

# Mixed Signals: Arterial Stiffness and Elite Sports

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## Arterial Stiffness

Arterial stiffness is a marker of vascular health and an independent predictor of cardiovascular disease [1]. Greater arterial stiffness induces a vicious circle of increased aortic blood pressure and accelerates arterial damage, leading to impaired diastolic function, increased myocardial oxygen demand, and left ventricular hypertrophy [2]. In clinical practice, arterial stiffness can be used as a risk modifier, enabling clinicians to reclassify individuals based on different measures of arterial stiffness. The current ESC cardiovascular disease prevention guidelines therefore recommend using arterial stiffness (above the threshold of >12 m/s) as a marker of target organ damage in hypertensive individuals [2, 3]. Consequently, arterial stiffness should be of interest not only to clinicians and researchers in internal medicine, vascular medicine, or specialized hypertension care but also to the general cardiologist.

## The Effects of Exercise

Regular exercise is beneficial for the prevention and management of cardiovascular disease [4]. On the vascular level, exercise has multiple effects, among others mod-

ifying blood flow, luminal wall stress, and arterial pressure. This results in changes in arterial diameter and vessel wall thickness and function and is associated with a significant reduction of atherosclerotic risk, improvements in blood pressure control, and maintaining microvascular health [5]. However, different types of exercise have been associated with different vascular effects. Broadly speaking, exercise can be categorized into 3 main groups: aerobic (endurance) exercise, resistance (strength) exercise, and mixed exercise. In short, aerobic exercise is any activity that involves major muscle groups and is continuous and rhythmical in nature. Resistance training is defined as any activity that involves brief, repeated execution of voluntary muscle contractions against a load. Mixed exercise is, logically, a combination of the 2 former groups. Endurance exercise has been shown to reduce arterial stiffness in healthy individuals and in patients with established cardiovascular disease [6]. Furthermore, vigorous interval training has been shown to be superior to traditional moderate continuous training in reducing arterial stiffness in normotensive subjects at risk for cardiovascular disease [6]. However, little is known about the effects of strength and mixed exercise training on arterial function, and the arterial effects of prolonged and strenuous endurance training in elite athletes.

## Arterial Stiffness in Elite Water Polo Players

In this issue of *Cardiology*, Oikonomou et al. [7] report their investigations on arterial wall properties in Olympic-level water polo players. Water polo players are subjected to high loads of high-intensity training, including both endurance and strength components. Compared with the control groups, consisting of sedentary and recreationally active subjects, Oikonomou et al. [7] demonstrate mixed arterial findings in these athletes. In water polo players, aortic systolic pressure is decreased, and augmentation index – an indirect measure of arterial stiffness – improved. However, no differences were found with carotid-femoral pulse wave velocity (PWV) – a direct measure of arterial stiffness – as compared with the control groups.

The elegant analysis by Oikonomou et al. [7] can teach us 2 important things about arterial properties in elite athletes. First, arterial stiffness does not seem to be either negatively or positively affected by the mix of endurance and strength training. This is in line with the findings on arterial stiffness in elite rowers, who also train using a combination of endurance and strength exercises [8]. Conversely, compared to athletes who engage mainly in resistance training, endurance athletes have been shown to have a more favorable arterial function-structure phenotype, with lower arterial stiffness [9]. These differences in arterial properties between endurance and strength athletes can potentially be explained by the differences in mechanical forces generated during exercise. In young water polo players, but also rowers, the strength training components may be dominant as compared to the endurance components. However, the long-term clinical consequences are unknown, as long-term follow-up data in elite athletes on the association between arterial properties and arterial outcomes are lacking.

Second, a mixed picture emerges of the effects of high-intensity training in water polo players on different arterial wall properties: Oikonomou et al. [7] demonstrate a lack of effect on PWV but an improvement in augmentation index. The lack of effect of mixed exercise on PWV is in line with previously published studies [8,9]. The improvement in augmentation index has not been previously reported in this group. Oikonomou et al. [7] suggest that the improvement in augmentation index could be the result of improved endothelial function. However, this finding could also partly be explained by how arterial stiffness is measured. Carotid-femoral PWV is generally accepted as the most simple, robust, and reproducible method to determine arterial stiffness. On the other hand, augmentation index, as determined using arterial wave

reflections and central pulse wave analysis, is an indirect surrogate measurement of arterial stiffness, and contains a number of inherent limitations. For a reliable result, measurements should be performed at a central site (i.e., carotid artery to optimally reflect the load on left ventricle and central large artery walls). As this is difficult to achieve, the radial artery is more frequently used combined with a transfer function; however, this yields a less reliable estimation of the augmentation index. Furthermore, the use of brachial artery pressure as a surrogate for radial artery pressure has been shown to be yet less accurate, and may introduce measurement errors [10]. In the study by Oikonomou et al. [7] the authors use the radial artery with transfer function, and brachial artery pressure. This could potentially explain the positive effects of mixed exercise on augmentation index. Considering the fact that using augmentation index to predict cardiovascular disease outcomes is currently under debate [11], studies with direct measurements of aortic stiffness, such as the carotid-femoral PWV, would be preferable when further investigating arterial properties in elite athletes.

Finally, morphological cardiac changes in mixed sports are well documented but highly variable [12]. Unfortunately, the study by Oikonomou et al. [7] does not include additional cardiac investigations, such as an electrocardiogram, an echocardiogram, or magnetic resonance imaging of the heart or the aorta, which would assist the reader in putting the findings in the correct clinical context.

In conclusion, the mixed arterial findings in Olympic water polo players are a welcome addition to a slowly growing body of evidence on arterial properties in elite athletes. However, the long-term significance of these findings remain uncertain, and the relationship with other signs of cardiac adaptation unclear. Yet, these mixed findings offer the opportunity for future collaborative, mixed research projects, combining the input and expertise of the internal medicine doctor specialized in vascular medicine, the (sports)cardiologist, and the sports- and exercise physician to elucidate the complex interplay of heart and arteries in the elite athlete.

### Conflict of Interest Statement

There are no conflicts of interest.

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## References

- 1 Vlachopoulos C, Aznaouridis K, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis. *J Am Coll Cardiol*. 2010;55(13):1318–27.
- 2 Chirinos JA, Segers P, Hughes T, Townsend R. Large-artery stiffness in health and disease: JACC state-of-the-art review. *J Am Coll Cardiol*. 2019;74(9):1237–63.
- 3 Piepoli MF, Hoes AW, Agewall S, Albus C, Brotons C, Catapano AL, et al. 2016 European guidelines on cardiovascular disease prevention in clinical practice: the sixth joint task force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in Clinical Practice (constituted by representatives of 10 societies and by invited experts) developed with the special contribution of the European Association for Cardiovascular Prevention & Rehabilitation (EACPR). *Eur Heart J*. 2016;37(29):2315–81.
- 4 Lobelo F, Rohm Young D, Sallis R, Garber MD, Billinger SA, Duperly J, et al. Routine assessment and promotion of physical activity in healthcare settings: a scientific statement from the American Heart Association. *Circulation*. 2018;137(18):e495–522.
- 5 Fletcher GF, Landolfo C, Niebauer J, Ozemek C, Arena R, Lavie CJ. Promoting physical activity and exercise: JACC health promotion series. *J Am Coll Cardiol*. 2018;72(14):1622–39.
- 6 Li Y, Hanssen H, Cordes M, Rossmeissl A, Endes S, Schmidt-Trucksäss A. Aerobic, resistance and combined exercise training on arterial stiffness in normotensive and hypertensive adults: a review. *Eur J Sport Sci*. 2015;15(5):443–57.
- 7 Oikonomou E, Siasos G, Marinou G, Zaromitidou M, Athanasiou D, Fountoulakis P, et al. High-intensity endurance and strength training in water polo olympic team players: impact on arterial wall properties. *Cardiology*. 2020 Jul 16;1–8. DOI: 10.1159/000508648.
- 8 Franzen K, Reppel M, Köster J, Mortensen K. Acute and chronic effects on central hemodynamics and arterial stiffness in professional rowers. *Physiol Meas*. 2016;37(4):544–53.
- 9 DeVan AE, Seals DR. Vascular health in the ageing athlete. *Exp Physiol*. 2012;97(3):305–10.
- 10 Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D, et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. *Eur Heart J*. 2006;27(21):2588–605.
- 11 Mitchell GF, Hwang SJ, Larson MG, Hamburg NM, Benjamin EJ, Vasan RS, et al. Transfer function-derived central pressure and cardiovascular disease events: the Framingham Heart Study. *J Hypertens*. 2016;34(8):1528–34.
- 12 Utomi V, Oxborough D, Whyte GP, Somaroo J, Sharma S, Shave R, et al. Systematic review and meta-analysis of training mode, imaging modality and body size influences on the morphology and function of the male athlete's heart. *Heart*. 2013;99(23):1727–33.