The Athlete’s Heart: A Meta-Analysis of Cardiac Structure and Function
Babette M. Pluim, Aeilko H. Zwinderman, Arnoud van der Laarse and Ernst E. van der Wall

Circulation 2000;101;336-344
Circulation is published by the American Heart Association. 7272 Greenville Avenue, Dallas, TX 75231
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The Athlete’s Heart
A Meta-Analysis of Cardiac Structure and Function

Babette M. Pluim, MD; Aeilko H. Zwinderman, PhD; Arnoud van der Laarse, PhD; Ernst E. van der Wall, MD, PhD

Background—It has been postulated that depending on the type of exercise performed, 2 different morphological forms of athlete’s heart may be distinguished: a strength-trained heart and an endurance-trained heart. Individual studies have not tested this hypothesis satisfactorily.

Methods and Results—The hypothesis of divergent cardiac adaptations in endurance-trained and strength-trained athletes was tested by applying meta-analytical techniques with the assumption of a random study effects model incorporating all published echocardiographic data on structure and function of male athletes engaged in purely dynamic (running) or static (weight lifting, power lifting, bodybuilding, throwing, wrestling) sports and combined dynamic and static sports (cycling and rowing). The analysis encompassed 59 studies and 1451 athletes. The overall mean relative left ventricular wall thickness of control subjects (0.36 mm) was significantly smaller than that of endurance-trained athletes (0.39 mm, \( P < 0.001 \)), combined endurance- and strength-trained athletes (0.40 mm, \( P = 0.001 \)), or strength-trained athletes (0.44 mm, \( P < 0.001 \)). There was a significant difference between the 3 groups of athletes and control subjects with respect to left ventricular internal diameter (\( P < 0.001 \)), posterior wall thickness (\( P < 0.001 \)), and interventricular septum thickness (\( P < 0.001 \)). In addition, endurance-trained athletes and strength-trained athletes differed significantly with respect to mean relative wall thickness (0.39 versus 0.44, \( P = 0.006 \)) and interventricular septum thickness (10.5 versus 11.8 mm, \( P = 0.005 \)) and showed a trend toward a difference with respect to posterior wall thickness (10.3 versus 11.0 mm, \( P = 0.078 \)) and left ventricular internal diameter (53.7 versus 52.1 mm, \( P = 0.055 \)). With respect to cardiac function, there were no significant differences between athletes and control subjects in left ventricular ejection fraction, fractional shortening, and E/A ratio.

Conclusions—Results of this meta-analysis regarding athlete’s heart confirm the hypothesis of divergent cardiac adaptations in dynamic and static sports. Overall, athlete’s heart demonstrated normal systolic and diastolic cardiac functions. (Circulation. 1999;100:336-344.)

Key Words: exercise • hypertrophy • echocardiography • myocardium

Top-level training is often associated with morphological changes in the heart, including increases in left ventricular chamber size, wall thickness, and mass. The increase in left ventricular mass as a result of training is called “athlete’s heart.”1 Morganroth et al2 were the first to postulate that 2 different morphological forms of athlete’s heart can be distinguished: a strength-trained heart and an endurance-trained heart. According to their theory, athletes involved in sports with a high dynamic component (eg, running) develop predominantly increased left ventricular chamber size with a proportional increase in wall thickness caused by volume overload associated with the high cardiac output of endurance training. Thus, endurance-trained athletes are presumed to demonstrate eccentric left ventricular hypertrophy, characterized by an unchanged relationship between left ventricular wall thickness and left ventricular radius (ie, ratio of wall thickness to radius). Athletes involved in mainly static or isometric exercise (eg, weightlifting) develop predominantly increased left ventricular wall thickness with unchanged left ventricular chamber size, which is caused by pressure overload accompanying the high systemic arterial pressure found in this type of exercise. Thus, strength-trained athletes are presumed to demonstrate concentric left ventricular hypertrophy, which is characterized by an increased ratio of wall thickness to radius.

Even though the morphology of athlete’s heart and the impact of different sports on cardiac structure have been investigated recently by several authors,3–6 they have not been able to resolve satisfactorily the question regarding the existence of 2 types of athlete’s heart. We chose to focus on the basic forms of exercise, ie, dynamic exercise (long-distance running), static exercise (all sports involving the

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throwing and lifting of heavy objects), and combined dynamic and static exercise (cycling and rowing). The hypothesis of divergent cardiac adaptations in endurance- and strength-trained athletes was tested by applying meta-analytical techniques with the assumption of a random study effects model of published data of male athletes engaged in the sports mentioned above. Female athletes were excluded, because to the best of our knowledge no studies on the effect of strength training on the heart of female athletes are available. Cardiac systolic and diastolic functions were also studied to evaluate the relationship between geometry and function of athlete’s heart.

Methods

Cardiac Structure

All available echocardiographic studies from the medical literature (from 1975 through 1998) on the anatomical structure of the heart in endurance-trained athletes (long-distance runners), strength-trained athletes (weight lifters, power lifters, bodybuilders, wrestlers, throwers), and athletes involved in combined forms of dynamic and static training (cyclists and rowers) were identified (Tables 1, 2, and 3). The outcome of the studies did not influence inclusion or rejection of data, and the following preset criteria for accepting data in our meta-analysis were applied: homogeneous groups of adult male athletes between 18 and 40 years of age. Nonuniform groups of athletes, women, mixed groups of men and women, children (<18 years) and veterans (>40 years) were excluded. Only original publications were considered; review papers were excluded. Original studies had to include assessment of left ventricular internal diameter and wall thickness. When left ventricular mass was not reported, it was calculated with the Penn-cube formula:

\[
\text{LVM} = 1.04[(\text{LVIDd} + \text{PWTd} + \text{IVSTd})^3 - \text{LVIDd}^3] - 13.6 \text{ g, in which LVM indicates left ventricular mass; LVIDd, left ventricular end-diastolic internal diameter; PWTd, diastolic posterior wall thickness; and IVSTd, diastolic interventricular septum thickness. Relative left ventricular wall thickness was calculated as PWTd/LVIDd and expressed as a fraction. When the diastolic interventricular septal thickness was not reported, it was considered to be equal to the diastolic posterior wall thickness.}
\]

Cardiac Function

All available echocardiographic studies from the medical literature (from 1975 through 1998) on left ventricular ejection fraction, fractional shortening, and ratio of transmural peak flow velocity during early left ventricular filling and peak flow velocity during atrial filling (E/A ratio) of endurance-trained athletes, strength-trained athletes, and athletes receiving combined forms of dynamic and static training were identified. The outcome of the studies did not influence inclusion or rejection of data, and the same set of criteria for accepting data in our meta-analysis were applied. To investigate whether there was any relationship between cardiac geometry and left ventricular systolic and diastolic functions, left ventricular function was studied in the respective subgroups of endurance-trained athletes, combined endurance- and strength-trained athletes, and strength-trained athletes.

Statistical Analysis

The means of the posterior wall thickness, interventricular septum thickness, left ventricular internal diameter, ejection fraction, fractional shortening, and E/A ratio in the individual studies were analyzed by use of a meta-analysis model with a random study effect as described by Dersimonian and Laird.* The different groups of athletes were also compared by use of this model. A value of \( P \leq 0.05 \) was considered statistically significant.

Results

Cardiac Structure

In Table 4, results of echocardiographic data regarding cardiac structure in endurance-trained athletes, strength-trained athletes, combined endurance- and strength-trained athletes, and control subjects are summarized. There were 23 studies of endurance-trained athletes,23–30 23 studies of combined endurance- and strength-trained athletes,16,19,24,26,29,39–57 and 24 studies of strength-trained athletes* included in the meta-analysis. The analysis involved a total of 413 endurance-trained athletes, 494 combined endurance- and strength-trained athletes, 544 strength-trained athletes, and 813 control subjects.

Mean Relative Wall Thickness

The overall mean relative left ventricular wall thickness of control subjects (0.36 mm) was significantly smaller than that of endurance-trained athletes (0.39 mm, \( P < 0.001 \)), combined endurance- and strength-trained athletes (0.40 mm, \( P = 0.001 \)), or strength-trained athletes (0.44 mm, \( P < 0.001 \)). Also, the mean relative wall thickness of endurance-trained athletes was significantly lower than that of strength-trained athletes (0.39 versus 0.44 mm, \( P = 0.006 \)). There was no significant difference in mean relative wall thickness between endurance- and combined endurance- and strength-trained athletes (\( P = 0.04 \)).

Left Ventricular Internal Diameter

There was a significant difference between the 3 groups of athletes and control subjects with respect to left ventricular internal diameter (\( P < 0.001 \)). The endurance-trained athletes and strength-trained athletes showed a trend toward a significant difference with respect to left ventricular internal diameter (\( P = 0.055 \)).

Interventricular Septum Thickness

In 6 studies, interventricular septum thickness was not mentioned and was considered to be equal to the posterior septum thickness.11,15,17,22,27,51 There was a significant difference with respect to interventricular septum thickness between control subjects and endurance-trained athletes (8.8 versus 10.5 mm, \( P < 0.001 \)) and between endurance-trained athletes and strength-trained athletes (10.5 versus 11.8 mm, \( P = 0.005 \)) but not between endurance-trained athletes and combined endurance-trained and strength-trained athletes (\( P = 0.042 \)).

Posterior Wall Thickness

There was a significant difference in posterior wall thickness between control subjects and endurance-trained athletes (8.8 versus 10.3 mm, \( P < 0.001 \)) but not between endurance-trained athletes and combined endurance- and strength-trained athletes (10.3 versus 11.0 mm, \( P = 0.064 \)) or between endurance-trained athletes and strength-trained athletes (10.3 versus 11.0 mm, \( P = 0.078 \)).

Left Ventricular Mass

The overall mean left ventricular mass of the control subjects (174 g) was significantly less than the overall mean left ventricular mass of the endurance-trained athletes (249 g, \( P < 0.001 \)), combined endurance- and strength-trained athletes (288 g, \( P < 0.001 \)), or strength-trained athletes (267 g, \( P < 0.001 \)).

### TABLE 1. Subject Characteristics: Endurance-Trained Athletes (Runners)

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<tr>
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**Legend:**
- NR: Not reported
- $V_{O2\text{max}}$: Maximum oxygen uptake
- Age: Age of participants
- LVM: Left ventricular mass

Note: The table includes various training intensities for different groups of runners, along with their respective $V_{O2\text{max}}$ values, ages, and left ventricular mass. The data spans various training intensities and periods, highlighting the impact on cardiovascular parameters and muscle mass.
P<0.001). Left ventricular mass did not differ significantly between the 3 groups of athletes.

**Cardiac Function**

In Table 4, results of echocardiographic data from 50 studies on cardiac function in endurance-trained athletes, strength-trained athletes, combined endurance-and strength-trained athletes, and control subjects are summarized.† There were no significant differences between the athletes and the control subjects with respect to left ventricular ejection fraction, fractional shortening, and E/A ratio.

**Discussion**

**Cardiac Structure**

The results of this meta-analysis of athlete’s heart demonstrated slightly divergent cardiac adaptations in dynamic and static sports, with an intermediate form of hypertrophy for those sports with combined high static and dynamic components. The development of an endurance-trained heart (eccentric hypertrophy) and a strength-trained heart (concentric hypertrophy) is not to be considered an absolute and dichotomous concept. Endurance-trained runners, who are thought to develop pure eccentric left ventricular hypertrophy, demonstrated a more pronounced increase in wall thickness than expected, in addition to an increase in left ventricular end-diastolic diameter. This resulted in an unexpected increase in relative wall thickness. The strength-trained weight lifters, power lifters, bodybuilders, throwers, and wrestlers, who are considered to develop pure concentric left ventricular hypertrophy, demonstrated an increase in both absolute and relative wall thickness and a significant increase in left ventricular diameter. Consequently, the geometric pattern of athlete’s heart is more complicated than expected. Endurance-trained athletes showed a significant increase in left ventricular relative wall thickness ratio instead of a proportional increase in left ventricular wall thickness and internal diameter with a normal relative wall thickness; strength-trained athletes showed an increase in left ventricular diameter in addition to an increase in left ventricular wall thickness. The combined endurance- and strength-trained cyclists and rowers showed a significant increase in relative wall thickness and the highest increase in left ventricular internal diameter. This observation is largely in accordance with the results reported by Spirito et al., who performed the largest study on athlete’s heart on 947 elite athletes representing 27 different sports. They ranked sports according to the impact on left ventricular diastolic cavity dimension and left ventricular wall thickness. Rowing was ranked first according to the calculated effect on left ventricular wall thickness (with cycling second), and cycling was ranked first according to the calculated effect on left ventricular internal dimension (with rowing seventh). The authors convincingly demonstrated that sports differ greatly with regard to their impact on left ventricular dimensions and that in general athletes training in sports associated with large diastolic cavity dimensions also have relatively high values of wall thickness.

**Endurance-Trained Athletes**

Adaptation of the heart to endurance training with an increase in both diameter and wall thickness is useful if we take into account heart rate and blood pressure responses during intense exercise. The cardiac output of trained endurance athletes may increase from 5 to 6 L/min at rest to up to 40 L/min during maximal exercise. The heart adapts to a lesser extent than during strength training. Blood pressure also increases during endurance exercise, although to a lesser extent than during strength training. Blood pressure readings of 175/69 mm Hg during treadmill running were recorded by Palatini et al. The authors convincingly demonstrated that sports differ greatly with regard to their impact on left ventricular dimensions and that in general athletes training in sports associated with large diastolic cavity dimensions also have relatively high values of wall thickness.
an increase in both left ventricular internal diameter and left ventricular wall thickness.

Strength-Trained Athletes
Adaptation of the heart to strength training with a slight increase in left ventricular internal diameter and a large increase in left ventricular wall thickness can be explained on the basis of blood pressure response and cardiac output during weight lifting.\textsuperscript{75–78} During heavy-resistance exercise, arterial blood pressure shows a large increase, amounting to values to 480/350 mm Hg.\textsuperscript{75} However, heart rate and cardiac output do not remain unchanged but show an increase during strength training. MacDougall et al\textsuperscript{75} demonstrated that heart rate during weight lifting ranged

\begin{table}[h]
\centering
\caption{Subject Characteristics: Combined Endurance- and Strength-Trained Athletes (Cyclists and Rowers)}
\begin{tabular}{lllllll}
Reference & Study Group & Training & Training, y & $V_O^{max}$ & n & Age, y & LVM, g \\
\hline
39 & Control subjects & NR & 30 (20–39) & 132±25 & 30 & 30 (20–39) & 187±19 \\
40 & Professional cyclists & 100–700 km/wk & 10±6 & NR & 20 & 30 (20–39) & 187±19 \\
41 & Control subjects & NR & 17 & 22±4 & 236 & 17 & 22±4 \\
42 & Junior rowers & 6–12 h/wk & 0.6 & NR & 9 & 20±2 & 303 \\
43 & Senior rowers & 10–14 h/wk & >1 & NR & 14 & 23±2 & 160 \\
44 & Control subjects & NR & 11 & 26±2 & 197±38 & 11 & 26±2 \\
45 & Professional cyclists & Professional & NR & 14 & 25±2 & 388±53 & 14 & 25±2 \\
46 & Control subjects & NR & 12 & 24±2 & 192 & 12 & 24±2 \\
47 & Cyclists & 600 km/wk & 8 (4–10) & 61±2 & 12 & 24±1 & 352 \\
48 & Control subjects & NR & 17 & 24 & 163±50 & 17 & 24 \\
49 & Competitive cyclists & NR & 7 & 64±10 & 15 & 26 & 337±70 \\
50 & Control subjects & NR & 12 & 24±2 & 168 & 12 & 24±2 \\
51 & Competitive cyclists & 200–900 km/wk & 8 & 64±2 & 12 & 23±1 & 286 \\
52 & Control subjects & NR & 8 & 22±4 & 185±24 & 8 & 22±4 \\
53 & National-level cyclists & Several hours & NR & 12 & 22±4 & 314±74 & 12 & 22±4 \\
54 & Control subjects & NR & 50 & 23±4 & 163±17 & 50 & 23±4 \\
55 & Top-level road cycling & NR & NR & 30 & 20±2 & 355±30 & NR & NR \\
56 & Control subjects & NR & 9 & 21±6 & 127±37 & 9 & 21±6 \\
57 & Cyclists & 3 h/wk & 0.4 & NR & 13 & 17±4 & 164±39 \\
58 & Control subjects & NR & 16 & 27±2 & 168 & 16 & 27±2 \\
59 & Road-racing cyclists & NR & NR & 15 & 23±1 & 234 & NR & NR \\
60 & Control subjects & NR & 16 & 27±2 & 168 & 16 & 27±2 \\
61 & Competitive cyclists & 534 km/wk & 7 & 72±6 & 16 & 22±5 & 311±60 \\
62 & Olympic cyclists & 14–20 h/wk & NR & 72±3 & 8 & 24±4 & 262±20 \\
63 & Control subjects & NR & 10 & 24±5 & 219±15 & 10 & 24±5 \\
64 & Competitive cyclists & Professional & NR & 14 & 22±3 & 418±31 & NR & NR \\
65 & Competitive cyclists & Professional & NR & 23 & 29±2 & 284±36 & NR & NR \\
66 & Top-level rowers & 30 h/wk & NR & 15 & 22±6 & 315±27 & NR & NR \\
67 & Control subjects & NR & 16 & 21–30 & 171±33 & 16 & 21–30 \\
68 & Professional cyclists & >40 h/wk & 7 & NR & 16 & 21–30 & 354±47 & NR & NR \\
69 & Olympic rowers & 12 Sessions & NR & NR & 6 & 24±4 & 315±19 & NR & NR \\
70 & Control subjects & NR & 21 & 26±4 & 203±28 & 21 & 26±4 \\
71 & Professional cyclists & 600–800 km/wk & >5 & NR & 26 & 26±3 & 324±41 & NR & NR \\
72 & Control subjects & Professional & 8 & NR & 69 & 27±4 & 267±47 & NR & NR \\
73 & Professional cyclists & 750 km/wk & >10 & NR & 40 & 26±3 & 273±65 & NR & NR \\
74 & Professional cyclists & 580 km/wk & >3 & NR & 37 & 26±3 & 274±36 & NR & NR \\
75 & Control subjects & NR & 32 & 22±4 & 214±48 & NR & NR \\
76 & Rowers & National/regional & NR & NR & 64 & 21±4 & 256±45 & NR & NR \\
77 & Rowers & NR & NR & 55.6±8 & 8 & 23±6 & 208±46 & NR & NR \\
\hline
LVM indicates left ventricular mass; NR, not reported. 
Values in parentheses are ranges; others are mean±SD.
\end{tabular}
\end{table}
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<thead>
<tr>
<th>Reference</th>
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<td>&gt;2</td>
<td>NR</td>
<td>16</td>
<td>28 (18–38)</td>
<td>241 ±70</td>
</tr>
<tr>
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<td>NR</td>
<td>7</td>
<td>23 ±4</td>
<td>225 ±51</td>
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<td>7 ±2</td>
<td>4 ±2</td>
<td>NR</td>
<td>12</td>
<td>26 ±5</td>
<td>242 ±43</td>
</tr>
<tr>
<td>59</td>
<td>Control subjects</td>
<td>NR</td>
<td>10</td>
<td>17 ±1</td>
<td>216 ±41</td>
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<td></td>
<td>National junior wrestlers</td>
<td>Daily</td>
<td>9 ±2</td>
<td>NR</td>
<td>17</td>
<td>18 ±1</td>
<td>326 ±46</td>
</tr>
<tr>
<td>28</td>
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<td>NR</td>
<td>33</td>
<td>22 ±6</td>
<td>168 ±55</td>
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<td></td>
<td>Power lifters</td>
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<td>&gt;4</td>
<td>NR</td>
<td>11</td>
<td>24 ±3</td>
<td>373 ±125</td>
</tr>
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<td>Control subjects</td>
<td>NR</td>
<td>10</td>
<td>19 ±1</td>
<td>197 ±31</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Throwners</td>
<td>9 ±2</td>
<td>3 ±1</td>
<td>NR</td>
<td>10</td>
<td>20 ±3</td>
<td>216 ±40</td>
</tr>
<tr>
<td>29</td>
<td>Bodybuilders</td>
<td>8 ±1</td>
<td>8 ±5</td>
<td>NR</td>
<td>46</td>
<td>27 ±6</td>
<td>265 ±55</td>
</tr>
<tr>
<td>30</td>
<td>Control subjects</td>
<td>NR</td>
<td>50 ±7</td>
<td>31</td>
<td>191</td>
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<tr>
<td></td>
<td>Olympic throwers</td>
<td>Several</td>
<td>Many</td>
<td>NR</td>
<td>38 ±11</td>
<td>4</td>
<td>NR</td>
</tr>
<tr>
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<td>10 ±2</td>
<td>8 ±4</td>
<td>39 ±3</td>
<td>7</td>
<td>26 ±5</td>
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<td>10</td>
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<td>NR</td>
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<td>26 ±7</td>
<td>135 ±21</td>
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<tr>
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<td>NR</td>
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<td>27 ±8</td>
<td>167 ±20</td>
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<td>&gt;3</td>
<td>NR</td>
<td>100</td>
<td>26 ±5</td>
<td>194 ±37</td>
</tr>
<tr>
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<td>Control subjects</td>
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<td>36 ±4</td>
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<td>27 ±4</td>
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<td>10</td>
<td>26 ±3</td>
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<td>36</td>
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<td>&gt;2</td>
<td>16</td>
<td>21 (18–30)</td>
<td>268 ±94</td>
<td></td>
</tr>
<tr>
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<td>31 ±7</td>
<td>165 ±23</td>
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<td></td>
</tr>
<tr>
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<td>Several</td>
<td>&gt;4</td>
<td>8</td>
<td>30 ±10</td>
<td>280 ±66</td>
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</tr>
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</table>

LVM indicates left ventricular mass; NR, not reported.
Values in parentheses are ranges; others are mean ± SD.
from 102 bpm between sets to peak values of 170 bpm during actual lifting. Accordingly, pure pressure load during strength training does not exist.

**Combined Endurance- and Strength-Trained Athletes**

Rowing and cycling represent typical strength and endurance sports involving combined dynamic and static exercise of large groups of muscles. Top-level cyclists can perform with near-maximal heart rate for long periods of time, sometimes up to 6 hours. Systolic and mean arterial blood pressures also are increased during cycling; Systolic blood pressure readings of $>200$ mm Hg can be found during maximal exercise testing on the bicycle ergometer. During rowing, heart rate increases to near-maximal values of $>190$ bpm, with peak systolic blood pressure waves of $>200$ mm Hg. The combination of both extreme volume load and extreme pressure load may explain why the largest increases in left ventricular internal dimension and left ventricular wall thickness are found in cyclists and rowers.

**Cardiac Function**

Left ventricular systolic function is generally assessed by measuring the extent and velocity of fiber shortening, ejection fraction, and velocity of circumferential fiber shortening. Our meta-analysis shows that in the group of athletes studied, overall systolic function as judged by fractional fiber shortening or ejection fraction is similar to that of sedentary control subjects. We therefore conclude that there is no relation between cardiac geometry and left ventricular systolic function in athlete’s heart. However, the parameters used in these studies reflect chamber mechanics rather than myocardial mechanics. Studies of myocardial contractile function in the hypertrophied left ventricle resulting from hypertension suggest that intrinsic myocardial performance may be depressed, even when left ventricular ejection fraction remains normal. However, the presumed innocent nature of the athlete’s heart does not allow the performance of more invasive studies in athletes.

Left ventricular diastolic function is commonly assessed by studying the pattern of ventricular filling through the mitral valve. The generally used diastolic function parameter is the E/A ratio. Our meta-analysis demonstrated a normal or slightly enhanced diastolic function in athletes compared with sedentary control subjects. These results should be interpreted with some caution because the E/A ratio not only is related to left ventricular compliance but also is influenced by other factors such as heart rate, preload, and afterload. A slower heart rate may reduce the atrial contribution to left ventricular filling by lengthening diastole. Generally, a normal or slightly enhanced diastolic function in athletes may be considered as a positive finding because in hypertensive patients the increase in left ventricular mass and wall thickness is associated with diastolic filling abnormalities.

**Potential Study Limitations**

Previous reviews only included those studies that used control subjects matched for body size. In studies of relative wall thickness, it is not mandatory to adjust for body size because body size parameters appear in both the numerator and denominator of the calculation, implying that relative wall thickness is dimensionless. Also body size parameters do not influence left ventricular systolic or diastolic function. It was therefore possible to include studies with control subjects of different body sizes or those without control subjects; thus, the greater number of observations lead to increased statistical power. Body size, however, does influence the diameter and wall thickness of the left ventricle.
and we can therefore not exclude the possibility that part of the differences in heart size may be ascribed to the larger body size of the athletes. Athletes ≥40 years of age and children were excluded from the analysis of cardiac structure and function to eliminate other factors besides training, such as hypertension or age-related increases in wall thickness, which may be responsible for any differences in cardiac mass or geometry.

It would have been interesting to study divergent cardiac adaptations of athlete’s heart in women. However, to the best of our knowledge, no literature is available regarding the effects of strength training on the heart of female athletes.

Conclusions

The present meta-analysis on the anatomic structure and function of the heart in endurance-trained athletes, strength-trained athletes, and combined endurance- and strength-trained athletes confirms the hypothesis of the existence of an endurance-trained and a strength-trained heart. Divergent cardiac adaptations do occur in athletes performing dynamic and static sports. However, the classification as an endurance-trained heart or a strength-trained heart is not an absolute and dichotomous concept but rather a relative concept. In every form of endurance training, blood pressure increases (pressure load), just as in every form of strength training, heart rate, cardiac output, and blood pressure increase.

References


