntary contraction of skeletal muscles on arterial stiffness. In addition, it is important to verify the effects of stretching in the elderly lacking exercise habits with advanced arterial stiffness.

Gando et al.⁹⁾ reported that the correlation between the amount of physical activity and attenuation of arterial stiffness is particularly remarkable in the elderly with low cardiorespiratory fitness. We hypothesized that stretching would attenuate arterial stiffness in elderly individuals lacking exercise habits. Therefore, the purpose of the present study was to verify the acute effects of static passive stretching without voluntary contraction of skeletal muscles on CAVI in elderly individuals lacking exercise habits.

Materials and Methods

Design and participants. The present study followed a pretest-posttest design without a control group. However, the control group of a previous study indicates that CAVI does not change during 30 and 70 min resting states in healthy young men¹³⁾. We determined the sample size of subjects before starting the present study by power calculations using Power and Sample Size Calculation (HyLown Consulting LLC, Atlanta, USA). To detect this difference at 80% power, a Cohen's effect size of 0.5, and a two-tailed α of 5%, the present study would need at least

thirty-three participants.

An orthopedic clinic provided the field with sampling dates. Participants were recruited from an orthopedic clinic from November 2017 to March 2018. Twenty-nine elderly individuals (mean age, 77.8 ± 7.0 years; 24 female) participated in the present study. The distribution of orthopedic disorders among the participants is shown in Table 1. The inclusion criteria were as follows: (1) age ≥ 65 years, (2) no exercise habits (not exercising ≥ 3 Mets, ≥ 30 min, $\geq$ twice a week). These criteria were determined according to the "Physical Activity Standards for Health Promotion 2013" formulated by the Ministry of Health, Labor and Welfare of Japan. The exclusion criteria were as follows: (1) having a diagnosis or history of cardiac disease, peripheral vascular disease, stroke sequelae, chronic renal failure, and/or mental disorder; (2) having a bone fracture; (3) having pain that would limit stretching exercises; and (4) having difficulty walking outdoors independently. All measurements were taken between 2 pm and 4 pm, and these measurements were performed in the rehabilitation room of the orthopedic clinic.

This study was approved by the institutional review board of the Osaka Kawasaki Rehabilitation University (approval number: OKRU29-A011), and written consent was obtained from participants.

Physical characteristics of participants. Height, body weight, body mass index (BMI), handgrip strength, and sit-and-reach distance were measured to clarify physical characteristics of the participants.

Table 1. Distribution of orthopedic disorder in participants

Orthopedic disorder	No
Cervical osteoarthritis (spondylosis)	2
Cervical spondylotic myelopathy (CSM)	3
Lumbar spondylosis	9
Lumbar spinal stenosis	12
Vertebral compression fracture (VCF)	1
Shoulder periartthritis	6
Shoulder osteoarthritis	1
Hip osteoarthritis	1
Knee osteoarthritis	9
Total knee arthroplasty operation	1
Femoral head replacement operation	3
Rheumatoid arthritis (RA)	1

Handgrip strength is widely used as an indicator of whole-body muscle strength. It is also used as an indicator of sarcopenia¹⁴⁾ and has been shown to be a predictor of cardiovascular diseases¹⁵⁾. The handgrip strength was measured using a grip dynamometer (T.K.K. 5401, Takei Scientific Instruments, Niigata, Japan) in the standing position with upper extremities naturally drooping (relaxed). The measurement was performed twice in the dominant extremity, and the stronger value was used.

Some studies indicate that arterial stiffness is significantly correlated with the sit-and-reach distance, an indicator of trunk and lower extremity flexibility^{16,17)}. The sit-and-reach distance was measured by a T-2791 device (Toei Light, Tokyo, Japan) as described in a previous study¹⁶⁾. The measurement was performed twice, and the higher value was used.

Static passive stretching. With reference to the self-stretching described by Yamato et al.¹⁰⁾, we decided to adopt the method of static passive stretching in the present study. Participants were subjected to a single round of static passive stretching of the neck, trunk, and extremities for about 40 mins. All stretching was performed by the same physical therapist. The static passive stretching involved the shoulder flexors/extensors, elbow flexors/extensors, wrist palmar flexors/dorsal flexors, hip flexors/extensors/adductors, knee flexors/extensors, ankle plantar flexors/dorsal flexors, neck muscles, and trunk muscles. All stretches were held for 30 sec at the point of maximal range of motion, followed by a 10-sec relaxation for 3 repetitions. The strength of the stretching was set such that the subject felt the stretch, but not pain.

Measurements of CAVI. CAVI has been used to evaluate arterial stiffness independently of blood pressure; its measuring method, principle, and reproducibility have been described previously¹⁸⁾. In addition, Shirai et al. reported that the average coefficient of variation for the five

measurements in 22 subjects was 0.038¹⁸⁾. To confirm the reproducibility of our CAVI measurements, we measured CAVI four times on different days in 10 healthy college students. As a result, the average coefficient of variation in subjects was 0.048. After resting for >10 min in the supine position, CAVI, ankle-brachial index (ABI), blood pressure, and pulse rate were measured using a noninvasive vascular screening system (VaSera VS-2000, Fukuda Den-shi, Tokyo, Japan). The same measurements were started 0 minutes after the static passive stretching protocol.

Statistical analysis. Results are expressed as mean $\pm$ standard deviation. Statistical significance was set at $p < 0.05$. The Wilcoxon rank sum test was used to compare the measured indices before and after the muscle stretching protocol. All statistical analyses were carried out using IBM SPSS Statistics, version 22 (IBM, Chicago, IL, USA).

Results

Physical characteristics of participants. Age, height, body weight, the body mass index (BMI), handgrip strength, and the sit-and-reach distance of participants are shown in Table 2.

Acute effects of static passive stretching. The values of the arterial stiffness index before and after static passive stretching are shown in Table 3. After stretching, the pulse rate, CAVI (Lt), and CAVI (Ave) were significantly reduced. In contrast, systolic blood pressure (SBP), mean blood pressure (MBP), diastolic blood pressure (DBP), CAVI (Rt), and ABI were not significantly altered after stretching.

Discussion

The acute effects of whole-body static passive stretch-

Table 2. Participants physical characteristics measured before static passive stretching

Variable	No = 29 (24 female)
Age, y	77.8 $\pm$ 7.0
Height, cm	153.3 $\pm$ 0.1
Weight, kg	55.8 $\pm$ 11.1
BMI, kg/m ²	23.9 $\pm$ 3.4
Handgrip strength, kg	22.1 $\pm$ 7.6
Sit-and-reach distance, cm	27.2 $\pm$ 11.0

Values are shown as mean $\pm$ standard deviation

Table 3. Blood pressure, pulse rate, cardio-ankle vascular index (CAVI), and ankle-brachial index (ABI) before and after static passive stretching

Measurement	Before		After		p-value
SBP, mmHg	132.3	± 16.4	135.1	± 15.7	0.063
DBP, mmHg	79.5	± 13.1	80.2	± 11.5	0.548
MBP, mmHg	97.1	± 13.0	98.5	± 11.4	0.191
Pulse rate, beats/min	69.7	± 12.5	62.9	± 9.9	0.000*
CAVI (Rt)	8.8	± 1.4	8.6	± 1.3	0.186
CAVI (Lt)	8.8	± 1.3	8.6	± 1.3	0.022*
CAVI (Ave)	8.8	± 1.4	8.6	± 1.3	0.043*
ABI	1.2	± 0.1	1.2	± 0.1	0.624

Values are shown as mean ± standard deviation

*, $p < 0.05$ VS before static passive stretching

SBP, systolic blood pressure; DBP, diastolic blood pressure; CAVI, cardio-ankle vascular index; ABI, ankle-brachial index

ing without voluntary contraction of the skeletal muscles on CAVI in the elderly lacking exercise habits were examined. The key new finding of the present study was that static passive stretching without voluntary contraction of skeletal muscles acutely and significantly improved CAVI (Lt and Ave), an indicator of arterial stiffness in elderly individuals lacking exercise habits.

Wang et al.¹³⁾ demonstrated that a single round of cycling for 30 min at 35% heart rate reserve reduced CAVI values after exercise in healthy young men. On the acute effects of stretching on arterial stiffness, Yamato et al.¹⁰⁾ showed that a single round of self-administered static stretching exercises reduced femoral-ankle PWV and brachial-ankle PWV in healthy young subjects. These aerobic and self-stretching exercises have shown acute effects of improving arterial stiffness in healthy young individuals with flexible CAVI and PWV. However, these exercises involve more or less voluntary contractions of skeletal muscles. Conversely, the present study showed that intervention without voluntary contraction of skeletal muscles has acute effects on improving CAVI. In addition, the subjects of the present study were elderly individuals with more advanced arterial stiffness than healthy young individuals. Static passive stretching without voluntary contraction of skeletal muscles is a low-load intervention. Therefore, it has been suggested that static passive stretching without voluntary contraction of skeletal muscles is a means of improving CAVI of elderly individuals who cannot perform exercises with voluntary contraction of skeletal muscles due to pain or disabilities.

Clinch¹⁹⁾ indicated that static stretching increased heat production in an in vivo experiment using the frog sar-

torius muscle. Guinea et al.²⁰⁾ indicated that the rise in temperature of the arterial wall dramatically increased the extensibility of isolated human carotid arteries. In the present study as well, it is considered that CAVI decreased due to the same mechanism. In addition, Kruse et al.²¹⁾ demonstrated that static stretching of the plantar flexor muscles increased mean leg blood flow after stretching. Increases in the level of shear stress caused by an increase in blood flow activates nitric oxide (NO)-mediated smooth muscle relaxation²²⁾. In addition, CAVI is considered to reflect the organic and functional stiffness of arterial blood vessels²³⁾. Functional stiffness mainly involves contraction of smooth muscle cells²⁴⁾. Shirai et al. reported that CAVI reflects the degree of arterial vascular smooth muscle contraction²⁵⁾. Therefore, it is thought that static passive stretching attenuates the contraction of smooth muscles by such a mechanism, thereby improving CAVI of the elderly in the present study. However, the mechanisms underlying the improvement of CAVI induced by static passive stretching remain unclear. Therefore, further examination of these mechanisms is necessary in the future.

The present study has several limitations. First, since we did not include a non-stretching control group, future studies should include such a control group to verify the findings in the present study. Second, as the subjects of the present study were limited to elderly individuals lacking exercise habits and with musculoskeletal disorders, it is not certain whether this study's results can be generalized to all elderly individuals lacking exercise habits. Third, our target sample size was not achieved, and thus a type II error (false negative) may have prevented us from

seeing significant benefits. Finally, the present study only verified the acute effects of static stretching. Hence it is necessary to verify the effects of long-term intervention in the future.

In conclusion, the present study revealed for the first time that static passive stretching without voluntary contraction of skeletal muscles improves CAVI in elderly individuals lacking exercise habits. Static passive stretching is a low-intensity exercise. Therefore, the present study suggests that static passive stretching without voluntary contraction of skeletal muscles might be effective in improving CAVI even in vulnerable elderly individuals.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Author Contributions

The study was conceived by TM and designed by TM, HN, MH and HF. TM and HN conducted the study and MI analyzed the data. TM and MI interpreted the data and TM wrote the manuscript. Finally, the paper was analyzed and advisory written by MH and HF. All authors approved the final version of the manuscript.

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