Exercise training modes and vascular adaptations

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Abstract Reduction of carotid arterial compliance and endothelial dysfunction are associated with advancing age and cardiovascular diseases. From the viewpoint of exercise physiology, exercise can be divided into that with aerobic components and that with resistance components. It is widely accepted that arterial compliance and endothelial function are improved by aerobic exercise training. On the other hand, it has been reported that resistance training decreases arterial compliance, but has no effect on endothelial function. In addition, according to research, combined aerobic and resistance training did not affect arterial compliance, which suggests that simultaneously performed aerobic training may negate and prevent the reduction in arterial compliance induced by resistance training. Considering the favorable effects of aerobic and resistance training on cardiorespiratory fitness and muscular strength, the author concludes it is necessary to perform both aerobic and resistance training to maintain and improve vascular and whole-body health.

Keywords : arterial compliance, arterial stiffness, endothelial function, intima-media thickness, aerobic training, resistance training, combined training

Introduction

Habitual exercise is negatively associated with arterial stiffening and elevated blood pressure, leading to prevention and improvement of cardiovascular diseases. From the viewpoint of exercise physiology, exercise can be divided into several categories: i.e., exercise with aerobic components, that with resistance components, as well as combined aerobic and resistance exercise. Therefore, it is possible to select an exercise training mode appropriate for the individual to increase cardiorespiratory fitness and/or muscular strength. The associations between training modes and vascular adaptations have been reported since the late 2000s. Exercise training modes are categorized as aerobic, resistance, and combined training, and vascular adaptations have been shown to differ between these different modes of training. This short review will introduce cross-sectional and longitudinal findings of vascular adaptations, i.e., arterial compliance, endothelial function, and intima-media thickness (IMT), with training modes to facilitate the selection of a suitable exercise training mode according to an individual's purpose and vascular status.

Aerobic training and vascular function

Reduced arterial compliance and increased arterial stiffness are independent risk factors of cardiovascular disease¹⁾. Indeed, the primary risk factor, i.e., aging, is closely

associated with reduction of arterial compliance^{2,3)}. It has been reported that aerobic exercise training improves the age-associated reduction in arterial compliance (Fig. 1)³⁾. Tanaka et al. compared values of central arterial compliance assessed using a combination of applanation tonometry and ultrasound methods among sedentary, recreationally active, and endurance-trained groups. The results indicated that age-associated reduced arterial compliance was attenuated in the endurance-trained group compared to the other groups. Moreover, these cross-sectional results were confirmed by a longitudinal study design,

Fig. 1 Carotid arterial compliance in sedentary, recreationally active, and endurance-trained men. * $P < 0.05$ vs. young men with the same physical activity; † $P < 0.05$ vs. sedentary men in the same age category; § $P < 0.05$ vs. recreationally active men in the same age category. Data are means $\pm$ SEM.

indicating that decreased arterial compliance in older individuals could be increased by just 3 months of aerobic exercise training. On the other hand, endothelial dysfunction is one of the underlying mechanisms of reduced arterial compliance, and this dysfunction is associated with both advancing age⁴⁾ and the incidence of cardiovascular disease⁵⁾. Some interventional studies indicated that endothelial function was also improved following aerobic exercise training in healthy young subjects⁶⁾, older men⁷⁾, and hypertensive patients⁸⁾. Although carotid artery IMT is also associated with advancing age and cardiorespiratory fitness⁹⁾, no changes in IMT were observed following aerobic exercise training in an interventional study¹⁰⁾. Therefore, these findings suggest that if vascular function is impaired by advancing age or hypertension, the impaired function can be improved with aerobic exercise training, with the exception of intima-media thickening with advancing age.

Resistance training and vascular function

Resistance training plays an important role for maintenance and improvement of functional capacity, and has become an integral component of exercise recommendations endorsed by a number of national health organizations¹¹⁻¹³⁾. In contrast to aerobic exercise training, regular resistance training was shown to be associated with decreased arterial compliance in both cross-sectional^{14,15)} and longitudinal studies¹⁶⁾, which suggests that resistance training may contribute to the incidence of cardiovascular disease. In addition, in a cross-sectional study, Kawano et al. examined whether a resistance training-induced reduction in arterial compliance is associated with endothelial function as evaluated by carotid arterial vasoreactivity response to cold pressor test (CPT)¹⁷⁾. In the study, resistance-trained men with lower arterial compliance showed the same level of carotid arterial vasodilatation in response to CPT as compared to sedentary men with normal arterial compliance (Fig. 2). These results suggest that reduced arterial compliance with resistance training may identify physiological adaptation of vascular function, unlike reduction in arterial compliance with advancing age or cardiovascular diseases. Moreover, another interventional study also indicated no effect of resistance training on endothelial function evaluated by endothelial-dependent vasodilatation in young men¹⁸⁾. Recently, meta-analysis of the association between resistance training and arterial stiffening indicated that high-intensity resistance training is associated with increased arterial stiffness in young adults with low baseline levels of arterial stiffness¹⁹⁾. Furthermore, resistance training doesn't seem to be associated with IMT of the carotid artery^{16,20)}. Taken together, resistance training should be performed for maintenance and improvement of functional capacity in middle-aged and older adults, because vascular dysfunction with resistance training may be low.

Fig. 2 Carotid arterial compliance (a), amount (b) and percentage change (c) in carotid artery diameter in response to cold pressor test (CPT) in resistance-trained and sedentary men. * $P < 0.05$ vs. sedentary men. Data are means $\pm$ SEM.

Combined aerobic and resistance exercise training and vascular functions

It is rare for physical activities or sports to involve only aerobic exercise or resistance exercise. In addition, it is important to gain both aerobic capacity and muscular strength to achieve and maintain good health. Therefore, it is necessary to understand the effects of combined aerobic and resistance exercise training on vascular function. Kawano et al. examined the effects of combined aerobic and resistance training on carotid arterial compliance,

and found that combined aerobic and resistance training did not affect arterial compliance (Fig. 3)²⁰. These results suggest that simultaneously performed aerobic training could negate or prevent the reduction in arterial compliance induced by resistance training. In addition, results showed there was no change in carotid IMT following combined aerobic and resistance training²⁰. Another subsequent study indicated that a training program involving aerobic exercise after resistance exercise attenuated arterial stiffness and improved endothelial function in young men; but the opposite training program, i.e., aerobic exercise before resistance training, had no effect on vascular function²¹. Taken together, these observations indicate that combined aerobic and resistance exercise training does not unfavorably affect vascular function. Furthermore, care taken in the order of exercise modes can provide three physiological benefits, i.e., cardiorespiratory fitness, muscular strength, and healthy vascular function.

Perspectives for further research

The present short review introduced the associations between training modes and vascular function. There are a variety of training modes and vascular functions. For example, the volume of training consists essentially of a balance between aerobic and resistance training; and vascular functions in humans are assessed by several indexes, such as arterial compliance, β -stiffness index, augmentation index, pulse wave velocity, cardio-ankle vascular index, flow-mediated dilatation, and reactive hyperemia in the microvasculature, etc. We need to understand the characteristics of these measurements for vascular function, and should provide useful measurements in the field

Fig. 3 Changes in carotid arterial compliance in the control group (CONTROL: white squares), intensity-training group (MODE: black triangles), and combined training group (COMBO: black triangles). * $P < 0.05$ vs. baseline; † $P < 0.05$ vs. after training period (4 months). There were no changes in either value in the CONTROL or COMBO for 8 months. Data are means $\pm$ SEM.

of exercise prescription. However, further studies are also needed to determine the physiological mechanisms underlying vascular adaptation in response to exercise training.

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