Human flexibility and arterial stiffness

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Abstract Most Japanese people have had their flexibility tested in childhood physical education classes. Recent studies may provide a retrospective answer as to why those measurements may be important. Flexibility is one of the components of physical fitness along with cardiorespiratory fitness and muscular strength. Although flexibility was originally assumed to correlate with other aspects of physical fitness, recent studies demonstrate that a less flexible body indicates arterial stiffening. Arterial stiffness has been identified as an independent risk factor for mortality and cardiovascular disorders. Therefore, there is a possibility that flexibility is a novel fitness indicator related to cardiovascular disease, which can be easily evaluated over all ages and in any area (e.g., medical check-up). Now, flexibility may no longer be simply viewed as important just for optimizing functional movement in daily life and/or reducing the risk of injury. This article reviews the recent findings on the relationship between flexibility and arterial stiffening, emphasizing “flexibility and arterial stiffness”, “genetics and flexibility”, “stretching and arterial stiffness”, and “flexibility and blood pressure”.

Keywords: flexibility, stretching, yoga, arterial stiffness, blood pressure

Introduction

Flexibility is one of the components of physical fitness in addition to cardiorespiratory fitness and muscular strength. Flexibility has traditionally been used as a determining factor for the performance of activities of daily living. Recent studies indicate that flexibility is associated with arterial stiffening. Now, flexibility may no longer simply be viewed as a supportive fitness measure that is used only to optimize functional movement in daily life and/or reduce the risk of injury.

Arterial stiffness increases progressively with aging and has been identified as an independent risk factor for mortality and cardiovascular disorders. Thus, the prevention and improvement of arterial stiffness is an important issue. This article reviews the recent findings on the relationship between flexibility and arterial stiffness.

In physical education and sports medicine, the simplest definition of flexibility may be the range of motion available in a joint or group of joints. Because flexibility can vary from joint to joint, there is no single test for overall flexibility. The sit-and-reach test is a common assessment of flexibility of the hamstrings, hips and lower back. In general, the flexibility assessed by the sit-and-reach test is called “trunk flexibility”.

Flexibility and arterial stiffness

Structurally, flexibility is determined by skeletal muscle and/or connective tissues such as the tendons, ligaments, and fascia. Arterial stiffness is also determined by the intrinsic elastic properties of smooth muscle and/or connective tissues (e.g., elastin-collagen composition) in the arteries. Age-related alterations in the muscles or connective tissues in the arteries may correspond to similar age-related alterations in the whole body. Accordingly, we examined the relationship between trunk flexibility and arterial stiffness in three age categories using cross-sectional analysis.

Fig. 1A shows the effects of age and trunk flexibility on arterial stiffness assessed by carotid-femoral pulse wave velocity (cfPWV or aortic PWV), which is an index of aortic stiffness. In middle-aged and older subjects, arterial stiffness was more severe in the poor-flexibility groups compared to the high-flexibility groups, suggesting that poor flexibility is associated with greater arterial stiffening. Fig. 1B shows the relationship between trunk flexibility and cfPWV in each age category. A significant relationship between flexibility and arterial stiffness was observed in middle-aged and older subjects, suggesting that a less flexible body indicates greater arterial stiffening, especially in middle-aged and older adults. Furthermore, trunk flexibility was associated with arterial stiffness, independent of cardiorespiratory fitness and muscular strength.

Recent studies have examined the relationship between flexibility and arterial stiffness. Douris et al. showed that middle-aged martial artists had significantly less arterial stiffness assessed by aortic PWV and greater trunk and hamstring flexibility than sedentary subjects. Nishiwaki...
et al. reported that trunk flexibility was related to arterial stiffness assessed by the cardio-ankle vascular index (CAVI), independent of blood pressure. They also found that sex differences existed in the relationship between trunk flexibility and arterial stiffness. That is, poor trunk flexibility was associated with arterial stiffening in young, middle-aged, and older men, whereas the association in women was found only in the elderly. These studies support the hypothesis that flexibility is associated with arterial stiffness.

We previously proposed two physiological mechanisms to explain the relationship between flexibility and arterial stiffness. First, both flexibility and arterial stiffness may be structurally determined by the muscles or connective tissues (e.g., elastin-collagen composition). Thus, age-related alterations in arterial stiffness may correspond to age-related alterations in flexibility within the same individual.

Second, arterial stiffness is functionally determined by the vascular tone of the artery. Vascular tone is partially regulated by sympathetic nerve activity. Stretching of skeletal muscle causes an increase in sympathetic nerve activity via the central nervous system. Repetitive stimulation of transient sympathoexcitation induced by habitual stretching exercises, which improve flexibility, may chronically reduce resting sympathetic nerve activity. This reduction in sympathetic nerve activity may result in a decrease in arterial stiffness. Flexibility exercise may also reduce stress. The reduction in stress may result in a decrease in sympathetic nerve activity.

**Fig. 1** A less flexible body indicates arterial stiffening, especially in middle-aged and older adults. (A) Carotid-femoral pulse wave velocity (cfPWV) in high- or poor-flexibility groups. In middle-aged and older subjects, cfPWV was more severe in the poor-flexibility groups compared to the high-flexibility groups. *P < 0.05 vs high-flexibility within same age category. (B) The relationship between trunk flexibility and cfPWV in each age category. A significant relationship between flexibility and arterial stiffness was observed in middle-aged and older subjects.

**Genetics and flexibility**

Although research in genetics and flexibility is limited, flexibility may be influenced by genetic factors. The estimated inheritability of flexibility, as assessed by the sit-and-reach test in twins, was 0.5 after adjustments for age and several anthropometric indicators of body size. Researchers have documented a genetic factor among some contortionist families. Inherited connective tissue syndromes such as Ehlers-Danlos syndrome (EDS) clearly have a genetic component. Ehlers-Danlos syndrome is a rare connective tissue disorder inherited as an autosomal-dominant trait. As a result, patients are pathologically hyper-flexible. A previous study showed abnormally low values of aortic PWV in the ecchymotic Ehlers-Danlos syndrome. Furthermore, Boutouyrie et al. reported that carotid distensibility was 27% higher in vascular type Ehlers-Danlos syndrome than control subjects. Thus, Ehlers-Danlos syndrome patients are less likely to have
stiff arteries. This provides the idea that the relationship between flexibility and arterial stiffness can be partly attributed to genetic factors. It would be interesting to determine the gene polymorphisms associating flexibility and arterial stiffness. Gene polymorphisms associated with arterial stiffness and cardiorespiratory fitness are reviewed in detail by Iemitsu20).

**Stretching and arterial stiffness**

Since a relationship between flexibility and arterial stiffness was found, the next logical question would be whether or not improving flexibility is capable of modifying age-related arterial stiffening. Although some studies showed that stretching improved arterial stiffness, there may be issues that still must be addressed before this conclusion can be accepted. Cortez-Cooper et al. showed that a 13-week stretching program increased carotid arterial compliance (reduced carotid arterial stiffness) in the absence of changes in aortic PWV in middle-aged and older adults21). Hunter et al. showed that 12 weeks of hatha yoga did not alter carotid arterial compliance22). They also found that an 8-week Bikram yoga intervention, which increased trunk flexibility, improved arterial stiffness, as measured by carotid arterial compliance and the β-stiffness index, in young but not older adults23). Wong

<table>
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cfPWV, carotid-femoral pulse wave velocity; baPWV, brachial-ankle PWV; CAVI, cardio-ankle vascular index.
and Figueroa indicated that 8 weeks of stretching training reduced blood pressure and vascular sympathetic activity in obese postmenopausal women with prehypertension and hypertension, whereas the same stretching training did not reduce aortic PWV and brachial-ankle PWV (baPWV), which is an index of systemic arterial stiffness[35]. Nishiwaki et al. found that 4 weeks of supervised static stretching reduced baPWV and CAVI in middle-aged men[26]. Yamato et al. reported that acute static stretching for 40 min reduced baPWV, whereas the stretching did not change cPWV[25]. As summarized in Table 1, findings regarding the effects of stretching or yoga on arterial stiffness are complicated. Nishiwaki et al. have inferred that stretching-induced vascular adaptations would differ according to the features of the participants such as age, sex, and medical history, as well as the mode, intensity, duration, frequency, and volume of exercise programs[26]. More studies regarding stretching and arterial stiffness will need to be conducted before a systematic review and meta-analysis can provide a conclusion for this issue.

Aortic PWV is directly linked with cardiovascular mortality and morbidity[2-5]. Unfortunately, aortic PWV was not altered in any studies in Table 1. The aorta is the largest artery, and adaptations of aortic stiffness induced by flexibility exercises might require longer periods of intervention. Studies using longer periods of intervention are needed to determine the effects of stretching on aortic stiffness.

**Flexibility and blood pressure**

Poor flexibility might be associated with high blood pressure. In middle-aged and older adults, systolic blood pressure in the poor-flexibility group was higher than in the high-flexibility group[3]. Constitutional stiffness of body tissues was associated with blood pressure levels in healthy children[36]. A randomized controlled trial has demonstrated that yoga reduces blood pressure in hypertensive patients[27]. A systematic review and meta-analysis has recommended yoga as an effective intervention for reducing blood pressure in adults with hypertension[28]. Stretching training reduced blood pressure and vascular sympathetic activity in prehypertension and hypertension[14]. These findings suggest that flexibility exercises, such as stretching and yoga, will be one strategy for treatment of hypertension.

Hypertension is acknowledged as one of the greatest and most established risk factors for cardiovascular disease[26-31]. Unfortunately, only 30 - 40% of patients, in Japan, currently taking antihypertensive drug treatments are controlling their blood pressure at less than 140/90 mmHg[32]. For these reasons, it has become increasingly crucial to explore alternative methods to reduce hypertension. High blood pressure can increase arterial stiffness[3]. My hope is that findings regarding flexibility and blood pressure or arterial stiffness will contribute to further exploration of alternative methods for hypertension treatment.

**Perspectives**

Recently, the popularity of yoga has grown dramatically. Yoga classes are offered at 75% of all U.S. health clubs[33]. The same trend exists in other developed countries. What is attracting participants to yoga? Yoga develops physical and mental well-being through the stretching of all muscle groups, indicating that yoga improves flexibility of body as physical fitness. Furthermore, yoga reduces blood pressure in hypertensive patients[27]. Thus, a flexible body might be beneficial in preventing cardiovascular disease. If so, flexibility will be a novel fitness indicator related to cardiovascular disease, and can be easily evaluated in all ages and in any area (e.g., medical check-up). Therefore, it would be interesting to determine in a longitudinal study if poor trunk flexibility accelerates the progression of age-related arterial stiffening. It would also be of interest to further identify the relationship between flexibility and cardiovascular disease.

**Conflict of Interests**

The author declares that there is no conflict of interests regarding the publication of this article.

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**References**

7) Nichols WW and O’Rourke MF. 2005. *McDonald’s Blood


