

Interval and Strength Training in CAD Patients

Authors

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Key words

- endurance training
- coronary artery disease
- high aerobic intensity interval training
- left ventricular ejection fraction
- 4×4 min intervals
- cardiovascular magnetic resonance

Abstract

This study sought to study the effect of high intensity aerobic interval endurance training on peak stroke volume and maximal strength training on mechanical efficiency in coronary artery disease (CAD) patients. 8 CAD patients (age 61.4 ± 3.7 years) trained 30 interval training sessions with 4×4 min intervals at 85–95% of peak heart rate while 10 CAD patients (age 66.5 ± 5.5 years) trained 24 sessions of maximal horizon-

tal leg press. In the interval training group peak stroke volume increased significantly by 23% from $94.1 \pm 23.0 \text{ mL} \cdot \text{beat}^{-1}$ to $115.8 \pm 22.4 \text{ mL} \cdot \text{beat}^{-1}$ ($p < 0.05$). Peak oxygen uptake increased significantly by 17% from $27.2 \pm 4.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ to $31.8 \pm 5.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ($p < 0.05$) in the same group. In contrast, there was no such exercise training-induced change in peak stroke volume or peak oxygen uptake in the maximal strength training group, despite a 35% improvement in sub maximal walking performance.

Introduction

Endurance training has been recognized to increase peak oxygen uptake ($\text{VO}_{2\text{peak}}$) in cardiovascular disease patients (CAD) [7] while high intensity aerobic interval training, employing 4×4 min (rest and recovery intervals), is a more effective approach [10,21,25]. Elevating $\text{VO}_{2\text{peak}}$ through endurance training is important as it relates to cardiovascular disease, due to the association between poor cardiovascular fitness, a sedentary lifestyle and mortality risk [16]. Similarly, low skeletal muscular strength is associated with increased mortality [19], and skeletal muscle strength decreases with age and inactivity [26].

Specific to the cardiac muscle itself, cardiovascular disease, aging and a sedentary lifestyle deteriorate cardiac function with left ventricular stiffness, decreased left ventricular compliance and diminished diastolic performance [1,20,23]. Endurance training can improve peak stroke volume and left ventricular function in CAD patients [5,6], but it has previously been recognized that, at least in healthy subjects, high intensity aerobic interval training at 90–95% of maximal heart rate is superior to less intense exercise in terms of increasing maximal stroke volume [10]. This aerobic interval training-induced increase in stroke

volume was not only associated with an increased $\text{VO}_{2\text{max}}$ [10], but also a reversal of left ventricular remodelling, improving left ventricular ejection fraction in heart failure patients [25]. Specific to skeletal muscle itself, there is a minimum muscular strength required for the activities of daily life such as walking or stair climbing and when lacking, may lead to disability [3]. Low muscular strength is associated with reduced mechanical efficiency, the oxygen cost of generating a given work load [17], during endurance activities. It has been documented that CAD patients walk with mechanical inefficiency, which is likely a consequence of skeletal muscle weakness [11]. Increased skeletal muscle strength and the subsequent improvement in the mechanical efficiency of a simple task such as walking could shift the stress of daily activity from severe, to tolerable and repeatable in such patients [14]. The beginning of an upward spiral in terms of daily activity will likely yield an improvement in endurance performance.

Peak oxygen pulse has been documented to increase as a consequence of 4×4 aerobic interval training at 85–95% of peak heart rate in healthy adults [22], however, to our knowledge, there has not been a study that has revealed the effect of such high intensity aerobic interval training on peak stroke volume in CAD patients.

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Additionally, although the importance of maintaining or improving skeletal muscle strength in CAD patients is clear, little is known about the impact of maximal strength training on this population. Therefore, the primary aim of the present study was to examine the effect of high aerobic intensity interval training on peak stroke volume and maximal strength training on mechanical efficiency in stable CAD patients.

Methods

Subjects

20 clinically diagnosed CAD patients were recruited from the St. Olav University Hospital of Trondheim, and randomly allocated to an aerobic interval training group (AIT) ($n = 10$) and a maximal strength training group (MST) ($n = 10$). In the AIT group 3 patients were diagnosed with previous myocardial infarction, 4 subjects with percutaneous coronary intervention and 3 patients with coronary artery bypass surgery. In the MST group 4 patients were diagnosed with previous myocardial infarction, 3 subjects with percutaneous coronary intervention and 4 patients with coronary artery bypass surgery.

Inclusion criteria were stable CAD: Angina pectoris class I–III in the Canadian Cardiovascular Society Classification (CCS), Ischemia detected on exercise electrocardiogram, or angiographic documented CAD. Exclusion criterion were unstable angina pectoris, myocardial infarction during the last month, PCI during the last month, left ventricular ejection fraction less than 40%, complex ventricular arrhythmias, and orthopaedic or neurological limitations to exercise. Patients remained on their standard medication throughout the study and no changes were reported. There was no difference in the medication use between the AIT and the MST group.

The study protocol was approved by the regional committees for medical research ethics, and was accomplished according to the declaration of Helsinki. All subjects gave written consent before participating. The study has also been performed in accordance with the ethical standards of the International Journal of Sports Medicine [8]. Patients were supervised during training and no discomfort or adverse events were reported. One patient in the AIT group withdrew from the study while one subject in the same group was excluded due to the inability to participate in post testing.

Oxygen uptake

Sub maximal and peak oxygen uptake was measured before and after the training interventions. After 10 min warm up consisting of treadmill walking at 3–5 km per hour and zero degree inclination subjects walked at a sub maximal work load corresponding to 40 watts for 5 min. The treadmill speed was 3–5 km per hour with appropriate inclination dependent upon the subjects' body mass. To define the walking speed corresponding to 40 watts on the treadmill the following equation was used [11]:

$$V = \frac{\text{workload}}{[m_b \cdot g] \cdot \sin(\theta)} \cdot 3.6$$

V = velocity ($\text{km} \cdot \text{h}^{-1}$)

workload = 40 Watt ($\text{Nm} \cdot \text{s}^{-1}$)

g = gravitational constant ($\text{m} \cdot \text{s}^{-2}$)

m_b = body mass (kg)

θ = treadmill inclination (degrees)

The work load was well below the lactate threshold, and steady state VO_2 values were achieved after 3 min of walking. Mechanical work efficiency was assessed after 5 min of treadmill walking. The mean VO_2 measured during the last minute of walking was used to calculate the net efficiency through the following equation:

$$\text{Net efficiency} = \frac{\text{Work Performed (Kcal} \cdot \text{min}^{-1})}{\text{Energy used (Kcal} \cdot \text{min}^{-1}) - \text{REE (Kcal} \cdot \text{min}^{-1})} \cdot 100$$

REE = Resting energy expenditure

Work performed = 40 watt, 1 Watt = $0.01433 \text{ Kcal} \cdot \text{min}^{-1}$

Resting energy expenditure was set to $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Both VO_2 and watts were converted to kilojoules to allow for calculation of percent mechanical efficiency [11].

After completion of the sub maximal measurements the treadmill speed was increased to fast walking and the inclination was increased by raising the inclination of the treadmill by 2% every minute until subjects reached exhaustion. Oxygen uptake was measured continuously during the tests (V-max spectra, Sensor-Medics, USA), and the average of the 3 highest measurements during 10 s determined $\text{VO}_{2\text{peak}}$. Criteria for exhaustion were an RQ value above 1.0 and a Borg scale value above 15. RQ was above 1.0 in all patients and Borg scale values above 15 were observed in 14 patients. In addition, the authors did a subjective evaluation of the level of exhaustion through observations of ventilation, walking action and facial expressions in patients at the end stage of the test. Heart frequency was measured by a heart rate monitor (Polar Sport, Finland) and 12 lead ECG readings were done during pre testing to evaluate the level of peak exercise ischemia and assess the safety for exercise training (V-max spectra, CardioSoft, USA). A capillary blood sample taken immediately after the tests, was analysed for lactate acid on an YSI 1500 sport tester (YSI Incorporated, USA), and subjects reported their level of perceived exhaustion by the Borg scale [2].

Stroke volume and cardiac output

Cardiac output (CO) and stroke volume were measured during rest (standing) and during treadmill walking at 80% of $\text{VO}_{2\text{peak}}$ before and after the training periods. CO was measured through a single breath gas technique, with a gas mixture containing 0.3% carbon monoxide, 0.3% acetylene, 0.3% methane and 21% oxygen balanced with nitrogen. In the solution acetylene serves as the soluble gas and methane the insoluble. Standing at rest and while walking subjects completely exhaled ambient air, inhaled the gas mixture, and completely exhaled again. Measurements of gas concentrations were carried out, and CO and HR registered (V-max Spectra, SensorMedics, USA). The test method has previously been validated and a coefficient of variation of 7.6% was found [4].

Maximal strength in the lower extremities was tested by one repetition maximum (1RM) in a dynamic horizontal leg press down to a knee joint angle of 90° using a horizontal leg press machine (Technogym, Italy). Subjects were familiarized with the lifting procedures before the start of the test. One repetition maximum was obtained by repeating the leg press exercise with increasing loads of 5–10 kilogram until the subjects were not able to complete the lift. A total of 6–8 lifts were used to achieve 1RM and the highest weight lifted was recorded as 1RM. Maximal voluntary rate of force development (RFD) and peak force during 90° dynamic leg press movement were assessed using a

force platform (9286AA, Kistler, Switzerland). Data were collected at 2000 Hz (Bioware v3.06b, Kistler, Switzerland). Subjects performed 2 repetitions of dynamic leg press focusing on maximal force production with a standardized resistance of 40 kilogram (kg). Rate of force development was measured between 10 and 90% of peak force in the concentric phase of the sub maximal leg press.

Quality of life

The MacNew Heart Disease Health-Related Quality of Life questionnaire was distributed to the patients for measurements of quality of life before and after the training periods.

Cardiovascular magnetic resonance (CMR)

All patients in the AIT group underwent CMR examination before and after the training period using a Philips Intera® 1.5T MR whole body scanner (Phillips, Best, Netherlands), equipped with a 5-element cardiac phased array coil and cardiac software package (R9.1.1).

Due to the long travelling distance and cost of travel only the AIT group was investigated with CMR.

Lying during breath-hold, 2-chamber, 4-chamber and long-axis views were acquired using a retrospectively electrocardiographically gated steady state free precession (SSFP) cine sequence. A stack of 10-mm thick contiguous slices encompassing the left ventricle from base to apex in the cardiac short-axis orientation was acquired for volumetric measurements. Imaging parameters included the following: 2.9/1.4 (repetition time ms/echo-time ms), 160×160 matrix, 320×320 mm field of view, 2.0×2.0 mm in-plane spatial resolution, half Fourier acquisition and 65-degree flip angle. A total of 30 heart phases were acquired. End diastolic volume (EDV), end systolic volume (ESV), left ventricular mass (LVM), stroke volume (SV), cardiac output (CO) and ejection fraction (EF) were measured by semi automated segmentation of end-diastolic and end-systolic areas using dedicated software (Easyvision, Philips, Best, Netherlands).

Training intervention

Subjects in the AIT group completed 30 interval sessions of treadmill walking in the 8 weeks following initial testing. During the initial 4 weeks 5 weekly sessions were undertaken, followed by 3 weekly sessions over the next 4 weeks until a total of 30 interval training sessions were performed. Each training session started with 5 min warm up, continuing with 4 times 4 min of interval training, with 3 min active breaks inbetween each interval. The training intensity for the 2 last minutes of intervals was set to 85–95% of HR_{peak} , and during active breaks subjects walked at an intensity corresponding to 60–70% of HR_{peak} . To compensate for increased VO_{2peak} capacity, treadmill speed and grade were increased several times during the study, to make sure the patients trained at 85–95% of their HR_{peak} at all times. Patients performed a 'warm down' by walking for 5 min after the interval period. HR was recorded continuously during exercise and self reported exercise stamina was reported by the Borg scale. All training sessions were supervised by an exercise physiologist. The MST group completed an 8 week strength training regime, 3 times per week, a total of 24 training sessions in our laboratory. Each training session consisted of 5 min warm up of stationary biking and 4 series with 4 repetitions in each series of horizontal dynamic leg press. The exercise was performed with emphasis on maximal mobilization of force in the concentric action and subjects started the concentric movement when the knee joint

Table 1 Physical characteristics of the subjects at inclusion.

	Endurance training (n=8)	Strength training (n=10)
men/women	6/2	10/0
age (years)	61.4±3.7	66.5±5.5
height (cm)	175.4±9.3	177.8±7.4
body mass (kg)	80.2±13.2	83.6±9.9
body mass index (kg/m ²)	26.1±2.9	26.5±3.1
systolic blood pressure (mmHg)	135±20	131±16
diastolic blood pressure (mmHg)	84±8	80±12

Data is presented as mean and SD for each variable

angle corresponded to 90°. The subjects trained with a progressive work load starting at 85–90% of the individual 1RM, and all training sessions were supervised by an exercise physiologist. When the subjects were able to perform all sets and repetitions, the load was increased by 2.5 kg. A 2 min rest period was employed between each set of exercise. The training regime lasted approximately 20 min per session.

Statistical analysis

All table values are expressed as mean±standard deviation (SD) while figure values are in percent change±standard error of the mean (SE). After data was tested for normal distribution, parametric tests were used to determine statistical significance. Changes within groups were determined by repeated measure ANOVA while differences between the AIT and the MST groups were calculated by using analysis of covariance (ANCOVA). Statistical analyses were performed using the software program SPSS, version 14.0 (Statistical Package for Social Science, Chicago, Illinois, USA). Post hoc testing was automatically done by SPSS. A 2-tailed p-value <0.05 was accepted as statistically significant for all tests.

Results



There were no significant differences in physical characteristics or peak metabolic data between the 2 training groups at inclusion (● Table 1, ● Table 2).

Peak stroke volume increased significantly by 23% in the AIT group, a change significantly greater than in the MST group where no change was detected (● Fig. 1). Peak cardiac output improved significantly from $12.1\pm3.1\text{ L}\cdot\text{min}^{-1}$ before to $15.6\pm3.7\text{ L}\cdot\text{min}^{-1}$ after training in the AIT group ($p<0.05$). In the MST group no change in peak cardiac output was detected from before to after training (10.7 ± 2.1 – $10.5\pm2.0\text{ L}\cdot\text{min}^{-1}$). There was no significant difference in peak cardiac output between the 2 training groups before training, but after training it was significantly higher in the AIT group ($p<0.05$).

VO_{2peak} was significantly improved by 17% in the AIT group after training, a significantly greater change compared to the MST group ($p<0.05$) where no change was detected from pre to post training (● Table 2). The AIT group significantly increased peak treadmill work load by 25% from 163 ± 29 to 203 ± 22 watts from before to after training. Peak work load at post test were significantly greater than in the MST group where work loads of 202 ± 37 and 208 ± 38 were recorded before and after training ($p<0.05$). The peak values for lactate and ventilation increased significantly from before to after training in the MST group (● Table 2), while the Borg scale score increased significantly

	Endurance training (n=8)		Strength training (n=10)	
	Before	After	Before	After
oxygen uptake				
L · min ⁻¹	2.20±0.54	2.59±0.64* #	2.43±0.49	2.48±0.53
mL · kg ⁻¹ · min ⁻¹	27.2±4.5	31.8±5.0* #	28.9±4.2	29.6±5.2
heart rate (beat · min ⁻¹)	163±21	162±17	143±20	143±19
ventilation (L · min ⁻¹)	89±17	97.0±23	88±13	94±10*
respiratory exchange ratio	1.13±0.05	1.17±0.06	1.15±0.07	1.18±0.06
lactate (mmol · L ⁻¹)	4.5±1.0	6.3±1.6	5.0±1.9	7.2±1.8*
Borg scale	15±2	17±1* #	16±2	17±1

Data is presented as mean and SD for each variable

* P<0.05 changes within group before vs. after training, # P<0.05 changes in the ET group vs. the MST group

Table 2 Peak data before and after training.

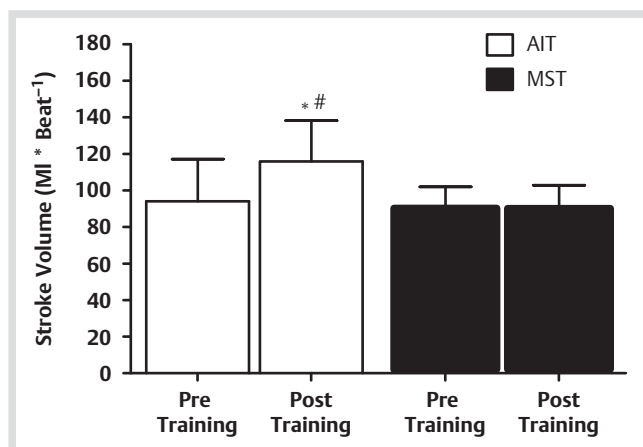


Fig. 1 Peak stroke volume before and after training, in the aerobic interval training (AIT)- and the maximal strength training group (MST). * P<0.05 changes within group before vs. after training, # P<0.05 changes in the AIT group vs. the MST group.

Table 3 Measurements of resting cardiac function by MRI in the endurance training group before and after the training intervention (n=8).

	Before	After
left ventricular end diastolic volume (mL)	137.1±24.1	136.7±28.8
left ventricular end systolic volume (mL)	52.4±17.2	48.7±18.2
stroke volume (ml · beat ⁻¹)	84.8±9.6	88.0±14.0
cardiac output (L · min ⁻¹)	6.2±0.8	6.1±1.1
heart rate (beat · min ⁻¹)	74.5±15.9	70.5±16.2
left ventricular ejection fraction (%)	62.3±6.5	65.4±7.2
left ventricular mass (g)	112.6±14.8	115.5±18.0

Data is presented as mean and SD for each variable

from before to after training in the AIT group with a larger change than in the MST group (● Table 2).

In the AIT group, measurements of left ventricular function by magnetic resonance imaging displayed a trend towards higher resting left ventricular ejection fraction, from 62.3±6.5% before to 65.4±7.2% after training (p=0.06) (● Table 3). A non-significant trend towards decreased end systolic volume and heart rate, as well as increased stroke volume was also found. Resting left ventricular end diastolic volume, cardiac output, and left ventricular mass were unchanged after training.

The MST group improved leg press strength significantly. Maximal leg strength improved from 138±24kg before training to 198±24kg after training (● Fig. 2), rate of force development improved from 2656±1090 N · s⁻¹ before training to 4905±1254 N · s⁻¹ after training, and sub maximal walking efficiency improved from 18±4% before training to 25±6% after training

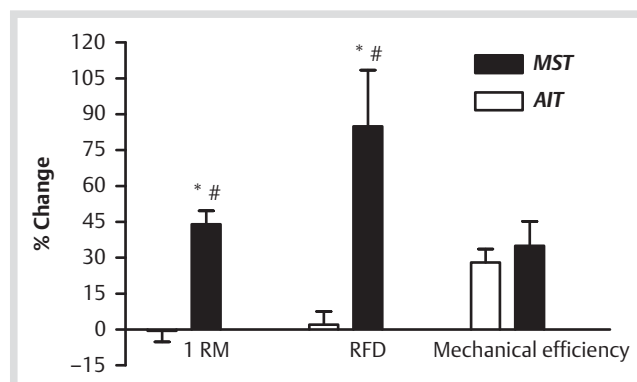


Fig. 2 Percent change in maximal leg strength (1RM), rate of force development (RFD) and walking mechanical efficiency from before to after training in the maximal strength training group (MST) and the aerobic interval training (AIT) group. * P<0.05 changes within group before vs. after training, # P<0.05 changes in the MST group vs. the AIT group.

(p<0.01). Maximal leg strength and rate of force development were unchanged in the AIT group from pre to post training, however walking mechanical efficiency improved from 19±4% before training to 25±5% after training (p<0.05) (● Fig. 2). Several scores for quality of life were significantly improved from before to after training within each exercise group. In the AIT group there was a 9%, 13%, and 10% improvement for the scores for total, physical and social quality of life detected by the MacNew questionnaire (p<0.05). In the MST group the social score detected by the MacNew questioner improved by 8% (p<0.05). There were no significant differences between groups in the change in quality of life measurements from before to after training.

Discussion

The main finding in the present study was that 8 weeks of high aerobic intensity interval training at 85–95% of HR_{peak} significantly improved peak stroke volume by 23% in CAD patients. Improved sub maximal endurance due to improved leg maximal strength and rate of force development did not improve peak stroke volume in CAD.

Endurance training is known to improve cardiac function [5,6]. High aerobic intensity interval training (4×4 min) at 90–95% of peak heart rate has been demonstrated to be more effective than moderate continuous training at 70% of peak heart rate for improving cardiac function in heart failure patients [25]. To our knowledge the present study is the first to document the effect

of 4×4 min of high aerobic intensity interval training on peak stroke volume in CAD patients with a better cardiac function (left ventricular ejection fraction ~ 62%) than reported in heart failure patients [25].

In the present study there was only a trend towards increased myocardial contractility as observed by increased resting left ventricular ejection fraction. This may serve as an explanation for the observed improvement in peak stroke volume. However, one could also argue that improving LVEF within the normal range probably has little clinical relevance [9].

In the present study resting left ventricle diastolic volume and mass were unchanged after aerobic interval training, and there was a trend towards decreased left ventricular end systolic volume with a subsequent increase in stroke volume. Heart rate decreased correspondingly, maintaining an unchanged cardiac output during rest. Left ventricular MRI measurements were done at rest, thereby the adaptation in the cardiovascular system may not be as evident as during peak exercise. Possible explanations for increased peak stroke volume may be a result of increased LVEDV effecting the Starling's law of the heart, calcium mediated changes in contractility or a adaptation in the balance between the cardiac filling time and the volume of venous return [9].

Despite improvements in sub maximal endurance measured as improved walking mechanical efficiency, peak stroke volume remained unchanged after maximal strength training in the CAD patients. Both the AIT and the MST groups increased walking mechanical efficiency after training indicating that different mechanisms may explain the adaptation seen in walking efficiency. Increased muscle strength has the potential of improving the circulatory management of day to day activities [15], and could thereby effect the afterload of the heart during exercise. Decreased afterload could potentially increase the stroke volume by lowering the pressure resistance in the main arteries. The safety of strength training in CAD patients has been debated, particularly focusing on the effect of blood pressure on cardiac function. At present, stable CAD patients are recommended to do strength training as a supplement to endurance training [18]. Judged by the present study, maximal strength training in cardiovascular disease patients does not affect stroke volume negatively.

Improved endurance through sub maximal performance may stimulate increased daily activity levels with the possible effect of increasing VO_{2peak} and cardiac function over time. In the present study neither VO_{2peak} nor peak stroke volume increased despite increased sub maximal performance. The time span of the training intervention (8 weeks) was probably too short for the improvement in sub maximal endurance to translate into increased daily activity resulting in a measurable level of VO_{2peak} . The present study documents that high aerobic intensity interval training is more effective in increasing peak stroke volume in CAD patients than through improved sub maximal endurance through strength training.

Contrary to earlier beliefs, cardiac stroke volume increases from rest until maximal performance in elite athletes, while stroke volume levels off at lower intensities in less endurance trained individuals [27]. Based on results from previous studies the level of interval intensity during training seems vital for the cardiovascular training response [10,21].

In addition to documenting changes in stroke volume, the present study confirms that high aerobic intensity interval training significantly improves VO_{2peak} in CAD patients [12,21].

The improvement in VO_{2peak} in the CAD patients in the AIT group was at the same absolute level as previously reported in healthy young men [10]. High aerobic intensity interval training improves maximal stroke volume in healthy young men as well [10]. In the present study high aerobic intensity interval training improved peak stroke volume by 21 ml/stroke, compared to ~14–15 ml/stroke in healthy young men [10]. Despite lower initial stroke volume and the presence of ischemic heart disease, CAD patients demonstrated approximately the same absolute myocardial response to high aerobic intensity interval training as healthy young men, and more importantly they are able to carry out the high aerobic intensity training despite their documented heart disease.

In the present study, the increase in stroke volume is parallel to the increase in VO_{2peak} with improvement in the magnitude of 23% in peak stroke volume and 17% in VO_{2peak} . The same pattern is reported by Helgerud et al. [10] in healthy young men where peak stroke volume increased by 10% and VO_{2max} by 7.2% after high intensity aerobic interval training. CAD patients are thereby able to carry out high aerobic intensity interval training with the same quality as healthy young men, achieving equal absolute training responses and relatively better scores due to lower fitness levels before training. The differences of the peak metabolic data before and after training in the AIT group could have been influenced by a higher degree of exhaustion after training. This is indicated by a significant higher score on the Borg scale after training (• Table 2). On the other hand no physiological parameter measured; heart rate, ventilation, RER or lactate, changed significantly from before to after training.

Stroke volume deterioration as observed with aging and heart disease may reflect increasing levels of inactivity at least before ischemia disrupts peak myocardial function. Heart patients were previously restricted from strength training due to the fear of a harmful effect on the myocardium. Today, studies on the effect of strength training on the myocardium have provided evidence of it being safe with no negative effect on myocardial contractility or enhanced myocardial deterioration [13]. The lack of response in VO_{2peak} and peak stroke volume in the strength training group supports the importance of performing high intensity endurance training for gaining cardiovascular training adaptations. Improving sub maximal endurance did not affect peak stroke volume.

Quality of life improved in both the aerobic interval training group and the strength training group indicating that shorter time periods of training may improve quality of life in CAD patients. This is an important aspect of training since better quality of life is associated with less self reported disability in heart patients [24]. The improvement in the social score in the strength training group may reflect the social aspect of supervised training during the training period.

The weakness of the present study is the low number of participants included, however the low number of patients did allow for high quality supervision during training. Also due to the long travelling distance and cost of travel only the AIT group was investigated with cardiac MRI.

Conclusion

▼
High aerobic intensity interval training significantly improves peak stroke volume and VO_{2peak} in CAD patients. Improved sub maximal endurance after maximal strength training does not improve peak stroke volume or peak oxygen uptake in CAD patients.

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