Non-invasive evaluation of cardiac function in professional cyclists

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SUMMARY Cardiac dimensions and left ventricular function were investigated at rest with non-invasive methods in 14 professional road race cyclists and in 11 age-matched sedentary control subjects.

The electrocardiographic findings were in agreement with previous studies in endurance athletes and the vectocardiographic data showed anterior displacement of the electrical forces.

Echocardiographic dimensions at end-diastole showed higher values in the cyclists for left ventricular internal diameter, left ventricular posterior wall thickness, and interventricular septal thickness. Derived values for left ventricular volume and left ventricular mass were also much larger in the cyclists and there was excellent agreement between total heart volume measured with radiology and total left ventricular volume measured by echocardiography.

There was a significant correlation between maximal oxygen consumption and end-diastolic left ventricular diameter.

The term “athlete’s heart” is used to describe a variety of alterations in the cardiac function of athletes engaged in vigorous competitive sports. These anomalies include bradycardia, often associated with intermittent tachyarrhythmias, repolarisation abnormalities, systolic murmurs, gallop rhythm, and ventricular hypertrophy.

Previous studies suggested that the response of the heart to “endurance” sports was ventricular enlargement without thickening of the wall, whereas the response to “resistance” or “isometric” sports was thickening of the ventricular wall without an increase in size.¹

Recently, however, other investigators found both an enlarged ventricular cavity and an increased wall thickness in endurance athletes such as long distance runners.² ³

The controversy may be partly explained by differences in the type of sport and in the performance level of the athletes under study, and by differences in the habitual activity and exercise performance of the control subjects.

To get a better insight into the “athlete’s heart” more data are needed on top class athletes specifically engaged in “endurance” or “resistance” sports.

The purpose of the present study was to investigate the cardiac dimensions and left ventricular function in a selected group of highly trained endurance athletes (professional cyclists) and in a group of age-matched sedentary control subjects.

Methods

Fourteen professional road race cyclists were studied after they had been participating for at least three months in the current season’s competitions. Their average age was 25 years (range 21 to 29 years).

The control group consisted of 11 medical students matched for age with the professional cyclists, who had been selected on the basis of a questionnaire to find out whether or not they had been involved in any regular or intense sporting activity during the previous 12 months.

None of the subjects had a relevant past medical history, or was taking any medication. Both groups were investigated at the same time and the following examinations were performed in all subjects.

MEDICAL HISTORY AND PHYSICAL EXAMINATION
Routine measurements and calculations included total body weight, height, surface area, and body fat content which was estimated from measurements of skinfold thickness obtained at 10 different sites...
and using the regression equation of Pañizkova.4

Frontal and lateral chest x-rays were taken to evaluate the heart volume.5

A 12 lead electrocardiogram and a vectorcardiogram were recorded using Frank's lead system with electrodes in the fifth anterior intercostal space. The three orthogonal leads were recorded simultaneously on magnetic tape to be processed later by the Pipberger program 3-6 on an HP computer. The computer generated data were validated by three investigators. For the diagnosis of left and right ventricular hypertrophy, the electrocardiographic criteria of Sokolow and Lyon6 7 and the vectorcardiographic criteria of Pipberger et al.8 were used.

A standard M-mode echocardiogram was recorded with an Organon Echo-cardiovisor-03 using a 2-25 MHz transducer with a diameter of 1-5 cm, and recorded with a Honeywell LS 6 HA Visorecorder on light sensitive paper. The measurements were recorded in the supine position, with the head of the bed raised about 30°. The transducer was placed on the chest wall in that intercostal space where maximum amplitude of the mitral valve was recorded. The transducer was held perpendicular to the chest wall and as close as possible to the left sternal border and then moved to search the standard left ventricular area.

Left ventricular internal diameter, left ventricular posterior wall thickness, interventricular septal thickness, and left atrial diameter were calculated at end-diastole and at end-systole from the echocardiographic measurements. The left ventricular internal diameter at end-diastole was divided by the body surface area to obtain the left ventricular internal diameter end-diastole index. Left ventricular volumes and mass measurements were derived by standard techniques using the cubed function. The ejection fraction, fractional shortening, and mean velocity of circumferential fibre shortening were calculated using classical criteria.9 10

For all measurements the mean of five beats was calculated, all echocardiograms were read independently by three different investigators, and the results were averaged.

The physical work capacity was evaluated with a bicycle ergometer using the standard test procedure of Hollmann11 with increase of the exercise load by 40 Watt every three minutes. Heart rate was calculated from the continuously monitored electrocardiogram. Oxygen consumption and CO₂ production were measured with open circuit ergospirometry using a Jaeger Pneumotest with a Dataspir Junior EDV-6 data processing system (Eric Jaeger, Wurzburg, West Germany). Physical work capacity at a heart rate of 170 beats/min (PWC 170) was calculated by interpolation from heart rate values at submaximal loads. Subjects were encouraged to continue until exhaustion to determine their maximal work capacity (max. Watt) and their maximal oxygen consumption (VO₂ max.). For statistical analysis the Wilcoxon test was used, and regression equations were used for the study of correlations.

Results

The physical characteristics of the athletes and the results of the exercise test are given in Table 1.

Athletes and control subjects were age-matched. The heights were not significantly different in the two groups but the athletes were significantly heavier than the control subjects and they had a lower percentage of body fat.

Resting heart rate was significantly lower in athletes than in the control subjects. Maximal heart rate was slightly but not significantly lower. Maximal oxygen consumption and maximal power were significantly higher in the athletes and the physical work capacity at a heart rate of 170 beats per minute was nearly twice the value observed in the control subjects.

The electrocardiogram showed left ventricular hypertrophy in 12 athletes and in one of these right ventricular hypertrophy was also present. Four athletes had signs of incomplete right bundle-branch block and two showed left posterior hemiblock, one of these also being detected by vectorcardiography. All athletes showed an increase of the J point and ST segment, and tall T waves. No arrhythmias were observed. None of the controls

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical characteristics and exercise test in athletes and control subjects</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Athletes n = 14</td>
</tr>
<tr>
<td>Age (y)</td>
<td>25 ± 2/2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177 ± 6/5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.9 ± 6/5</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>11.4 ± 1.3</td>
</tr>
<tr>
<td>Resting heart rate (beats/min)</td>
<td>50 ± 5</td>
</tr>
<tr>
<td>Maximal heart rate (beats/min)</td>
<td>186 ± 7</td>
</tr>
<tr>
<td>Maximal oxygen consumption (ml/min)</td>
<td>4860 ± 345</td>
</tr>
<tr>
<td>Maximal oxygen consumption (ml/kg per min)</td>
<td>67 ± 6</td>
</tr>
<tr>
<td>PWC (170) (Watt)</td>
<td>333 ± 34</td>
</tr>
<tr>
<td>Maximal power (Watt)</td>
<td>442 ± 38</td>
</tr>
</tbody>
</table>

Values are means ± SD.
showed significant abnormalities on the electrocardiogram.

The most relevant indices from the vectorcardiogram are given in Table 2. Typical changes observed in athletes were a prolonged QT interval, an increased amplitude of the R wave in leads X and Y, an increased summation Rx+Rz, and an increased ratio of Q/R in lead Z. The amplitude of the T wave in lead X was augmented, the J point raised, and the amplitudes of QRS and T max. were increased. There was also an anterior displacement of the QRS maximum vector, and inversely a posterior displacement of the T maximal vector in the horizontal projections. The spatial data are in agreement with azimuths of QRS and T behaving as the horizontal maximal vectors while the spatial maximal amplitude was increased in the same way as the planar amplitudes. Finally, the spatial QRST angle was smaller in athletes than in the control group. Nine athletes showed signs of left ventricular hypertrophy and two of right ventricular hypertrophy. The control subjects showed no significant abnormalities on the vectorcardiogram.

The echocardiographic data are shown in Table 3. The left ventricular internal diameter at end-diastole and at end-systole, and the corresponding

<table>
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<tr>
<th>Table 3</th>
<th>Echocardiographic data in athletes and in control subjects</th>
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<tbody>
<tr>
<td></td>
<td><strong>Athletes</strong></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>52 ± 5</td>
</tr>
<tr>
<td>Left ventricular internal diameter (mm)</td>
<td>59.8 ± 2.5</td>
</tr>
<tr>
<td>End-diastole</td>
<td>38.1 ± 2.8</td>
</tr>
<tr>
<td>End-systole</td>
<td>215.0 ± 26.5</td>
</tr>
<tr>
<td>Left ventricular volume (ml)</td>
<td>55.6 ± 12.5</td>
</tr>
<tr>
<td>End-diastole</td>
<td>31.48 ± 2.92</td>
</tr>
<tr>
<td>Left ventricular posterior wall thickness (mm)</td>
<td>11.9 ± 1.2</td>
</tr>
<tr>
<td>End-systole</td>
<td>18.6 ± 1.5</td>
</tr>
<tr>
<td>Interventricular septal thickness (mm)</td>
<td>12.4 ± 1.0</td>
</tr>
<tr>
<td>End-diastole</td>
<td>17.9 ± 1.5</td>
</tr>
<tr>
<td>Thickness ratio of septum/posterior wall</td>
<td>1.05 ± 0.07</td>
</tr>
<tr>
<td>Left atrial diameter (mm)</td>
<td>40.9 ± 2.8</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>73 ± 4</td>
</tr>
<tr>
<td>Mean velocity of circumferential fibre shortening (circumferences/s)</td>
<td>1.20 ± 0.14</td>
</tr>
<tr>
<td>Fractional shortening (%)</td>
<td>36 ± 4</td>
</tr>
</tbody>
</table>

Values are means ± SD.

left ventricular volumes were significantly greater in athletes than in the control subjects, as was the left ventricular internal diameter index at end-diastole.

Septal and posterior wall thicknesses were significantly increased in athletes, but no significant difference was found between the two groups for the thickness ratio of septum/posterior wall. Ejection fraction, fractional shortening, and mean velocity of circumferential fibre shortening were not significantly different.

Total left ventricular volume and total left ventricular mass, calculated from the echocardiographic findings, were considerably larger in the athletes than in the control subjects, and the differences persisted when these values were corrected for body weight or body surface area (Table 4).

The total heart volume assessed on x-ray film was significantly greater in athletes when measured both directly and when corrected for body weight or body surface area (Table 4).

There was a good correlation between total left ventricular volume measured by echocardiography, and total heart volume measured with radiology (r = 0.90) (Fig. 1).
There was a statistically significant correlation between the echocardiographically measured left ventricular internal diameter index at end-diastole and maximal oxygen consumption ($r = 0.63$; $p < 0.001$) (Fig. 2).

**Discussion**

Since maximal oxygen consumption is dependent not only on the habitual level of physical activity but also on the type of sporting activity and the athletes’ performance level,$^{12}$ it is important to define clearly both the “athletes” and the “control” subjects.

The results of the anthropometric measurements and the values obtained during the maximal exercise test are consistent with those previously described (Table 1). A low percentage body fat is a typical finding in well-trained endurance athletes.$^4$

The low resting heart rate and the high values obtained for maximal oxygen consumption, physical work capacity (PWC 170), and maximal power during the exercise test are in agreement with the values obtained by other authors in European road race cyclists.$^{13,14}$ Maximal oxygen consumption ($67 \pm 6$ ml/kg per min) is slightly lower than the values reported for world class road race cyclists by Saltin and Astrand$^{13}$ and by Hollmann$^{16}$ (75 to 80 ml/kg per min). This is probably because our group of athletes consisted of all the members of one single team rather than the best single cyclists from different teams.

The exercise values obtained in the control subjects are similar to the values obtained by other investigators in untrained subjects of similar age.$^{16}$

**Table 4**  
*Total cardiac dimensions in athletes and in control subjects*

<table>
<thead>
<tr>
<th></th>
<th>Athletes</th>
<th>Controls</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n=14$</td>
<td>$n=11$</td>
<td></td>
</tr>
<tr>
<td>Total left ventricular volume on echocardiography (ml)</td>
<td>585 ± 63</td>
<td>301 ± 65</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ml/kg BW</td>
<td>8.1 ± 0.9</td>
<td>4.7 ± 1.0</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ml/m² BSA</td>
<td>309 ± 32</td>
<td>171 ± 35</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Total left ventricular mass on echocardiography (g)</td>
<td>388 ± 53</td>
<td>197 ± 38</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>g/kg BW</td>
<td>5.4 ± 0.7</td>
<td>3.1 ± 0.6</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>g/m² BSA</td>
<td>205 ± 26</td>
<td>112 ± 22</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Total heart volume on x-ray (ml)</td>
<td>1130 ± 130</td>
<td>660 ± 150</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ml/kg BW</td>
<td>15.5 ± 1.5</td>
<td>10.1 ± 1.4</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ml/m² BSA</td>
<td>595 ± 58</td>
<td>370 ± 64</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

Values are means ± SD in absolute terms and related to body weight (BW) or body surface area (BSA).

The resting scalar electrocardiogram of endurance athletes has been intensively studied before, and the findings of the present study are generally in agreement with previous studies.$^{17-19}$ A high incidence of left ventricular hypertrophy, incomplete right bundle-branch block, and typical signs of increased vagal tone with an increase in the J and ST segment together with peaked T waves were found in this study. Vectorcardiography confirmed left ventricular hypertrophy in most cases and also showed posterior hemiblock in two. The criteria described by Sokolow and Lyon$^6,7$ for the diagnosis of left and right ventricular hypertrophy on the electrocardiogram may give some false positive results when applied to younger people but this should not invalidate the comparison between the athletes and the control group in the present experiments.

Summarising the vectorcardiographic data of the professional cyclists, a striking anterior displacement of the QRS loop was seen (Table 2). There was a definite increase in the maximal spatial and planar QRS and T vectors and a decrease in the QRST angle. These data confirm the hypothesis of Leclercq $et$ $al.$ who suggested an anterior displacement of the electrical forces in endurance sportsmen.$^{20-22}$

Earlier echocardiographic studies suggested that the heart responds differently to different types of
Cardiac function in athletes

Endurance athletes, such as runners and swimmers, were thought to develop ventricular dilatation rather than hypertrophy whereas athletes engaged in sports with a large isometric component, such as wrestlers and shot putters, were said to develop hypertrophy but not dilatation.

The echocardiograms in our group of athletes, however, showed both an increased wall thickness and an enlarged left ventricular cavity (Table 3) when compared with the control subjects. Since road race cyclists can be considered as typical endurance athletes, the results of our experiments suggest that the pattern of left ventricular hypertrophy in athletes is not so specific as previously reported. Other investigators have found both an enlarged ventricular cavity and an increased wall thickness in endurance athletes such as long distance runners which agrees with the present findings in professional cyclists. Furthermore, DeMaria et al. have recently shown that a programme of endurance physical conditioning can increase both left ventricular cavity size and wall thickness in healthy young subjects.

The values obtained for left ventricular internal diameter and for left ventricular volume at end-diastole in the cyclists are larger than the values reported in long distance runners and basketball players, which emphasises the high degree of cardiac dilatation in well trained professional road race cyclists. Left ventricular wall thickness at end-diastole is less in our cyclists than in wrestlers and shot putters. The increased left ventricular volume at end-systole does not indicate an impaired left ventricular function since ejection fraction, fractional shortening, and mean velocity of circumferential fibre shortening were not significantly different from the values observed in the control subjects.

Total left ventricular volume, total left ventricular mass, and total heart volume were considerably larger in the professional cyclists than in the control subjects in absolute terms, and the differences between the groups persisted when the values were corrected for body weight or body surface area (Table 4).

Total left ventricular mass in the cyclists is greater than the values reported for long distance runners and is even larger than the values reported in wrestlers and shot putters. The radiographically determined total heart volumes are comparable to the values reported by Israel and Weber and the values of the sedentary control subjects are in the lower range of the normal values.

It must be emphasised that there was a good correlation \( r = 0.90 \) between total heart volume measured with the radiological method and total left ventricular volume measured by echocardiography (Fig. 1).

Since there is a relation between heart volume, maximal cardiac output, and maximal oxygen consumption in healthy young subjects, the greater maximal oxygen consumption of our athletes could result from their enlarged ventricular cavity.

There was a significant correlation \( r = 0.63; \ p < 0.001 \) between the echocardiographically measured left ventricular internal diameter index at end-diastole and maximal oxygen consumption (Fig. 2), which is in agreement with the results of Zeldis et al. in female athletes and control subjects. The groups, however, were too small to establish this correlation separately in the athletes and in the controls.
Conclusion

The electrocardiographic and vectorcardiographic findings in professional road race cyclists are generally in agreement with data from previous studies on endurance athletes. The heart volume is enlarged and the echocardiographic findings show both an increased wall thickness and an enlarged ventricular cavity. This suggests that the pattern of left ventricular hypertrophy in athletes is not as specific as previously suggested.

References

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7 Sokolow M, Lyon TP. The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. Am Heart J 1949; 37: 161-86.

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