Comparative Left Ventricular Dimensions in Trained Athletes

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Little is known about the structure of athletes' hearts or anatomic variations associated with training. Echocardiograms of 56 active athletes were obtained. Mean left ventricular end-diastolic volume and mass were increased in athletes involved in isotonic exercise, such as swimming (181 ml, 308 g) and running (160 ml, 302 g), compared with controls (101 ml, 211 g); wall thickness was normal (≤ 12 mm). Athletes involved in isometric exercise, such as wrestling and shot putting, had normal mean left ventricular end-diastolic volumes (110 ml, 122 ml), but increased wall thickness (13 to 14 mm) and mass (330 g, 348 g). Thus, athletes participating in isotonic exercise had increased left ventricular mass with cardiac changes similar to those in chronic volume overloads. Athletes participating in isometric exercise had increased left ventricular mass with cardiac changes similar to those in chronic pressure loads. Recognizing greater left ventricular mass and volume in well-trained athletes aids in interpreting values deviating from "normal" limits.

TRAINED ATHLETES often have abnormal electrocardiograms (ECGs), radiographic evidence of cardiac enlargement, and systolic murmurs, findings that have been referred to as the "athlete's heart syndrome" (1). In addition, it would appear that while athletes participating in isotonic or endurance events usually have radiographic evidence of cardiac enlargement, athletes involved in isometric or strength training usually show peripheral muscular hypertrophy without an obvious increase in cardiac size (2-4). Aside from these radiographic observations, however, no other information is available relative to the gross morphologic characteristics of the hearts of athletes, or to the anatomic variations associated with different kinds of physical conditioning. Undoubtedly, this has been due largely to the lack of a noninvasive technique that can provide a more sophisticated analysis of cardiac anatomy than simple chest roentgenography affords. In recent years, however, echocardiography has provided a noninvasive and sensitive means for assessing, among other things, ventricular cavity size and myocardial wall dimensions. We therefore employed echocardiography to study the hearts of trained athletes to ascertain whether athletes have an increased left ventricular mass, and, if so, whether athletes participating in different events have different patterns of hypertrophy and enlargement.

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Patient Selection

Forty-two actively competing male college varsity athletes from the University of Maryland (15 swimmers, 15 long-distance runners, and 12 wrestlers) were studied during their competitive season. Their ages ranged from 18 to 24 years, and 97% were Caucasian. All athletes had participated in their athletic event for more than 3 years and trained actively more than 200 days per year. Sixteen age- and sex-matched students who did not normally compete in athletics were selected from the same university and served as a normal control population. No subject was known to be on any pharmacological agent. All of the college athletes checked their resting heart rate for one complete minute daily for several days prior to study; these values were averaged and the mean resting heart rate was recorded. In addition, 10 long-distance runners and 4 shot putters of world class caliber (International Track Association, Los Angeles, California) were studied. The acknowledged world record holders in each of these two events were among those studied.

Data Collection

A medical history, physical examination, and a standard 12-lead electrocardiogram were obtained at rest for all subjects. Echocardiograms were obtained during resting conditions with an Aerotech gamma transducer (Aerotech Laboratories, Division of Branson Instrument Co., Lewistown, Pennsylvania) and a modified Ekoline 20A ultrasonic unit (Smith Kline Instrument Co., Philadelphia, Pennsylvania). The signal was connected via a custom-built video amplifier to a Honeywell 1856 visicorder (Honeywell Co., Denver, Colorado) and recorded continuously on light-sensitive paper. The T-scan technique (5) was used to visualize the ventricular septum and the posterobasal left ventricular wall. The ventricular septum was measured inferior to the distal margins of the mitral leaflets just before atrial systole. Posterobasal left ventricular free wall thickness was measured at the same time in the cardiac cycle with the transducer oriented so that part of the ultrasonic beam was reflected from the posterior mitral leaflet. Left ventricular end-diastolic volume was estimated from left ventricular internal dimension at end diastole using a previously described method (6). Left ventricular mass was calculated from the echocardiographic measurements by the method of Troy, Pombo, and Rackley (7).

Results

GENERAL INFORMATION

No subject in this study had a history of a serious medical condition. The only symptom identifiable in the college athletes was intermittent dizziness, experienced either after extreme exertion or with sudden postural changes. None considered this anything but a casual and infrequent symptom. Dizziness was reported in 4 of 15

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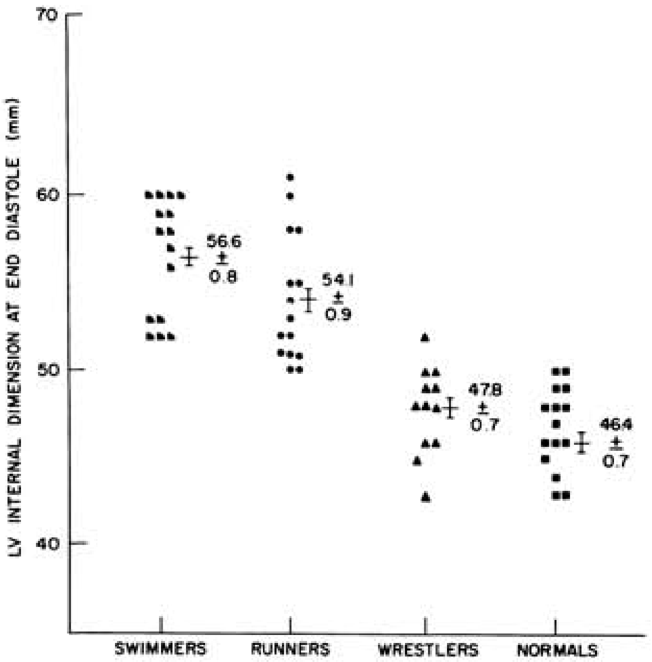

Figure 1. Echocardiographically measured left ventricular (LV) internal dimensions at end diastole in college athletes. Numbers represent mean values ± SEM. Data of swimmers and runners are statistically different from those of wrestlers and normal subjects ($P < 0.001$).

swimmers, 4 of 15 runners, 3 of 12 wrestlers, and 4 of 15 normal subjects. The mean ages (years) for the college swimmers, runners, wrestlers, and normal subjects were 19.9 ± 0.4, 19.2 ± 0.3, 19.8 ± 0.5, and 19.4 ± 0.4, respectively; body surface areas (m^2) averaged 1.93 ± 0.03, 1.84 ± 0.03, 1.86 ± 0.04, and 1.87 ± 0.03. There was no statistically significant difference among the groups. The mean ages for the world class runners and shot putters were 27.1 ± 1.3 and 26.3 ± 1.0 years, respectively; the body surface areas were 1.82 ± 0.4 and 2.52 ± 0.03 m^2, respectively. Five of the 42 college athletes and 1 of the normal control subjects had innocent (grade I-II/VI) systolic ejection murmurs at the lower left sternal border, or apex, or both.

Electrocardiographic abnormalities of increased precordial voltage (S wave in V_2 or V_3, or R wave in V_5 or $V_6 > 25$ mm) were present on ECGs of 3 of 15 college swimmers, 10 of 15 college runners, 3 of 12 college wrestlers, 9 of 10 world class runners, 1 of 4 world class shot putters, and 1 of 16 normal subjects. No subjects had abnormal ventricular complex (QRS) duration (greater than 0.09 ms) or abnormal ST-T waves, and none had any dysrhythmia except one wrestler who had intermittent Mobitz type I atrioventricular block.

Resting heart rate in college athletes was statistically less in swimmers, 61.3 ± 1.7; runners, 53.0 ± 1.8; and wrestlers, 59.4 ± 1.9; as compared with normal subjects, 76.1 ± 1.7; ($P < 0.001$). Resting heart rates were not obtained in world class athletes.

ECHOCARDIOGRAPHY

Technically satisfactory echocardiograms were obtained in all subjects. Echocardiographic data were evaluated both in raw form and corrected for body surface area and for weight. There were no statistically significant differences between the results of any set of data using these corrections; hence, all data will be presented in absolute form.

Mean left ventricular internal dimensions at end-diastole (Figure 1) and left ventricular end-diastolic volumes were greater in swimmers and collegiate runners than in normal subjects. In contrast, wrestlers had normal left ventricular internal dimensions and left ventricular end-diastolic volumes. Stroke volume was increased in swimmers and runners compared with wrestlers and normal subjects ($P < 0.001$). No statistically significant differences were found in the values of left ventricular internal dimensions, left ventricular end-diastolic volumes, and stroke volumes for world class runners and shot putters when compared with college runners and wrestlers respectively (Table 1).

Posterobasal left ventricular wall and ventricular septal thicknesses were within the range of normal in swimmers and runners (both collegiate and world class) but were greater than normal in wrestlers and world class shot putters (Figure 2, Table 1, $P < 0.001$). Left ventricular mass (in grams) was increased in all athletes compared with control subjects (Figure 3, Table 1, $P < 0.001$). No significant differences in left atrial and aortic root transverse dimensions were found among any of the groups (Table 1).

Discussion

This study shows that left ventricular hypertrophy mani-

Table 1. Comparative Cardiac Dimensions in College Athletes and World Class Athletes Measured by Echocardiography*

	College Runners	World Class Runners	College Wiestlers	World Class Shot Putters
LVID†, *mm*	50 to 61	48 to 59	43 to 52	46 to 51
LVEDV‡, *ml*	160.1 ± 8.6	154.5 ± 8.3	110.3 ± 4.9	122.0 ± 8.5
SV‡, *ml*	116.5 ± 13.1	113.4 ± 11.2	75.2 ± 8.1	67.8 ± 16.7
LV wall‡, *mm*	11.3 ± 0.1	10.8 ± 0.2	13.7 ± 0.4	13.8 ± 0.5
Septum‡, *mm*	10.9 ± 0.2	10.9 ± 0.2	13.0 ± 0.5	13.5 ± 0.5
LV mass‡, *g*	301.9 ± 9.0	282.9 ± 10.6	330.1 ± 15.9	348.3 ± 20.8
LA†, *mm*	25 to 39	31 to 38	24 to 39	27 to 36
Ao†, *mm*	24 to 30	23 to 30	21 to 32	23 to 29

* LVID = left ventricular internal dimension at end-diastole; LVEDV = left ventricular end-diastolic volume; SV = stroke volume; LV wall = posterobasal left ventricular wall thickness; Septum = ventricular septal thickness; LV mass = left ventricular mass; LA = left atrial transverse dimension at end-systole; Ao = aorta.
† Range.
‡ Mean ± SEM.

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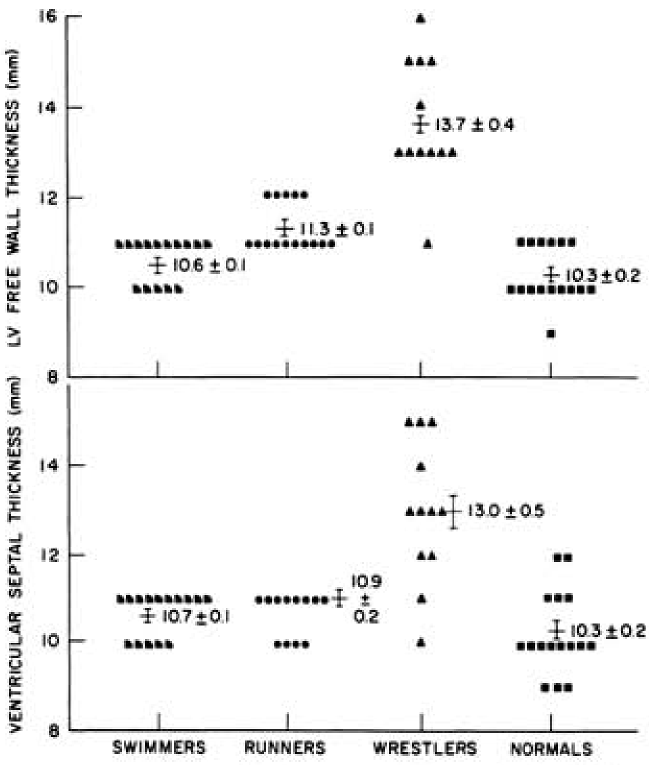

Figure 2. Echocardiographically measured left ventricular (LV) free wall thicknesses (*upper panel*) and septal thicknesses (*lower panel*) in college athletes. Numbers represent mean values ± SEM. Data of wrestlers are statistically different from those of swimmers, runners, and normal subjects for both measurements ($P < 0.001$).

fested by an increase in calculated left ventricular mass may be present in highly trained athletes. Although hypertrophy occurs in athletes participating in sports requiring either primarily isotonic (endurance) or isometric (resistance) efforts, the patterns of left ventricular hypertrophy are different and appear to depend upon the nature of the exercise-conditioning characteristic of each sport. For instance, the increase in calculated left ventricular mass observed in athletes participating in isotonic or endurance training (swimmers and runners) is associated with an increase in left ventricular end-diastolic volume, but left ventricular wall thickness remains normal. In contrast, the increased left ventricular mass observed in those athletes participating in isometric or resistance exercises is associated with an increase in left ventricular wall thickness, whereas left ventricular end-diastolic volume remains normal.

The physical stress of long-distance running or swimming requires for an optimal effort a large increase in cardiac output during physical exertion. Athletes participating in such events often sustain this hemodynamic burden for many hours of each day when in training (as was the case in the subjects we studied). In addition, stroke volume in these athletes characteristically is elevated even at rest (8), a finding confirmed by the data obtained in the present study. Thus, the hemodynamic load on the heart present in such individuals is similar to that seen in patients with aortic or mitral regurgitation (9, 10); the increased left ventricular mass resulting from these valvular abnormalities, interestingly enough, also is associated with an increase in left ventricular end-diastolic volume. In contrast, athletes who participate in physical conditioning involving primarily isometric exercise are not subjected to a volume stress, but rather to intermittently elevated arterial pressure that is generated during straining. Thus, these athletes are subjected to stresses similar to those induced by systemic hypertension or aortic stenosis (9, 10); the increased left ventricular mass observed in patients with these diseases, like wrestlers and shot putters, is associated with an increased left ventricular wall thickness.

The increased left ventricular mass present in athletes is probably important in maintaining optimal cardiac performance during training and competition. It is clear, however, that cardiac hypertrophy cannot be the sole factor determining superior performance, since college athletes, despite having left ventricular end-diastolic volumes and left ventricular masses similar to those of world class athletes, manifest consistently inferior competitive times. Whether such differences among athletes are a result of a greater cardiac response to maximal exertion, peripheral circulatory adaptations (such as decreased arterial resistance or increased oxygen extraction), or noncardiovascular mechanisms (such as greater muscle strength, enhanced aerobic or anaerobic sources of energy production, or psychological factors) cannot be ascertained from the results of the present investigation. Moreover, it remains to be established whether the differences in cardiac dimensions observed in the trained athlete, when compared with nonathlete control subjects, are solely a result of intense prolonged physical conditioning, or are influenced substantially by genetic factors.

The results of this study also are relevant to the question of what should be considered as the "normal" range of cardiac dimensions. For instance, if athletes are included inadvertently in a normal control population, then the

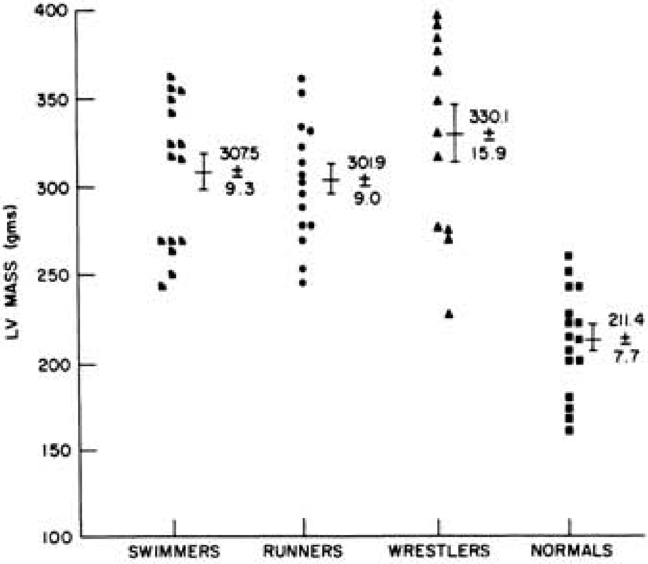

Figure 3. Echocardiographically measured left ventricular (LV) masses in college athletes. Numbers represent mean values ± SEM. Data of swimmers, runners, and wrestlers are statistically different from those of normal subjects ($P < 0.001$).

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range of left ventricular volume and wall thickness recorded as normal will be large, and decreased sensitivity in detecting patients with true cardiac abnormalities will result. Likewise, unless it is recognized that cardiac dimensions of trained athletes may fall considerably outside the range observed in nonathletic controls, an incorrect diagnosis of cardiac disease may result when evaluating a person who is participating in competitive athletics.

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