Left Ventricular Diastolic Function in Elite Athletes With Physiologic Cardiac Hypertrophy

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Left ventricular hypertrophy due to aortic stenosis, hypertension and other forms of heart disease is associated with abnormalities of diastolic function. It is uncertain whether these changes are an inherent consequence of the hypertrophic process or represent additional pathologic factors. To investigate this issue, echocardiographic indexes of left ventricular early diastolic function in highly trained athletes were compared with those in age-matched normal control subjects. Athletes were equally classified into two groups: 11 swimmers who had a pattern of myocardial hypertrophy with normal wall thickness to dimension ratio and 11 power lifters whose wall thickness to dimension ratio was increased.

The peak rates of left ventricular dimension increase and wall thinning in swimmers and power lifters were greater than in control subjects despite significantly higher left ventricular wall thickness and left ventricular mass index in the athletes. This increase in diastolic function indexes was associated with greater ventricular size and systolic performance. Normalization of the peak rate of dimension increase for end-diastolic dimension and adjustment of the peak rate of wall thinning for the fractional systolic thickening resolved any differences between groups. Thus, after the effects of ventricular size and systolic function were taken into consideration, diastolic function was normal in these subjects with considerable physiologic hypertrophy. This is in contrast to the findings in patients with hypertrophy associated with left ventricular pressure or volume overload, and suggests that abnormalities of diastolic function seen in pathologic hypertrophy are due to factors other than cardiac hypertrophy itself.

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Left ventricular hypertrophy due to primary myocardial disease, valvular aortic stenosis or hypertension has been associated with abnormal diastolic function (1–4). The factors that have been suggested (5,6) as being responsible include increased wall thickness, altered geometry, regional variation in wall thickness, interstitial fibrosis, loss of contractile elements, delayed intraventricular conduction and alterations in the reuptake of the myoplasmic activating calcium. It is uncertain whether the described abnormalities are a necessary consequence of the hypertrophic process or relate to the nature of the primary hypertrophic stimulus. One approach to this issue is to examine diastolic performance in subjects with hypertrophy not associated with disease. However, few studies (7,8) have addressed the effect of physiologic hypertrophy on diastolic function. This study examines noninvasive indexes of early diastolic function in two groups of elite athletes with substantial degrees of eccentric or concentric left ventricular hypertrophy.

Methods

Study group. The study group consisted of 22 athletes (11 swimmers and 11 power lifters, aged 17 to 30 years, mean 22) and 22 age-matched healthy control subjects. Swimmers were recruited from a swim team with a training program of 25 to 30 h/week; all had more than 5 years of competitive participation. Power lifters were all participants in national level competition within the prior 6 months and had more than 4 years of serious lifting experience. Control subjects were healthy, nonsedentary individuals who participated in athletic endeavors on a strictly amateur level and were not engaged in any routine training program. All were free of known cardiovascular disease, were taking no
cardioactive medications and had normal physical examination, electrocardiogram and intracardiac anatomy by two-dimensional echocardiography.

**Echocardiography.** High speed (100 mm/s) M-mode echocardiographic recordings of the left ventricular minor axis and simultaneous phonocardiogram were obtained using either an Advanced Technology Laboratories (ATL) real-time digital scanner or an Irex system II ultrasound module. High quality tracings were selected for computer analysis on a Franklin Quantic 1200 (Bruce Franklin, Inc.) echocardiographic review station. This device is equipped with a digitizing pad with a sampling rate of 80 points/cm, yielding a net digitizing rate of 800 points/s. Three to five beats were digitized for each subject, including the left ventricular septal endocardium and the free wall endocardium and epicardium.

**Measurements.** From the digitized data, the following instantaneous measurements are derived: 1) the left ventricular internal dimension throughout the cardiac cycle, including end-diastole taken at the Q wave on the electrocardiogram and end-systole taken at the time of aortic valve closure (that is, the first high frequency component of aortic second heart sound); 2) the first derivative of left ventricular dimension including the magnitude and timing of the peak rate of dimension change; 3) the left ventricular posterior wall thickness throughout the cardiac cycle with end-diastole and end-systole as defined previously; and 4) the first derivative of left ventricular wall thickness, including the magnitude and timing of the peak rate of wall thinning.

**Fractional shortening** was calculated as the difference between end-diastolic and end-systolic dimension divided by end-diastolic dimension. Fractional wall thickening was calculated as the end-diastolic to end-systolic wall thickness change divided by end-diastolic wall thickness. Left ventricular mass was calculated by modification of the formula of Devereux and Reichek (9):

\[
\text{Mass} = 1.04 [(D + 2h)^3 - D^3] - 14 \text{ g},
\]

where D and h represent end-diastolic dimension and wall thickness, respectively. Left ventricular mass index was calculated by dividing mass by body surface area.

**Normalized peak rate of dimension change** was calculated as \((dD/dt)_{max}/\text{EDD}\), where \((dD/dt)_{max} = \text{peak rate of dimension increase and EDD = end-diastolic dimension. Normalized peak rate of wall thinning was calculated as } (-dh/dt)_{max}/\text{FWT} = \text{peak rate of wall thinning and FWT = fractional wall thinning.**

The best method for adjusting these indexes for ventricular size and systolic function is controversial (1,10–12). In a previous study (13) in normal subjects we found the peak rate of chamber enlargement to be dependent on a variety of interacting factors including end-diastolic dimension. Peak rate of wall thinning was found to correlate most closely with fractional wall thickening (13). Large differences in end-diastolic dimensions and fractional wall thickening were found between the athletes and control subjects in our study. The extent to which these differences may contribute to any observed variation in diastolic function was therefore examined by directly adjusting peak filling rate for end-diastolic dimension and peak thinning rate for fractional wall thickening.

**Statistics.** Data are expressed as mean ± 1 SD unless otherwise noted. Comparisons among the three groups were made by one-way analysis of variance; overall differences were considered significant for \(p < 0.05\). Comparisons between individual groups were then performed using Bonferroni’s method for multiple simultaneous comparisons.

**Results**

Comparative data for control subjects, swimmers and power lifters are given in Table 1. As expected, body surface area was significantly greater in the power lifters. Both groups of athletes when compared with control subjects had significantly larger end-diastolic dimension with no difference in end-systolic dimension. Wall thickness was increased in power lifters at both end-diastole and end-systole. Swimmers had significantly increased wall thickness at end-systole only. Both fractional shortening and fractional wall thickening were increased in swimmers. Power lifters had increased fractional shortening with normal wall

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*p < 0.05 compared with control subjects; \(p < 0.05\) compared with swimmers. \(A_{2-(dD/dt)_{max}} = \text{time interval from aortic valve closure to peak rate of chamber enlargement}; A_{2-(dD/dt)_{max}} = \text{time interval from aortic valve closure to peak rate of wall thinning}; BSA = \text{body surface area}; (dD/dt)_{max} = \text{peak rate of chamber enlargement}; (-dh/dt)_{max} = \text{peak rate of wall thinning}; EDD = \text{end-diastolic dimension}; EDh = \text{end-diastolic wall thickness}; ESD = \text{end-systolic dimension}; ESh = \text{end-systolic wall thickness}; FS = \text{fractional shortening}; FWT = \text{fractional wall thinning}; HR = \text{heart rate}; LVM1 = \text{left ventricular mass index.}
thickening. Left ventricular mass index was significantly increased in both groups of athletes compared with that in control subjects, being significantly greater in power lifters than in swimmers. There was a trend toward slower heart rates in swimmers but the difference did not attain statistical significance.

The peak rate of dimension increase was significantly higher for both sets of athletes than for control subjects, with significantly higher values for swimmers than for power lifters. The peak rate of wall thinning was greater in swimmers than in control subjects or power lifters, and power lifters had a significantly higher peak rate of wall thinning than did control subjects. The timing of the peak rates of dimension increase and wall thinning was not significantly different for either group.

The significant differences in peak chamber enlargement rate between groups appeared to be due partly to differences in ventricular size. Thus, when adjusted for end-diastolic dimension (Fig. 1), normalized peak chamber enlargement rate was not different for the three groups. The variation in peak wall thinning rate between groups was associated with concomitant variations in fractional wall thickening. When adjusted for systolic performance, the normalized peak rate of wall thinning was not different for the three groups (Fig. 2).

Figure 1. Relative peak rate of dimension change (above) and normalized peak rate of dimension change (below) in 11 swimmers (S), 11 power lifters (L) and 22 control subjects (C). After normalization for end-diastolic dimension there were no differences among groups.

Figure 2. Relative peak rate of wall thinning (above) and normalized peak rate of wall thinning (below) in 11 swimmers (S), 11 power lifters (L) and 22 control subjects (C). Variation among groups could be explained by differences in systolic fractional wall thickening as no difference remained after normalization.

Normal diastolic function. Diastole can be divided into an early period of active, energy-consuming relaxation followed by a passive filling phase (14). The overlap that occurs between these two periods depends on the uniformity and completeness of the relaxation process (15). Relaxation appears to be dependent on the rate of myofibril inactivation and the loading conditions (16), whereas the passive filling phase is dependent on intrinsic elastic, viscous and inertial properties of the myocardium as well as certain external factors, predominant among which are the right ventricle and pericardium (17). Hypertrophy due to hypertension and valvular disease has been associated with abnormalities of both phases of diastole (3–5,14). The period of early diastolic rapid filling and wall thinning coincides with the transition between the active and passive phases of diastole and appears to be dependent on the combined effects of intrinsic myocardial properties, inactivation and loading conditions (1,2,12,13,18). Abnormalities of this period of diastole have been similarly noted (1,2,4,12,19–22) in various pathologic conditions associated with myocardial hypertrophy.

Diastolic function in physiologic hypertrophy. Hypertrophy that occurs in response to the stimulus of chronic exercise (that is, physiologic hypertrophy) does not appear to result in similar abnormalities in early diastolic function. The athletes in our study had a significant increase
in left ventricular mass, even when this value was normalized for body surface area. Despite this absolute and relative increase in left ventricular mass, the peak rates of dimension increase and wall thinning were significantly increased. We (12) and others (21) have previously noted a direct relation between the degree of left ventricular hypertrophy and impaired filling in patients with pathologic hypertrophy. In athletes with either concentric (increased wall thickness to dimension ratio) or eccentric (normal wall thickness to dimension ratio) hypertrophy, the opposite trend was observed.

Few previous studies (7,8,23) of diastolic function in physiologic hypertrophy have been performed. The diastolic properties of the left ventricle evaluated by the diastolic pressure-length relation (8,23), peak negative rate of rise of pressure (dP/dt) (23,24) and peak rate of chamber enlargement (23) have been found to be normal or increased in conditioned animals. Long-distance runners were found (7) to have greater peak rates of dimension increase compared with those of age-matched normal subjects, with even greater differences seen during exercise. Similar increases of the peak rates of chamber enlargement and wall thinning were found in our study for swimmers, who also displayed an eccentric pattern of hypertrophy, and for power lifters, whose pattern of hypertrophy more closely resembles that seen in aortic stenosis or hypertension.

Determinants of abnormal diastolic function. There are a number of interacting factors that may account for these findings and for the differences between pathologic and physiologic hypertrophy. Left ventricular filling and wall thinning depend in a complex fashion on ventricular size, function, contractile state and loading conditions (11,13,16). In addition to increased indexes of early diastolic function, the athletes in this study had increased ventricular size and systolic function. The augmentation of diastolic function in these subjects appears to be secondary to these factors since no differences were found after normalization. In contrast, subjects with aortic stenosis have reduced filling and wall thinning rates, even after adjustment for ventricular size and systolic function (12). Another potential source of variation relates to the fact that the athletes were assessed in the “unloaded” state (that is, the hemodynamic stress that leads to hypertrophy was not active at the time of evaluation), whereas, in general, subjects with aortic stenosis or hypertension are assessed with the hemodynamic load present. However, in the well compensated patient with aortic stenosis, peak wall stress is normal or low (25,26). Thus, early diastolic function would be either unaltered or increased in response to this influence (13,16). Differences in contractile state could contribute to the differences in diastolic function. This appears unlikely, however, because abnormal relaxation has been observed in patients with aortic stenosis who have a normal contractile state (27). Additionally, we (28) and others (7) found normal contractile function in highly trained subjects. Finally, training could have primary effects on the activator calcium reuptake process. At present, there is no data to address the latter hypothesis.

Conclusions. Athletes with significant physiologic hypertrophy display augmented early diastolic function that appears to be secondary to increased systolic function and cardiac size. Diastolic abnormalities in subjects with pathologic hypertrophy are unlikely to be related to increased wall thickness alone, but must reflect intrinsic myocardial abnormalities, altered systolic function, or both.

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