The cardiac profile of individuals who participate regularly in vigorous, isotonic exercise is characterized by left ventricular (LV) volume overload with increased LV internal dimension, LV end-diastolic volume, stroke volume, and LV myocardial mass. Such adaptations are commonly reported in highly trained endurance athletes, especially runners. Because running is associated with a significant number of musculoskeletal and orthopedic injuries, distance walking is increasingly prescribed to promote health and fitness. To clarify the cardiovascular adaptive changes to long-distance high-speed walking, we studied the cardiac dimensions, systolic time intervals, and aerobic capacity of national-caliber race walkers and compared them with those of control subjects and other endurance athletes of similar age.

**Subjects and Methods**

**Subjects**

Ten actively competing white male race walkers were evaluated. Seven of the ten walkers were of national caliber, having placed in either the Olympic trials, Pan-American Games, or masters or junior competition; the other three were highly trained walkers. Their mean (±SEM) age, weight, and weekly walk-training distance were 29.6±3.9 years, 69.3±1.9 kg, and 69.5±8.3 miles, respectively. Ten age-matched men who did not participate in any regular exercise or athletic activity served as control subjects.

**Methods**

Complete medical histories and physical examinations were obtained on all subjects. After each subject rested supine for 30 min, a 12-lead ECG, phonocardiogram, and carotid pulse tracings were recorded on a Marquette three-channel recorder (model 2000) during supine rest and immediately after (ie, within 90 s) maximal exercise testing. Systolic time intervals were calculated by standard methods. M-mode echocardiograms in the resting supine position were obtained with use of an Ekoline 20 A (Smith Kline Instruments Company, Philadelphia) interfaced with a recorder (Honeywell Company, Denver). The transducer was placed in the third, fourth, or fifth intercostal space along the left sternal border. Echocardiographic scans from the aorta to the cardiac apex were recorded with light-sensitive paper. Left ventricular internal dimensions, interventricular septal thickness, and LV posterior wall thickness were measured just below the level of the mitral valve, as previously described. The data presented are the average of five consecutive cardiac cycles. Left ventricular volumes and LV myocardial mass were estimated from the LV internal dimension, LV posterior wall thickness, and interventricular septal thickness in diastole by standard methods.

Physical work capacity was assessed by maximal exercise testing using the conventional Bruce treadmill protocol (Fig 1). The test proceeded to each subject's volitional fatigue or until clinical signs and/or symptoms appeared. Respiratory variables, heart rate, and blood pressure (standard cuff method) were determined during each exercise stage and at maximal exercise. Metabolic data were obtained with a mass spectrometer (model MGA-1100, PerkinElmer, Norwalk, Conn) interfaced with a PDP-8 computer and automated instrumentation system that provides on-line teletype monitoring of cardiopulmonary variables during exercise testing. Before each test, the pneumotachometer was referenced with a 3-L syringe, and the mass spectrometer was calibrated with room air and a certified oxygen/carbon dioxide concentration. Electrocardiogram and heart rate were monitored continuously via oscilloscope and recorded on a three-channel recorder (model 2000, Marquette Electronics, Milwaukee) or Marquette CASE system. The ECG was calibrated to 1 mV/10 mm of deflection before each test.

**Results**

None of the subjects had concomitant medical conditions. Physical examinations were unremarkable except that three subjects had grade II/VI systolic ejection murmurs at the left sternal border radiating to the carotid arteries.

Electrocardiographic analyses showed that eight subjects had resting sinus bradycardia, one had junctional bradycardia, and another had a wandering atrial pacemaker. The average heart rate in the supine position was 54.7 beats/min. Two subjects had a P-wave amplitude of more than 0.25 mV in lead II; however, PR intervals were normal. The precordial voltage (Sv1 or Sv4 + Rv4) was greater than 52, 35, and 25 mm in 3, 8, and 10 subjects, respectively. One subject demonstrated an incomplete right bundle branch block pattern in lead V1. No subject showed atrial or ventricular premature beats at rest.

All subjects completed the treadmill protocol with-

---

*From the Department of Medicine (Cardiology), Case Western Reserve University, Cleveland (Drs. Moir and Hellerstein); Department of Cardiology, Rapides Regional Medical Center, Alexandria, La (Dr. Kaimal); and Cardiac Rehabilitation and Exercise Laboratories, William Beaumont Hospital, Royal Oak, Mich (Dr. Franklin).

Supported in part by a grant from Blue Cross of Northeast Ohio.

Reprint requests: Dr. Franklin, Beaumont Rehab and Health Center, 746 Purdy Street, Birmingham, Michigan 48009
Table 1—Echocardiographic Dimensions of National-Class Race Walkers*

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Range</th>
<th>Mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVIDd, mm</td>
<td>46-62</td>
<td>54.2 ± 1.5</td>
</tr>
<tr>
<td>LVEDv, ml</td>
<td>133-238</td>
<td>162.6 ± 13.4</td>
</tr>
<tr>
<td>SV, ml</td>
<td>75-199</td>
<td>124.5 ± 12.4</td>
</tr>
<tr>
<td>EF, %</td>
<td>62-85</td>
<td>75.9 ± 2.5</td>
</tr>
<tr>
<td>LVWd, mm</td>
<td>8-13</td>
<td>9.5 ± 0.5</td>
</tr>
<tr>
<td>IVST, mm</td>
<td>9-14</td>
<td>9.7 ± 0.6</td>
</tr>
<tr>
<td>LVM, g</td>
<td>192-346</td>
<td>251.1 ± 15.2</td>
</tr>
<tr>
<td>LA, mm</td>
<td>21-42</td>
<td>31.5 ± 2.1</td>
</tr>
<tr>
<td>Ao, mm</td>
<td>29-40</td>
<td>33.0 ± 1.4</td>
</tr>
</tbody>
</table>

*LVIDd = LV internal dimension at end diastole; LVEDv = LV end-diastolic volume; SV = stroke volume; EF = LV ejection fraction; LVWd = LV wall thickness; IVST = interventricular septal thickness; LVM = LV myocardial mass; LA = left atrial dimension; Ao = aortic root dimension.

out evidence of significant ST-segment depression (≥1.0 mm horizontal or downsloping), serious ventricular arrhythmias, or abnormal blood pressure responses or symptoms. Measured maximal oxygen consumption (VO₂ max), expressed on an absolute and relative basis (x ± SD), was 4.2 ± 0.5 L/min and 60.6 ± 8.0 ml/kg/min, respectively. The ratio of the pre-ejection period (PEP) to the LV ejection time (LVET) at rest and immediately after exercise decreased from 0.31 ± 0.05 to 0.15 ± 0.07 in the race walkers and from 0.36 ± 0.02 to 0.28 ± 0.06 in the control subjects.

Echocardiographic studies were technically satisfactory in all subjects. Measurements corrected for both heart rate and body surface area were not significantly different from uncorrected data (Table 1). Compared to the control subjects, race walkers demonstrated significantly greater mean LV internal dimensions and volumes at end diastole (p<0.001), greater stroke volume (p<0.001), and greater LV ejection fraction (p<0.001). In contrast, left atrial and aortic root dimensions in the race walkers did not differ significantly from those in the control subjects.

**DISCUSSION**

We found that highly trained race walkers have ECG alterations similar to those previously reported for long-distance runners. These changes are characterized by resting sinus bradycardia (a classic adaptation to chronic aerobic exercise training), atrioventricular junctional rhythm in the resting state, occasional aberrant atrial rhythms, increased precordial QRS voltage, and incomplete right bundle branch block patterns. Nine of ten subjects had voltage criteria of LV hypertrophy in the precordial leads. None, however, demonstrated ST-segment depression or T-wave inversion in the resting state, as reported in long-distance runners.

At supine rest, race walkers demonstrated a PEP/LVET ratio that was within normal limits. In the postexercise state, however, their PEP/LVET ratio was greatly shortened relative to our control subjects. Because the PEP/LVET ratio correlates highly with LV ejection fraction, these findings suggest that trained race walkers demonstrate greater LV contractility and stroke volume during exercise than do control subjects. Interestingly, the postexercise PEP/LVET ratio in our race walkers was similar to that reported in clinical conditions characterized by an increased LV ejection fraction (eg, hyperthyroidism).

The measured VO₂ max of 60.6 ml/kg/min of the walkers in this study was 17 percent higher than the value reported for active men of comparable age (51.6 ml/kg/min). Although the race walkers' VO₂ max is significantly lower than the value of 75 ml/kg/min or more usually observed in world-class endurance athletes (Nordic skiers and distance runners), it is comparable to or higher than that of orienteers and

---

Figure 1. The standard Bruce treadmill protocol, showing progressive stages (speed in miles per hour [MPH]/percent grade) and the corresponding estimated aerobic requirement.

Cardiac Profiles of National-class Race Walkers (Kalmel et al)
soccer, 23 racquetball, 24 football, 25 basketball, 26 and tennis 27 players. These findings indicate that national-class race walkers have a lower aerobic capacity than elite athletes in other endurance sports, particularly distance runners. Perhaps successful race walking performance depends more on technique, strategy, and efficiency than on a great aerobic capacity.

The echocardiographic data show that race walkers have increased LV end-diastolic volume and stroke volume. These variations from the values for the control subjects are quantitatively similar to those reported for long-distance runners and swimmers (Fig 2). The thicknesses of the interventricular septum and the LV posterobasal wall in our race walkers were similar to those found in the control subjects (Fig 3). Because of the high LV end-diastolic volume in race walkers, however, the estimated LV muscle mass was higher than that of control subjects, yet substantially lower than the value reported for long-distance runners (Fig 4). Thus, the echocardiographic profile of race walkers is somewhat similar to that of long-distance runners and swimmers, and is characterized by LV dilation, increase stroke volume, and a mild increase in LV muscle mass. Nevertheless, there is a pronounced difference in the degree of LV hypertrophy. Long-distance runners have a greater myocardial mass for the same degree of LV dilation and, therefore, a greater degree of LV hypertrophy than race walkers. This difference may account for the higher incidence of ECG ST-T wave abnormalities reported in long-distance runners. 4

In summary, the cardiac profile of national-class race walkers is characterized by some of the ECG variations reported in long-distance runners, by increased shortening of the PEP/LVET ratio from the
resting state to that immediately after exercise, and by echocardiographic evidence of volume overload of the left ventricle with less LV hypertrophy than found in long-distance runners. These changes are associated with enhanced LV performance and significantly higher aerobic capacity compared with similarly aged control subjects.

REFERENCES
8 Blair SN, Kohl HW, Paffenbarger RS, Clark DJ, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. JAMA 1989; 262:2385-401
17 Froelicher VF. Exercise and the heart: clinical concepts. Chicago: Year Book Medical Publishers, 1987
24 Pipes TV. The racquetball pro: a physiological profile. Physician Sportsmed 1979; 7:91-4