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ORIGINAL ARTICLE

Evaluation of a static stretching intervention on vascular endothelial function and arterial stiffness

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Abstract
Purpose: Maintenance and enhancement of vascular endothelial function contribute to the prevention of cardiovascular disease and prolong a healthy life expectancy. Given the reversible nature of vascular endothelial function, interventions to improve this function might prevent arteriosclerosis. Accordingly, we studied the effects of a 6-month static stretching intervention on vascular endothelial function (reactive hyperaemia peripheral arterial tonometry index: RH-PAT index) and arterial stiffness (brachial-ankle pulse wave velocity: baPWV) and investigated the reversibility of these effects after a 6-month detraining period following intervention completion. *Methods:* The study evaluated 22 healthy, non-smoking, premenopausal women aged ≥40 years. Subjects were randomly assigned to the full-intervention ($n = 11$; mean age: 48.6 ± 2.8 years) or a half-intervention that included a control period ($n = 11$; mean age: 46.9 ± 3.6 years). *Results:* Body flexibility and vascular endothelial function improved significantly after 3 months of static stretching. In addition to these improvements, arterial stiffness improved significantly after a 6-month intervention. However, after a 6-month detraining period, vascular endothelial function, flexibility, and arterial stiffness all returned to preintervention conditions, demonstrating the reversibility of the obtained effects. *Conclusion:* A 3-month static stretching intervention was found to improve vascular endothelial function, and an additional 3-month intervention also improved arterial stiffness. However, these effects were reversed by detraining.

Keywords: Endothelial function, arterial stiffness, flexibility, static stretching

1. Introduction

Regular physical activity, including exercise, contributes to the prevention of metabolic syndrome and cardiovascular diseases (Mitchell, Peter, Otto, & Lawrence, 2006). Studies have reported that aerobic exercise and resistance training affect vascular endothelial function and arterial stiffness (Sugawara et al., 2009), and static stretching not only affects the muscles and tendons but also the vasculature of the target muscle (Poole, Musch, & Kindig, 1997). Specifically, when a blood vessel is stretched, its diameter decreases and its vascular resistance changes, modifying the inflow of blood and affecting the intramuscular vasculature (Kagaya & Muraoka, 2005).

Yamamoto et al. (2009) demonstrated a significant relationship between arterial stiffness and flexibility in people aged ≥40 years. Another study indicated that the flexibility-arterial stiffness relationship was not affected by blood pressure, which is a major confounding factor. Further, sex differences were observed in this relationship; poor trunk flexibility increased arterial stiffness in young, middle-aged, and older men, but this relationship was found only in elderly women (Nishiwaki, Kurobe, Kiuchi, Nakamura, & Matsumoto, 2014). According to Moreau and Hildreth (2014), arterial stiffness is enhanced in women due to menopause and aging. Eight weeks of stretching training reduces aortic

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wave reflection magnitude and blood pressure in obese postmenopausal women (Wong & Figueroa, 2014). Four weeks of regular static stretching reduces arterial stiffness in middle-aged men (Nishiwaki, Yonemura, Kurobe, & Matsumoto, 2015). Thirteen weeks of moderate stretching twice or thrice a week increases central arterial compliance in middle-aged and older adults (Cortez-Cooper et al., 2008). The precise mechanism underlying these differences remains unclear. Although several reports have described multipart exercise interventions that included static stretching, few studies have verified the effects of an intervention comprising static stretching alone on vascular endothelial function and arterial stiffness. Therefore, our hypothesis was that static stretching alone improved vascular endothelial function and arterial stiffness.

To study this hypothesis, we investigated the effects of a 6-month static stretching intervention on vascular endothelial function and arterial stiffness in healthy women as well as the effects of a 6-month detraining period.

2. Methods

2.1. Subjects and intervention period

Twenty-two healthy, non-smoking, premenopausal women aged ≥40 years were investigated. We defined healthy women as women with a body mass index (BMI) <25 kg/m^2 and without neurological diseases, physical diseases, or lifestyle-related diseases (e.g. hypertension, hyperlipidaemia). Women were randomised to either the full ($n = 11$, 48.6 ± 2.8 years) or the half group ($n = 11$, 46.9 ± 3.6 years), which included a control period (Table I). In the full group, the intervention period was 6 months, with the women performing 15 minutes of static stretching at least once per day, every day. In the half group, the women did not perform the intervention during the first 3 months (control period) but started doing the same thing as the full group did for the next 3 months. In both groups, variables were assessed four times: before the intervention, at 3 months, at 6 months, and after 6 months of detraining.

This study was conducted in accordance with the Kansai Medical University Code of Ethics. The study objectives, description, and precautions were thoroughly explained to all participants, and they gave their consent before the study.

2.2. Measurement variables

2.2.1. Body composition. The body composition (height, weight, BMI, and body fat percentage) was

Table I. Changes in body composition, flexibility and IPAQ during the study period

	Full group ($n = 11$)				Half group ($n = 11$)			
	Pre	3 months	6 months	Detraining	Pre	3 months	6 months	Detraining
Age (years)	47.9 ± 2.2				46.9 ± 3.6			
Height (cm)	157.8 ± 7.0				161.0 ± 4.6			
Weight (kg)	54.0 ± 11.6	54.1 ± 11.3	53.9 ± 11.5	54.1 ± 11.9	53.6 ± 8.6	53.6 ± 8.5	53.5 ± 8. 2	53.7 ± 8.0
BMI (kg/m^2)	21.6 ± 4.3	21.7 ± 4.2	21.6 ± 4.3	21.7 ± 4.4	20.8 ± 4.2	20.8 ± 4.2	20.8 ± 4.0	20.8 ± 3.9
Body fat percentage (%)	25.4 ± 9.8	26.6 ± 9.7	25.5 ± 9.4	25.5 ± 8.8	26.0 ± 7.2	25.9 ± 8.2	25.2 ± 7.7	25.5 ± 7.9
Straight leg raising (SLR) (Right · Degrees)	85.7 ± 15.9	95.6 ± 14.9**	102.8 ± 13.4**	87.4 ± 17.7**	88.0 ± 21.5	89.2 ± 21.8*	96.0 ± 23.1**	87.7 ± 21.3**
SLR (Left · Degrees)	87.4 ± 15.5	92.6 ± 14.2**	98.5 ± 13.3**	87.8 ± 15.4**	90.2 ± 17.8	87.6 ± 17.5	94.5 ± 20.1**	88.7 ± 18.0**
Trunk flexion (cm)	34.7 ± 13.6	39.6 ± 8.8*	44.9 ± 9.0**	35.0 ± 13.7**	39.8 ± 11.0	39.9 ± 10.9	46.0 ± 11.8**	40.7 ± 11.6**
IPAQ (kcal/day)	139.8 ± 100.2	144.2 ± 97.3	143.5 ± 96.0	139.2 ± 94.2	168.8 ± 247.8	168.0 ± 247.1	177.3 ± 255.6	166.9 ± 246.4

Notes: Results are expressed as means ± SD.
Asterisks show statistically significant difference (*$p < .05$, **$p < .01$).
IPAQ: International physical activity questionnaire.

measured. Weight and body fat percentage were measured by InBody720 device (BIOSPACE Company, Seoul, Korea).

2.2.2. Flexibility. Flexibility was measured with SLR and the sit-and-reach test. SLR was measured using a Todai-style joint goniometer (Tsutsumi Seisakusho, Y.K., Chiba, Japan) once on each side. The sit-and-reach test was performed thrice using the T.K.K.5112 device (Takei Kiki Kogyo, Tokyo, Japan); the mean of the three trials was used in the analyses.

2.2.3. Physical activity. Physical activity in a normal week was determined using the IPAQ short version (August 2002 edition). The subjects were asked to complete questions 1a–4. Consumption energy (kcal) = Amount of physical activity (METs.mins) × 3.5 (ml/kg/min) × 0.005 (kcal/ml) × weight (kg). Exercise intensity on the summary of IPAQ Short Version was evaluated following with by the method. METs that collected by the questionnaire multiple by time (min) shows the amount of physical activity for one week. Then, the number divided by 7 shows the average for one day. The amount of energy on 1 ml oxygen uptake was set as 0.005kcal, and 1METs was set as 3.5 ml/kg/min was used for calculation.

2.2.4. Vascular endothelial function. Blood pressure was measured after urination, after 10 minutes of rest in the supine position and at two other times continuously. We already reported in our previous study that endothelial function was evaluated by reactive hyperaemia peripheral arterial tonometry (Kurose et al., 2014). And, we used the same method in this study.

Brachial-ankle pulse wave velocity (baPWV), an index of arterial stiffness, was measured using the vascular screening device BP-203RPE III (Omron Colin, Tokyo, Japan). The distance between sampling points for baPWV was calculated automatically according to the subject's height. Pulse wave data were measured at the upper arm and ankle, and the velocity was calculated by determining the time difference and distance between these two recording sites. baPWV was measured at two consecutive times in the supine position. Before measurement, subjects abstained from caffeine and fasted for at least 4 h. The left and right limb baPWVs were measured using the oscillometric method. Pulse volume records of both brachial and ankle arteries were monitored by continuous cuff deflation. The distance between sampling points for baPWV was calculated automatically according to the subject's height. The RH-PAT index, autonomic function, and baPWV were measured in all subjects in that order on the same day.

2.2.5. Autonomic function. Autonomic function was evaluated by the heart rate variability of the R-R interval (Kiritsu Meijin; Crosswell, Kanagawa, Japan). Low frequency (LF), high frequency (HF), the LF-to-HF ratio (L/H) were measured. Heart rate variability was measured over a 3-minute period in which the participant was sitting quietly and for 3 minutes after a 10-minute resting period. Autonomic function was analysed at every beat 30 seconds after starting.

All measurements were carried out at Kansai Medical University Health Science Centre. Room temperature was maintained at 26°C. All subjects were assessed under the same conditions. Therefore all measurements were quite stable. The coefficient of variation as day-to-day reproducibility of baPWV, RH-PAT, LF/HF, and Flexibility indexes were 0.1, 0.1, 0.1, and 0.1, respectively.

2.3. Static stretching

Static stretching of the following 15 sites were performed whilst standing, sitting, or lying down: trapezius, arm flexors, deltoids, triceps, upper back muscles (trapezius and rhomboid), pectoralis major, latissimus dorsi, gastrocnemius, soleus, hip abductors, hip adductors, quadriceps, hamstrings, gluteus maximus, and the lower erector spinae. The stretching duration was 20–30 seconds per site. The stretching was performed to a degree that the participant characterised as "somewhat heavy" to "heavy" on the Rating of Perceived Exertion (called Borg Scale). A calendar specifically designed to keep a record of the intervention was created, which the participants filled on their own. The rate of exercise completion was calculated by the number of interventions performed for the number of days in the intervention. Six optional stretching seminars for both groups were offered once per month during the intervention period. Additionally, emails were sent out once per week to distribute health-related information, respond to participant questions, and provide materials that encouraged continuation, especially for both groups during the intervention period.

2.4. Statistics

All measurements are expressed as means ± standard deviations. We used the Spearman test and Wilcoxon signed rank sum test. SPSS19.0 J for Windows was used for analysis, and $p < .05$ was considered significant.

3. Results

3.1. Participants' characteristics and changes in body composition

None of the measured variables changed significantly over time in both the full group and the half group (Table I).

3.2. Flexibility

In the full group, significant increases in trunk flexion and right and left SLR were observed after the first 3 months and from 3 to 6 months of intervention. Significant decreases was seen after 6 months of detraining compared with the values after the 6-month intervention period. However, no significant differences in these variables were observed between preintervention and after 6 months of detraining.

In the half group, none of the measured variables changed significantly after the 3-month control period. After the 3-month intervention period, however, trunk flexion and right and left SLR increased significantly. No significant differences in the values measured during preintervention and after 6 months of detraining (Table I).

3.3. Blood pressure, vascular endothelial function, and arterial stiffness

In the full group, systolic blood pressure decreased significantly after 3 months of intervention, and both systolic and diastolic blood pressure decreased significantly from 3 to 6 months. Systolic blood pressure also decreased significantly after 6 months of intervention, compared with the preintervention value. After 3 months of intervention, systolic blood pressure decreased significantly (Table II). Additionally, at the 6-month period, there was a significant difference ($p < .05$) in the mean blood pressure and pulse pressure (Table II).

The blood pressure and RH-PAT index were significantly related to the amount of change observed at 3 and 6 months into the intervention in the full group ($p < .05$).

In the full group, the RH-PAT index increased significantly after 6 months of intervention, compared with the preintervention value. A significant decrease in this value was observed after 6 months of detraining. In the half group, a significant increase was observed after 3 months of intervention (Figure 1).

In the full group, the baPWV decreased significantly after 6 months of intervention, compared with the 3-month and preintervention values. A significant increase in this value was observed after 6 months of detraining (Figure 2).

Table II. Changes in blood pressure, autonomic function during the study period

	Full group ($n = 11$)				Half group ($n = 11$)			
	Pre	3 months	6 months	Detraining	Pre	3 months	6 months	Detraining
Systolic blood pressure (mmHg)	112.0 ± 13.7	108.8 ± 12.3*	102.8 ± 10.6**	105.3 ± 13.5	113.4 ± 13.0	111.2 ± 14.4	107.4 ± 11.5*	110.7 ± 14.9
Diastolic blood pressure (mmHg)	70.5 ± 9.9	67.9 ± 9.5	63.0 ± 7.5*	67.0 ± 8.4*	68.0 ± 10.4	66.8 ± 9.9	64.9 ± 10.1	66.6 ± 12.3
mean blood pressure (mmHg)	37.3 ± 4.6	36.3 ± 4.1	34.3 ± 3.5	35.1 ± 4.5	37.8 ± 4.3	37.1 ± 4.8	35.8 ± 3.8*	36.9 ± 5.0
pulse pressure (mmHg)	55.4 ± 5.1	54.6 ± 5.1	53.0.8 ± 4.2	51.0 ± 6.8	60.5 ± 3.5	59.2 ± 6.1	56.7 ± 1.9*	58.8 ± 3.5
L/H	1.6 ± 2.0	2.2 ± 2.9	0.9 ± 0.6	4.1 ± 5.2*	1.0 ± 0.7	8.1 ± 10.1*	3.0 ± 7.1**	4.7 ± 5.9

Notes: Results are expressed as means ± SD.
Asterisks show statistically significant difference (*$p < .05$, **$p < .01$).
L/H: the ratio of low frequency to high frequency component of heart rate variability.

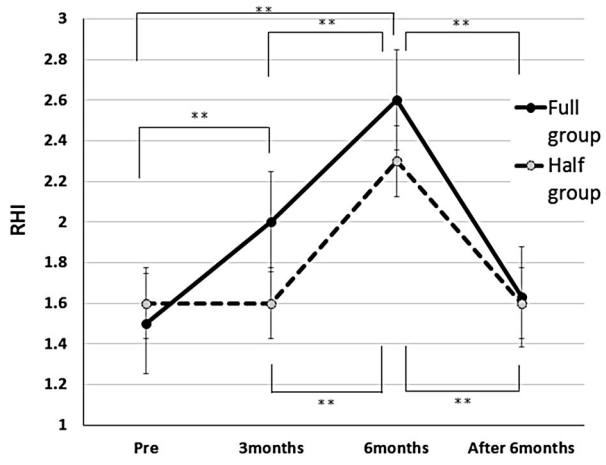

Figure 1. Change in the RH-PAT index of the full and half groups. $^{**}p < .01$, significant difference between the full and half groups.

3.4. *Autonomic function*

In the full group, the L/H increased significantly after 6 months of detraining, compared with the value measured after the 6-month intervention. However, a significant difference was not observed between the values measured at the preintervention and after 6 months of detraining. In the half group, the L/H increased significantly after the control period and decreased significantly after 3 months of intervention (Table II).

4. Discussion

4.1. *Improvements in flexibility*

The static stretching completion rate was 80.9 ± 14.7% during the 6-month period for the full group and 81.0 ± 17.4% during the 3-month period for the half group. This corresponds to having performed at least five interventions per week. No correlation was observed between the amount of change in stretching completion rates and rate of increases in flexibility. Once a week, an email was sent to participants to confirm the number of times the stretches were performed and to provide continued support. The stretching was performed voluntarily, without supervised enforcement.

The stretching duration was 20–30 seconds per site, which is the duration generally recommended in the literature (Bandy & Irion, 1994). The results of the present study suggested that intervention frequency, stretching duration, intensity, and intervention duration contributed to the improvement in flexibility.

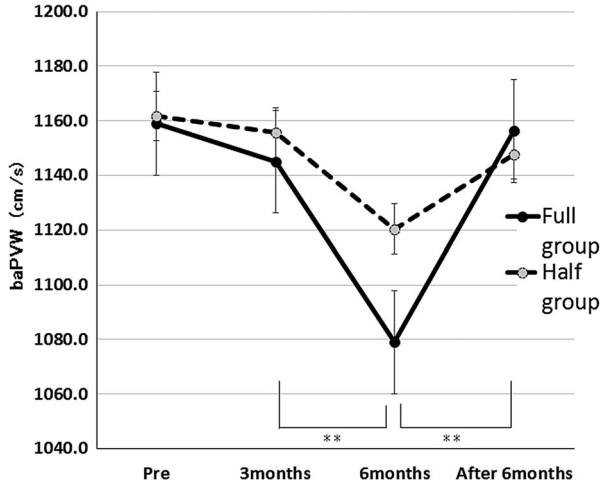

Figure 2. Change in baPWV of the full and half groups. $^{**}p < .01$, significant difference in the full group.

4.2. *Improvement in vascular endothelial function*

In both groups, the preintervention RH-PAT index was lower than the reference range for vascular endothelial function (1.67) (Maiorana, O'Driscoll, Taylor, & Green, 2003). After the respective intervention periods, this index improved significantly in both groups to levels that exceeded the reference range (1.68–2.09). Because of the changes in tension around the vascular wall, the stretching stimuli are applied to the vascular smooth muscle. Additionally, shear stress caused by increased blood flow is applied to the endothelial cells that face the vascular lumen and the muscle fibres are stretched along the long axis. When the shape of the muscle changes, the blood vessels that run parallel to the muscle also stretch (Katanosaka et al., 2008). These phenomena decrease blood vessel diameter and cause temporary blood flow restriction (Cui, Blaha, Moradkhan, Gray, & Sinoway, 2006). The increase in muscle blood volume after static stretching was thought to be due to the increase in blood flow after the release of a temporary cut-off, which may have induced reactive hyperaemia. After the stretch is released, shear stress is applied to the vascular endothelial cells owing to the increased blood flow (Yamamoto et al., 2003). This response leads to the secretion of vasodilatory factors such as nitric oxide (NO) (Maeda et al., 2001) and endothelium-derived hyperpolarising factor from the vascular endothelial cells. Based on these observations, static stretching presumably induces mechanical stress on the stretching site, which contributes to augmented muscle blood flow, which thus affects the endothelial cells. Furthermore, the participants were premenopausal women, and oestrogen was possibly involved in the improvement of vascular endothelial function (Hayashi et al., 2006). Increases in NO production

in vascular endothelial cells and suppression of vascular smooth muscle proliferation are some of the properties of oestrogen that inhibit arteriosclerosis (Hambrecht et al., 2003); a synergistic effect with shear and mechanical stress caused by static stretching was also considered.

Participants in this study were premenopausal women, and no restrictions were placed on diet. The impact of other exercises, as obtained from the IPAQ, was small.

4.3. Improvement in arterial stiffness

An improvement in baPWV has been reported immediately after performing short-term static stretching (Yamato et al., 2016). The 4-week study of Nishiwaki et al. (2015) monitored the effects of a stretching intervention in men. In a study by Wong and Figueroa (2014), no improvement in baPWV after 8 weeks of intervention was noted in postmenopausal obese women. Our study may have produced different results because our intervention and participants were different.

Preintervention baPWVs in the present study were 1159.0 ± 116.0 and 1161.7 ± 135.4 cm/s in the full and half groups, respectively, both of which were within the reference range for age-matched individuals. With 3 months of stretching intervention in both groups, the RH-PAT index increased significantly, but not on baPWV did not change significantly. This results did not come as our assumption. However, a significantly lower baPWV was observed after 6 months of intervention in the full group. We had postulated that vascular endothelial function would improve, which would simultaneously change the property of the blood vessel and consequently improve arterial stiffness (Wallace et al., 2007). No direct relationship between blood pressure and baPWV was observed. The blood pressure and RH-PAT index were significantly related to the amount of change observed at 3 and 6 months into the intervention in the full group.

Flexibility increased in both groups during the postintervention period; the RH-PAT index showed a reduced or downward trend; and baPWV improved. In the full group, no correlation between flexibility and the RH-PAT index or baPWV was observed.

IPAQ results did not change significantly during the intervention period; therefore, the changes in the RH-PAT index and baPWV were also considered to have been caused by static stretching.

The results of the present study did demonstrate differences at 3 months of intervention, showing that to improve vascular endothelial function. However, In order to improve the arterial stiffness for the at least 3 months more of intervention is required.

4.4. Autonomic function

A parasympathetic-dominant state is thought to occur as an acute effect after static stretching (Hotta et al., 2013); however, the measurements in this study were not conducted at the time when participants were quietly resting immediately after stretching, and this may have contributed to the absence of the parasympathetic-dominant state.

4.5. Limitations and future directions

The limitations of this study include the small sample size and infrequent evaluation periods (at 3 and 6 months) during the intervention. Although we confirmed the menstrual cycle stage of each subject, it was not considered when the three measurements were carried out. In future research, the influence of the menstrual cycle must be considered when setting the measurement date. In addition, future studies should also investigate the effects of haematological properties and ascertain when these effects appear and when reversibility occurs, by increasing the number of evaluations during the intervention.

5. Conclusion

A 3-month static stretching intervention was found to improve vascular endothelial function, and an additional 3-month intervention also improved arterial stiffness. However, these effects were reversed by detraining.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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