Effect of a short-term intermittent exercise-training programme on the pulse wave velocity and arterial pressure: a prospective study among 71 healthy older subjects

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SUMMARY

Aims of the study: Stiffening of large arteries has been associated with increased cardiovascular outcomes among older subjects. Endurance exercises might attenuate artery stiffness, but little is known about the effects of intermittent training programme. We evaluate the effect of a short Intermittent Work Exercise Training Program (IWEP) on arterial stiffness estimated by the measure of the pulse wave velocity (PWV).

Methods and subjects: Seventy-one healthy volunteers (mean age: 64.6 years) free of symptomatic cardiac and pulmonary disease performed a 9-week IWEP that consisted of a 30-min cycling twice a week over a 9-week period. Each session involved six 5-min bouts of exercise, each of the latter separated into 4-min cycling at the first ventilatory threshold alternated with 1-min cycling at 90% of the pretraining maximal tolerated power. Before and after the IWEP, the following measurements were made: carotid–radial PWV and carotid–femoral PWV with a tonometer and systolic and diastolic blood pressure.

Results: Training resulted in a non-significant decrease of the carotid–radial PWV, a significant decrease of the carotid–femoral PWV from 10.2 to 9.6 m/s (p < 0.001) (that was no longer significant after adjustment for mean arterial pressure) and a significant decrease in both systolic and diastolic blood pressure, respectively, from 129.6 ± 14.9 mmHg to 120.1 ± 14.1 mmHg (p < 0.001) and from 77.2 ± 8.8 mmHg to 71.4 ± 10.1 mmHg (p < 0.001).

Conclusion: The present results support the idea that a short-term intermittent aerobic exercise programme may be an effective lifestyle intervention for reducing rapidly blood pressure and probably central arterial stiffness among older healthy subjects.

What’s known
- Regular endurance training prevents arterial stiffening and decreases blood pressure among older healthy subjects.
- There are some concerns about the effects of resistance training on arterial stiffness.
- Little is known about the effect of intermittent endurance training programmes on arterial stiffening.

What’s new
- A 9-week intermittent endurance programme with only 18 sessions of cycling decreases significantly blood pressure among healthy community-dwelling older subjects.
- A 9-week intermittent endurance programme seems to have a favourable effect on carotid–femoral pulse wave velocity (that reflects arterial stiffness), i.e. in part, mediated by a decrease of the mean blood pressure.

Introduction

Large elastic artery stiffness increases with age in both sexes, whereas stiffness of muscular arteries changes little with age (1,2). Central arterial stiffness leads to systolic hypertension, left ventricular hypertrophy, impaired coronary perfusion and is increasingly recognised as an independent predictor of cardiovascular morbidity and mortality in general population and in older subjects (3–5). Arterial pulse wave velocity (PWV) provides a robust estimate of arterial stiffness (6). PWV is measured as the velocity of the pressure wave between two remote portions of the arterial tree. The stiffer the vessel is, the faster the pulse pressure moves along the vessel. The recent joint guidelines for the management of arterial hypertension of the European Society of Hypertension recognise PWV as a marker of subclinical target-organ damage (7).

Arterial stiffness may be reduced with an optimal control of the usual cardiovascular risk factors including physical activity (8–10). Nevertheless, the relationship between physical activity and arterial stiffness is complex, as aerobic exercise has been shown to reduced central arterial stiffness among healthy older subjects (11) and in contrast, some randomised intervention studies have reported unfavourable effects of high-intensity resistance exercises on central arterial stiffness (12,13). Furthermore, there is a huge debate concerning which type of
aerobic exercise (continuous vs. intermittent) has a greater effect on arterial stiffness (14). Using an intermittent exercise-training programme derived from the Square-Wave Endurance Exercise Test (SWEET) proposed by Gimenez (15), Tordi et al. observed a significant decrease in PWV among young subjects after an acute exercise (16). In our geriatric department, we have developed and validated, since few years, an Intermittent Work Exercise Training Program (IWEP) also derived from the SWEET and similar to Tordi’s protocol (17,18). We previously demonstrated that the IWEP improves significantly after 18 training sessions maximal cardio-respiratory function and endurance parameters among healthy ‘young seniors’ in both genders (19) and among ‘older seniors’ (20).

In view of these considerations, this study was designed to assess, first of all, the effect of our tailored-made IWEP on both central and peripheral arterial stiffness using the measurement of PWV, and secondly to evaluate the effect of IWEP on both systolic and diastolic pressure.

Materials and methods

Subjects

The initial cohort was consisted of more than 400 elderly community-dwelling volunteers from the Strasbourg University Hospital geriatric department (see for details reference 20). Briefly, they first completed a personal interview as well as a physical examination including an ECG, and received instructions about the study protocol. All the subjects were free from symptomatic cardiac or pulmonary disease and participated in the study after giving their written informed consent. Among this cohort, 123 subjects aged over 50 years accepted an initial measurement and the supra-sternal notch. All the distance from the measurement sites divided by transit time delay. We note here that for the carotid–femoral PWV values were the mean of two successive measurements performed before and after the 9-week IWEP. PWV and blood pressure assessment

PulsePen device (DiaTecne srl, Milan, Italy), was used for measuring carotid–radial PWV, which reflects upper limb arterial stiffness and carotid–femoral PWV corresponding to aortic stiffness (23). The procedure has been detailed previously in detail (24). Briefly, the PulsePen device is a validated, easy-to-use, high-fidelity tonometer. PWV was calculated as the distance between the measurement sites divided by transit time delay. We note here that for the carotid–femoral measurements, distance of the pulse wave transit represents the difference between the distance from the supra-sternal notch to the femoral point of application of the tonometer and the distance from the carotid point of tonometer application and the supra-sternal notch. All the measurements were preceded by a preliminary 15-min supine rest in quiet and temperature controlled room at 21 °C. Carotid–radial PWV and carotid–femoral PWV values were the mean of two successive assessments.

Systolic and diastolic blood pressure measured with an oscillometric sphygmomanometer at the site of the brachial artery after 20 min of rest were also introduced in the PulsePen software and were used for the calibration of pressure wave assessed with the PulsePen. Pulse pressure was defined as the difference between systolic and diastolic blood pressure.
The intermittent work exercise programme

The IWEP was performed on the same upright electronically braked cycle ergometer and consisted of a 30-min cycling workout twice a week over a 9-week period. Each session involved six 5-min bouts of exercise, each of the latter separated into 4-min cycling at the measured pretraining VT1 workload (called ‘BASE’), alternated with 1-min cycling at 90% of the pretraining MTP (called ‘PEAK’) sustained during the IWEP. During this exercise, HR was continuously recorded with a heart rate monitor (Suunto T6c, Vantaa, Finland). The HR measured at the 28th and 30th min were taken as the ‘target values’ for the entire training programme. As exercise tolerance improves with training, each HR decrease of 10 beats⁄min led to a 10% increase in the ‘BASE’ and ‘PEAK’ workload values (Figure 1).

Analysis

To determine the effects of the IWEP on cardiorespiratory function, PWV and blood pressure, the following comparisons were made: (i) pre and post IET maximal parameters: MTP, VO2peak, MMV, HRmax; (ii) endurance parameters: relative intensity at VT1, HR at absolute intensity of pre-IWEP VT1 and lactate at absolute intensity of pre-IWEP MTP; (iii) carotid–radial PWV and carotid–femoral PWV [including a crude analysis firstly, and secondly an analysis with adjustment for mean arterial pressure (defined as diastolic pressure + 1⁄3 pulse pressure)]; (iv) systolic, diastolic and pulse blood pressure.

Statistical analysis

After testing for data distribution normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene test), IET, PWV and blood pressure differences were evaluated using a two-way analysis of variance for repeated measures. A Fisher’s test was carried out when appropriate. Analysis was performed using Sigma Stat for windows (ver. 14.0; SPSS, Chicago, IL, USA). The level of significance was taken as p < 0.05. Data were expressed in terms of means and standard deviation (± SD) and per cents of variation after vs. before IWEP.

Results

The IWEP adherence rate for the 71 participants amounted 100% with no training-related injuries reported. No changes in their medication occurred during the study period.

Regarding the pretraining spirometric parameters, the measured VC/theoretical VC ratio and the measured FEV1/theoretical FEV1 ratio were both higher than 99% in all groups. For the measured pretraining MTP and pretraining VO2peak the values were, respectively, at 83% and 88% of the theoretical values (Table 1).

Effects of IWEP

Maximal parameters

The training programme resulted in a significant increase in MTP, VO2peak, MMV and lactate concentration at absolute posttraining MTP, respectively, by

![Figure 1 Protocol design of the IWEP](image-url)
19.6% (p < 0.05), 19.5% (p < 0.05), 31.7% (p < 0.05) and 16.4%. HR posttraining peak values at exhaustion were similar to those at pretraining values (Table 2).

Endurance parameters
The endurance parameters improved considerably after the exercise programme. VT1 improved by 21.4% (p < 0.05). After the IWEP when subjects were cycling at a power output corresponding to their pretraining VT1, a significant decrease of HR (5 beats/min) was observed (Table 2). The subjects presented a significant lower blood lactate value after training at the same absolute intensity as that of pretraining MTP, with a decrease of 1.7 mmol/l (p < 0.05) (Table 2).

Pulse wave velocity
The relationships between PWV and age among our study population are reported in Figure 2 (PWV carotid–radial) and Figure 3 (PWV carotid–femoral). It appeared that carotid–femoral PWV had a strongest relationship with advancing age (correlation coefficient: 0.52; p < 0.001) compared with carotid–radial PWV (correlation coefficient: 0.22; p = 0.05).

Training resulted in a non-significant decrease in the carotid–radial PWV from 8.5 ± 1.2 m/s to 8.4 ± 1.3 m/s (p = 0.6) and a significant decrease in the carotid–femoral PWV from 10.2 ± 2.8 m/s to 9.6 ± 2.5 m/s (p < 0.001) (Figure 2). After adjustment for mean arterial pressure, the decrease in carotid–femoral PWV was not statistically significant (p = 0.15) (Figure 4).

Blood pressure
After training, both systolic and diastolic blood pressure decreased significantly, respectively, from 129.6 ± 14.9 mmHg to 120.1 ± 14.1 mmHg (p < 0.001) and from 77.2 ± 8.8 mmHg to 71.4 ± 10.1 mmHg (p < 0.001). Pulse pressure decreased significantly after the IWEP from 52.4 ± 12.6 mmHg to 48.6 ± 9.8 mmHg (p = 0.02) (Figure 5).

Discussion
To the best of our knowledge, this is the first study to investigate the effect of a short-term interval training programme on PWV among older subjects. Primary findings of this study are as followed. Fitness, endurance parameters, systolic blood pressure,

| Table 2 Cardio-respiratory responses during IET before and after training session (n = 71) |
|-------------------------------------------------|---------------------------------|-----------------|-----------------|
| Values                                          | Pretraining                     | Post-training   | p               |
| Maximal tolerated power (watts ± SD)            | 108.3 ± 52.7                    | 129.4 ± 55.4    | < 0.001         |
| Peak of oxygen uptake (ml/min/kg ± SD)           | 18.9 ± 5.9                      | 22.6 ± 6.3      | < 0.001         |
| Maximal minute ventilation (l/min ± SD)          | 55.8 ± 22.7                     | 73.5 ± 25.0     | < 0.001         |
| Peak heart rate value (beats/min ± SD)           | 136 ± 24                        | 141 ± 25        | 0.39            |
| Lactate at rest (mmol 100/ml ± SD)               | 0.9 ± 0.4                       | 0.9 ± 0.5       | 0.97            |
| Lactate at Maximal tolerated power (mmol 100/ml ± SD) | 5.5 ± 2.2                     | 6.4 ± 2.2       | 0.01            |
| First ventilatory threshold (watts ± SD)         | 66.2 ± 29.8                     | 80.4 ± 35.2     | < 0.001         |
| Heart rate at pretraining first ventilatory threshold (beats/min ± SD) | 113 ± 18                     | 108 ± 17        | 0.03            |
| Lactate at pretraining maximal tolerated power (mmol 100/ml ± SD) | 5.5 ± 2.2                     | 3.8 ± 1.8       | < 0.001         |

IET, incremental exercise test.
diastolic blood pressure and PWV are improved after a 9-week interval exercise-training programme.

The favourable effects of intermittent aerobic exercises on maximal cardio-respiratory function and endurance parameters among older subjects are already known, but usually in other studies, the older subjects underwent usually more than 9 weeks training. Three main reasons may explain the short-term benefit of the IWEP. First of all, IWEP is an individualised programme, at baseline and during the training period, depending on the HR evolution. Secondly, IWEP is supervised with an optimal adherence rate and a supportive role played by supervision in a positive environment. At last, the specific design of our training programme, which included intermittent rather than continuous exercise, may contribute towards the improvement of both cardio-respiratory and endurance parameters. The IWEP decreased significantly systolic blood pressure, diastolic blood pressure and pulse pressure.

Benefits of aerobic activity on blood pressure value are robust evidences in general population as reported by Whelton et al. in a meta-analysis (25). Benefits of physical activity on blood pressure in older subjects are less consistent and usually involve study using long-term week training period (26). In a small-randomised trial including 44 sedentary healthy normotensive subjects aged 60–79 years, Braith et al. reported after 6 months a significant decrease in both systolic (−9 mmHg) and diastolic blood pressure (−8 mmHg) in a moderate intensity exercise group (70% VO$_{2\max}$) compared with a control group (27). Jessup et al. showed, in a randomised study including 31 older subjects (68.5 years old), a significant benefice of physical activity on 24-h systolic blood pressure (−7.9 mmHg) and 24-h diastolic blood pressure (−3.6 mmHg) in the active group compared with the control group (28).

In contrast, Vaitkevicius et al. reported, in a small-pilot study including 22 older subjects (mean age of 84 years), a significant reduction only in resting systolic blood pressure (146 ± 18 mmHg vs. 133 ± 14 mmHg, p = 0.01) without significant effects on resting diastolic blood pressure, after 6 months of aerobic exercise training (at 60–80% of maximal heart rate) (29).

In our study, the improvement of PWV after training is consistent with other findings, such as Tanaka et al. study’s using a 3-month aerobic exercise intervention among 20 middle-aged subjects (8). Recently, Kawano et al. reported that habitual rowing exercise in older men is associated with high muscle power and aerobic capacity, and favourable blood lipid profile without affecting arterial stiffness indices (carotid β-stiffness and cardio-ankle vascular index) (30). Figueroa et al. showed, in a small-randomised trial among healthy postmenopausal women, that a combined resistance and endurance 12-week training programme reduced the brachial–ankle PWV (31). Nevertheless, to our best knowledge, this study is the first that reported after a short period of 9-week training a decreased in PWV among older subjects.

Our finding that the relationship between carotid–femoral PWV and advancing age is stronger compared with the relationship between carotid–radial PWV and ageing is in accordance with other findings (32). The stiffness process of the arterial wall affects essentially the large central elastic arteries and that relatively spares the peripheral muscular arteries (33).

Furthermore, we observed a significant interaction effect of the exercise training on PWV and the arterial site. The 18 sessions of IWEP were associated
with a significant decrease in the central arterial stiffness (estimated by the carotid–femoral PWV) without effect on the peripheral arterial stiffness (estimated by the carotid–radial PWV). Such findings are in accordance with other study results. Hayashi et al. reported in a small study including 17 sedentary middle-aged men a significant decrease in aortic PWV and not legs PWV after a 16-week moderate intensity-training period (34). The differential effects of ageing on central and peripheral arterial stiffness may explain the present results.

Little is known about the mechanisms by which regular aerobic exercise may decrease large elastic artery stiffness. In some animal models, aerobic exercise has been associated with an increase in elastin content in arterial wall and a decrease in calcium content (35). Nevertheless, it appears unlikely that such favourable changes occur after a short training period of 9 weeks.

In our study, the decrease in the carotid–femoral PWV after exercise was no more statistically significant after adjustment for the mean blood pressure. Such finding means that the decrease in PWV may be in part, mediated by a decrease in blood pressure. In a post hoc analysis focused among hypertensive subjects, the carotid–radial PWV was similar before and after training, $8.5 \pm 1.4$ m/s and $8.7 \pm 1.5$ m/s respectively. Compare with the whole population, the carotid–femoral PWV was higher among hypertensive at baseline, without significant effect of training (before and after training $10.9 \pm 3$ m/s and $10.8 \pm 2.8$ m/s respectively).

Our study has some limitations. Older population was selected. They all were volunteers, well-educated, from middle to upper socioeconomic status with a good medical follow-up, living all independently and most of them practised physical activity. Taking into account the poor level of physical activity in the whole population, we could expect a higher benefit of the IWEP on maximal cardio-respiratory function and endurance parameters. In contrast, arterial stiffness may be greater in some specific older subject’s sub-groups, especially those with cardio-vascular diseases, those with many comorbidities or those living in institution. In addition, the study was not randomised to compare programmes. Therefore, potential confounding by unmeasured factors related to the high socioeconomic status, such as motivation, as well as dietary changes may influence, in part, the effects of IWEP. However, the homogeneity and the size of our study sample strengthen the internal validity of the results. Therefore, it appears unlikely that confounding factors may explain all of the improvement of physiological parameters and arterial stiffness observed after the IWEP.

**Conclusion**

The present results support the idea that a short-term intermittent aerobic exercise programme may be an effective lifestyle intervention for reducing rapidly blood pressure and probably central arterial stiffness among older healthy subjects. The specificity of our tailored IWEP, including a structured, personalised and supervised interval exercise-training programme, contributes largely to the short-term benefits. A further large randomised controlled study is needed to confirm the positive effects of the IWEP on arterial stiffness and to evaluate the clinical relevance of a carotid–femoral PWV decrease.

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**Author contributions**

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