Influence of 12 Weeks of Jogging on Magnetic Resonance-Determined Left Ventricular Characteristics in Previously Sedentary Subjects Free of Cardiovascular Disease

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Hypertrophy of the left ventricle is a diagnostic dilemma in subjects who engage in regular endurance exercise. We studied prospectively whether endurance training in previously sedentary young and middle-aged men and women can alter left ventricular (LV) characteristics. We recruited 33 healthy young and middle-aged subjects (18 women, 15 men, ages 21 to 59 years) to undergo 12 weeks of home-based brisk walking and jogging at a target heart rate ≥120 beats/min for ≥30 minutes 3 times a week. LV characteristics were measured by cine magnetic resonance imaging. Training intensity as estimated by heart rate correlated positively with the increase in LV myocardial area ($r = 0.51$, $p = 0.005$) in the 28 men and women completing the study. In the 13 men and women who trained with heart rate of ≥120 beats/min, LV myocardial area was larger after than before training (17.7 ± 2.9 vs 16.8 ± 2.8 cm^2, $p < 0.05$). Moreover, in these subjects LV myocardial area increased more ($5.5 \pm 9.0\%$ vs $-3.0 \pm 5.0\%$) than in the 15 men and women who trained at a lower intensity ($p < 0.05$). LV end-systolic and end-diastolic area and ejection fraction did not change significantly. In conclusion, moderate-to-vigorous endurance training at moderate volumes does not influence LV end-diastolic volume or ejection fraction, but has a minor influence on LV hypertrophy in previously sedentary young and middle-aged men and women. © 2009 Elsevier Inc. (Am J Cardiol 2009;103:567–571)

There are only a few prospective studies that have studied the influence of aerobic training on left ventricular (LV) characteristics,[1–9] most of which have been performed using echocardiography.[1–5,7,8] Because of its high interstudy variability, however, echocardiography is not a method of choice to evaluate exercise-induced morphological alterations in the left ventricle.[10] In addition, echocardiography may be difficult to perform blindly, which may influence the measurement results. In contrast, magnetic resonance imaging (MRI) is considered to be the gold standard in the assessment of LV anatomy and function because it is accurate and reproducible.[10,11] With image archiving, image analysis can be performed completely blinded to the imaging date and subject's intervention history. Brisk walking and jogging are common endurance activities to maintain and improve health and well-being. Accordingly, the purpose of the present study was to evaluate whether 12-weeks home-based endurance training performed by jogging can induce changes in LV dimensions in normal volunteers.

Methods

Through local newspaper advertisements, we recruited subjects <65 years without chronic diseases or medication. Of the 64 eligible subjects, 34 subjects were randomly selected for the study. The training program consisted of home-based brisk walking and jogging. The subjects received guidance and motivation about the training program from a physician with experience in endurance running at the beginning of the study and as needed. Training began with brisk walking 3 times a week at a target heart rate of 120 beats/min, with instructions to supplement walking with jogging to maintain the heart rate >120 beats/min as the subjects became accustomed to training. The subjects were encouraged to gradually increase training to 4 to 5 times per week if possible. All subjects used a heart rate monitor that recorded the heart rate minimum and maximum during the training session (Polar Electro, Kempele, Finland). The subjects were asked to record the duration of training and the heart rate minimum and maximum in an exercise logbook.

MRI was performed before and after exercise training program by 1 physicist (JH) with 1 year of experience in cardiac MRI using a 1.0-T clinical MRI unit (Magnetom, Siemens Medical Systems, Erlangen, Germany). To determine interstudy reproducibility, 10 subjects were reexamined in 1-week intervals. Routine daily quality assurance measurements were conducted on the MRI equipment according to the vendor's recommendations. A phased-array body coil was used as the receiver. After initial images were taken, 8-mm sections with no intersection gap were acquired in the short-axis plane, from the base to the apex of

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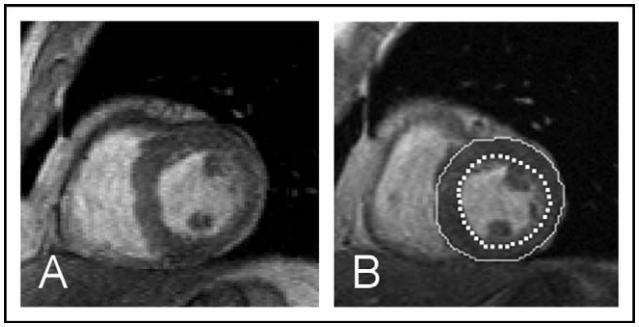

Figure 1. Typical midcavity end-diastolic cine images. Both images are from the same subject. One image was obtained before *(A)* and another after 12-weeks exercise training *(B)*. Image analysis was performed to the set of both images simultaneously, but analyzer was blinded which of the images was obtained before and which after the training. The analyzer manually planimetered the endocardial (dotted line in *B*) and epicardial surfaces (continuous line in *B*).

the heart, using a turbo fast low-angle shot sequence. The parameters for cine MRI were as follows: 56/6.1 (repetition time/echo time in ms) with fivefold k-space segmentation, a 20° flip angle, a 256 × 256 data matrix, 360-mm field of view, and a pixel size of 1.4 × 1.4 mm in the LV short-axis orientation. The subjects were imaged during multiple breath holds (1 section acquired per breath hold). The average length of time for a breath hold was 20 seconds.

The same radiologist with 6 years of experience of cardiac MRI (PS) performed all of the anatomic measurements on the images using Numaris software (Siemens, Erlangen, Germany). Within a 1-week interval image analysis was performed in a different city than imaging without any information on whether imaging was performed before or after exercise training or whether imaging was done for repeatability purposes. Image analysis was performed at the short-axis orientation using 1 short-axis tomogram obtained at the papillary muscle level. A section that had excellent image quality and that was in the identical anatomical position in both imaging sessions was selected for image analysis (Figure 1). The congruence between levels at follow-up was assured by selecting the slices with identical size and shape at the level of the papillary muscles. In image analysis, the endocardium and the epicardium were manually traced, with the papillary muscles and the trabeculations excluded on end-diastolic and end-systolic images. The end-diastolic image was the first image acquired after the R wave of the electrocardiographic signal, and the end-systolic image was the image showing the smallest LV area. Myocardial area was calculated by subtracting the epicardial area from the endocardial area. The representativeness of LV mass measured by single-slice for LV mass was studied by comparing single-slice LV myocardial area to 3-dimensional (3D) LV myocardial area in 29 subjects without cardiac medication or aortic stenosis (16 women, 13 men, ages 23 to 60 years). Technical parameters of MRI and image analysis for 3D myocardial area measurements has been previously described in detail.[12] End-diastolic - end-systolic area difference was calculated by subtracting the LV end-systolic endocardial area from the LV end-diastolic endocardial area. Ejection fraction index was calculated as the end-diastolic - end-systolic area difference divided by the end-diastolic endocardial area.

Table 1
Characteristics of study subjects, exercise training, and left ventricle according to cardiac magnetic resonance imaging (n = 33)

Men/Women	15/18
Body mass index (kg/m^2)	25.2 ± 4.2 (19.7–43.5)
LV characteristics	
Myocardial area (cm^2)	17.1 ± 2.4 (13–23)
End-diastolic area (cm^2)	23.6 ± 3.6 (18–34)
End-systolic area (cm^2)	12.6 ± 2.1 (10–34)
End-diastolic - end-systolic area difference (cm^2)	10.9 ± 2.4
Ejection fraction index (%)	46 ± 6

Data are presented as mean values ± SDs; data in parentheses are ranges. LV characteristics were measured from a single short-axis slice at the level of papillary muscles.

Table 2
Subject, training, and left ventricular (LV) characteristics in subjects who trained at a minimal heart rate ≥120 beats/min and in those who trained at a minimal heart rate of <120 beats/min

Characteristic	≥120 beats/min	Other Subjects
Men/Women	5/8	7/8
Age (yrs)	46 ± 11	40 ± 12
Body mass index (kg/m^2)	25 ± 3	24 ± 3
Number of training sessions	43 ± 10	38 ± 10
Heart rate minimum (beats/min)	123 ± 8	98 ± 14*
Heart rate maximum (beats/min)	147 ± 5	145 ± 23
Changes in LV characteristics		
Myocardial area		
Absolute (cm^2)	0.8 ± 1.3	–0.5 ± 0.8†
Percentage (%)	5.5 ± 9.0	–3.0 ± 5.0*
End-diastolic area (cm^2)	–0.6 ± 2.4	–0.2 ± 1.8
End-systolic area (cm^2)	0.0 ± 1.9	0.1 ± 1.5
End-diastolic - end-systolic area difference (cm^2)	0.8 ± 1.7	–0.3 ± 1.5
Ejection fraction index (%)	–2 ± 7	–1 ± 5

Data presented as means ± SDs.
* $p < 0.001$; † $p < 0.01$.

The Wilcoxon test was used to assess differences in LV characteristics before and after exercise training program. The Mann-Whitney test was used to to assess differences in LV characteristics in subjects who trained with heart rate ≥120 beats/min and other subjects. Associations between exercise training intensity and LV myocardial characteristics were assessed using the Spearman rank correlation. Interstudy repeatability was estimated by calculating within-subject coefficient of variation expressed as percentages.[13] The statistical power of the study was calculated with the power set to 0.80 and the significance level set to 0.05.[14] The correlation of a LV mass measured by single-slice with 3D LV mass was studied with linear regression analysis. The power calculation and within-subject coefficient of variation (CV) analysis was performed with computer software (Excel for Windows 2003, Microsoft, Redmond, Washington). Other statistical analyses were performed with SPSS Windows 9.0 (SPSS, Chicago, Illinois). Data are presented as means ± SDs.

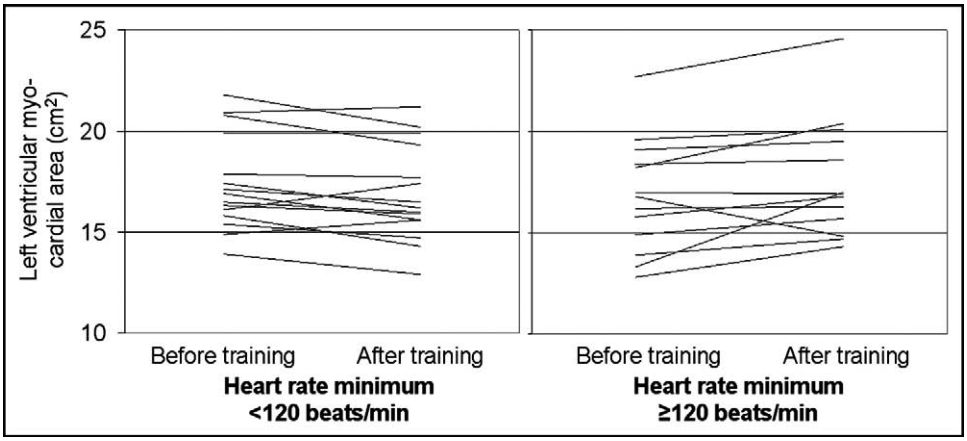

Figure 2. Graphs illustrate LV myocardial area before and after 12-weeks exercise training in subjects who trained with heart rate minimum <120 beats/min and in subjects with heart rate ≥120 beats/min.

Table 3
Spearman rank correlation coefficients for associations between exercise training intensity and change in left ventricular (LV) characteristics before and after training

	LV End-Diastolic Area	LV Myocardial Area	LV End-Systolic Area	LV Ejection Fraction Index
Number of training sessions	–0.009	0.052	0.152	–0.064
Heart rate minimum	–0.243	0.512*	–0.036	–0.073
Heart rate maximum	0.005	–0.066	0.241	–0.325

* p <0.01.

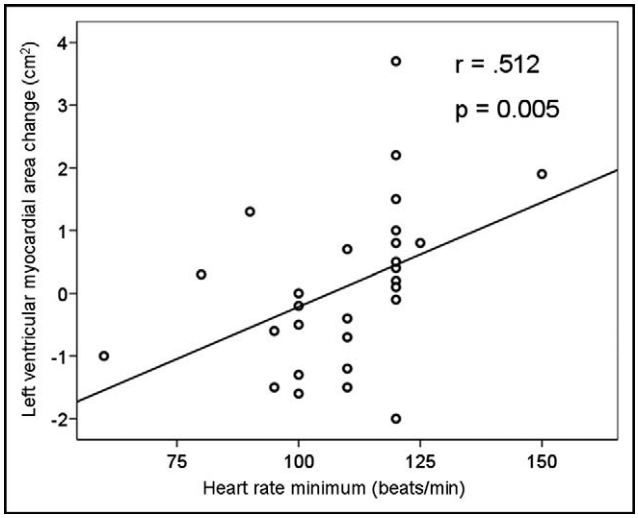

Figure 3. Scatterplot shows the associations of LV myocardial area change during 12 weeks of exercise training with the minimum heart rate during training.

Results

Of the 33 subjects 18 were women (55%). The mean age of the subjects was 42 years (range 22 to 55). The mean body mass index was 25 kg/m^2. The mean number of training sessions during the training period was 41 ± 9 times (range 29 to 55). The mean minimum and maximum heart rate during exercise was 117 ± 13 beats/min (range 100 to 150) and 147 ± 12 beats/min (range 130 to 180), respectively; 28 subjects maintained an exercise logbook.

Table 4
Results of reproducibility measurements

Measurement	First Measurement	Second Measurement	CV%*	SD†
LV end-diastolic area (cm^2)	23.0 ± 3.0	23.1 ± 3.8	7.9%	2.7
LV myocardial area (cm^2)	17.7 ± 2.8	17.3 ± 2.8	5.3%	1.3
LV end-systolic area (cm^2)	12.5 ± 2.4	12.6 ± 2.8	7.4%	2.2
Ejection fraction index (%)	45.5 ± 8.0	45.0 ± 9.5	8.5%	5.7

For 10 subjects measurements were taken twice within 1 week.
* CV, coefficient of variation.
† SD of the difference between first and second measurement.

Recordings affirmed the correct exercise intensity during home training in 13 subjects (38%).

Single-slice myocardial area measurements correlated closely with 3D measured LV myocardial volume in linear regression analysis (r = 0.92; p <0.001). Table 1 shows LV characteristics before exercise training in all study subjects. The mean LV ejection fraction index measured by area change in the short-axis orientation only was smaller than the normal value for MRI-derived 3D ejection fraction.[15]

In the entire group, no significant changes in LV mass, end-systolic or end-diastolic volume, or ejection fraction index during the training period was found (data not shown). However, the LV myocardial area increase was larger in subjects who trained with a minimal heart rate ≥120 beats/min than in those who trained at a lower intensity (Table 2 and Figure 2). LV myocardial area increased in 11 of 13 subjects (85%) who trained at 120 beats/min or more, but in only 3 of 15 subjects (20%) who trained at a lower intensity (p = 0.002). The increase in myocardial area in subjects who trained with a minimal heart rate ≥120

beats/min corresponds to a <0.4-mm increase in LV mean wall thickness if the increase in LV wall thickness increment was distributed evenly around the free wall and septum. LV end-diastolic endocardial area, a proxy of LV end-diastolic volume, increased in 6 of 13 subjects (46%) who trained at ≥120 beats/min and in 5 of 15 subjects (33%) who trained at a lower intensity (difference not significant). The changes in LV end-diastolic or end-systolic volumes or ejection fraction index with training did not differ between those who trained at ≥120 beats/min and those who trained at a lower intensity (Table 2). The change in LV myocardial area was associated with the minimum heart rate during training (Table 3 and Figure 3). Training intensity and frequency was not associated with changes in other LV characteristics.

Based on the reproducibility analyses (Table 4) and that 13 subjects trained according to the protocol, the study protocol enabled the detection of a change of 1.9 cm^2 (8%) in LV end-diastolic area, 1.1 cm^2 (6%) in LV myocardial area, 1.3 cm^2 (10%) in LV end-systolic area, and 3% change in LV ejection fraction index.

Discussion

This is the first study investigating by MRI the influence of brisk walking and jogging on LV characteristics in healthy, previously sedentary volunteers. We found that when previously sedentary subjects carried out a 12-week period of fitness training at a heart rate ≥120 beats/min 3 times a week in 30 minute sessions, LV myocardial area, a marker of LV mass, increased. LV area increased in 85% of subjects who trained with LV minimum heart rate ≥120 beats/min, but in only 20% of others, suggesting that a heart rate ≥120 beats/min was needed to stimulate LV myocardial mass growth. Although the age of the subjects varied, 120 beats/min corresponds to about 70% of the estimated maximal heart rate based on age, implying that sustained physical activity of at least moderate intensity is necessary to induce LV hypertrophy. Our results are consistent with 2 studies showing that 2 to 3 months of moderate-to-vigorous bicycle ergometry and rowing increase LV mass as estimated by MRI.[6,9]

The reported compliance with the frequency of training and the duration of the exercise sessions did not differ between those who maintained a minimum heart rate during exercise of 120 beats/min and those who did not. On average, no increase in LV mass was noted in those who reported a minimum heart rate of <120 beats/min (on average 98 beats/min or about 54% of the estimated maximal heart rate), again suggesting that sustained physical activity of at least moderate intensity is needed to consistently induce LV hypertrophy at the exercise volumes that were prescribed in this study.

We did not find an increment in LV end-diastolic or end-systolic size after 12 weeks of exercise training. LV end-diastolic volume seemed to increase more often in subjects who trained at a heart rate ≥120 beats/min, but this difference was not statistically significant. Based on statistical power calculations, our analysis would have been able to find an 8% increase in LV end-diastolic area.

Previous findings of changes in the LV end-diastolic and end-systolic volume are conflicting. LV end-diastolic cavity as assessed by MRI did not increase after 3 months of bicycle ergometer training,[6] but LV end-diastolic diameter increased after 3-month jogging training as assessed by echocardiography,[16] and LV end-diastolic volume increased by 7% after 8 weeks of rowing ergometer training as studied by MRI.[9] The conflicting findings may be related to differences in training methods.

LV mass and end-diastolic volumes as assessed by MRI has been higher in elite cyclists than in control subjects, but LV ejection fraction did not differ significantly from those of controls.[17] Our finding that exercise training did not change ejection fraction index is in accordance with previous echocardiographic and MRI studies.[9]

Previously, most information on the effects of training on the heart has been gathered by echocardiography in competitive athletes. Echocardiography is not a suitable method to study the effect of exercise on LV characteristics because of the large interstudy variability. MRI is substantially more reliable in the measurement of LV anatomy and function.[10] In some echocardiographic studies LV end-diastolic volume has increased even in some small study samples after short term training.[4,7] This is surprising because the statistical power of echocardiographic studies is far lower than for MRI.[10] Moreover, in contrast to MRI, echocardiographic studies cannot easily be performed blindly.

We found a <0.4-mm increase in LV thickness that was estimated based on area measurements. This is in accordance with a meta-analysis in which the interventricular septum thickness differed by slightly >1.0 mm between sedentary controls and competition-level endurance-athletes.[17] To detect such small increases in LV wall thickness in response to training would require substantially larger numbers of subjects due to measurement variability. Measurement of myocardial area is therefore the preferable measurement of wall thickness.

We performed image analysis in the short-axis orientation at the basal part of papillary muscles. This level is the most accurate region for image analysis because the normal LV is uniformly round at this area, and the LV outflow tract does not influence LV morphology. This level is also commonly affected by LV hypertrophy in patients and is likely to be sensitive to the physiological adaptation of the heart to the increased hemodynamic stresses of endurance training. Measurement of area in the short-axis orientation at the basal level overcomes the problems of LV myocardial delineation in most basal and apical slices. The method also has high repeatability. The limitation of the method using 1 short-axis level only is that the increase in the length of the left ventricle is not considered. Repeatability of single-slice measurements were, however, comparable with measurements of the entire left ventricle.[11]

In end-systole, papillary muscles can be in contact with the endocardial wall, which may cause difficulties in the detection of endocardium. This may explain the somewhat higher interstudy variability in reproducibility area measurements in the end-systolic phase.

In our study only 1/3 of the subjects completed the 12-week training according to guidelines. This demonstrates the need for training diaries and objective exercise monitoring to determine compliance with the exercise

goals. Without heart rate monitoring we could not have detected subjects who trained according to guidelines. To achieve continuous active training in sedentary subjects during an extended time period is a challenge for research and health promotion.

Moderate quantities of moderate-to-vigorous exercise training performed by healthy previously sedentary subjects has no or minor influence only on LV end-diastolic volume, and except in borderline cases it should not be considered as a reason for LV cavity enlargement in patients who engage in noncompetitive aerobic exercise. Training has some influence on LV mass. However, it is unlikely that cut-off limits for normality should be changed in patients who engage in noncompetitive sports. It should be noted, however, that the increment in LV wall thickness can be unevenly distributed so that thickening in LV septum may be higher than the 0.4 mm estimated in the present study. It is also possible that longer periods of training could have more pronounced effects on LV structure, but even in competitive endurance athletes the changes are not very large.

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