The effects of isometric stress on left ventricular filling in athletes with isometric or isotonic training compared to hypertensive and normal controls

E. G. Abinader, D. Sharif, M. Sagiv and E. Goldhammer

Heart Institute and CCU, Bnai Zion Medical Center, (Rothschild) and Faculty of Medicine, Technion, Haifa, Israel

Hypertrophy of the left ventricle may be associated with altered left ventricular filling dynamics. To test whether isometric and isotonic training affect left ventricular filling differently at rest and during isometric stress, 38 males, 13 long distance runners, eight weight-lifters, eight hypertensive patients and nine age-matched healthy male controls with a mean age of 30 ± 7 years, were studied before and after 90 s of 50% maximal handgrip force. Left ventricular Doppler filling parameters were compared in the four groups while they were resting and during isometric stress testing, and the results assessed in relation to left ventricular mass index and wall stress. All subjects had normal resting filling patterns except for hypertensive patients, and peak meridional wall stress was low in both athletic groups at rest. Weight-lifters had a hypertensive response during isometric stress testing, associated with a reduction in peak E velocity and a marked increase in peak A velocity, resembling the filling pattern in hypertensive subjects. In runners the filling pattern remained normal.

Thus, while the resting left ventricular pattern was normal in all athletes, isometric stress testing was associated with a hypertensive filling pattern only in weight-lifters compared to normal filling in runners.

(Eur Heart J 1996; 17: 457-461)

Key Words: Runners, weight-lifters, hypertension, Doppler ventricular filling, isometric stress.

Introduction

Hypertrophy of the left ventricle occurring in several disease states, such as chronic pressure overload and hypertrophic cardiomyopathy, may be associated with altered left ventricular filling dynamics. Abnormal left ventricular filling occurs even in young subjects with mild hypertension without hypertrophy.

Left ventricular hypertrophy in athletes is considered to be physiological, with subjects experiencing normal resting left ventricular filling. However, in clinical practice, cardiac hypertrophy and/or dilatation in athletes is often considered as bordering on disease and thus limitation of athletic activities may be advised. It is argued that in such a setting stress may have a deleterious effect on cardiac function. The present study was conducted in order to test whether athletes with left ventricular hypertrophy and preserved systolic function have occult left ventricular filling abnormalities that may become manifest during exercise and whether the type of sport, isotonic or isometric, affects left ventricular filling. Two control groups were formed from normal and hypertensive subjects.

Methods

Thirty-eight males, comprising 13 long-distance runners, eight weight-lifters, eight hypertensive patients and nine age-matched healthy male controls, with a mean age of 30 ± 7 years were studied. All the athletes were national competitive sportsmen engaged in periodic sporting events and were examined to exclude usage of performance-enhancing drugs. Long-distance runners were at national level actively engaged in running at least 60 km per week and weight-lifters had been training for at least 4 years for several hours per session at least three times a week, and each could bench-press at least 100 kg. Blood pressures in hypertensive patients had been elevated for 3-5 ± 2 years before the study, and were found repeatedly to have systolic and diastolic pressures greater than 140 and 90 mmHg, respectively. Normal subjects were sedentary healthy age-matched males. Physical examination was normal in all and all were in sinus rhythm, as revealed by resting 12-lead
electrocardiograms. All were considered normal except for four subjects with hypertension in whom the voltage criteria was indicative of left ventricular hypertrophy.

**Study protocol**

Informed consent was obtained from subjects. To determine maximal hand-grip force, at least 3 min intervals three brief (<10 s) maximal voluntary right hand contractions were performed. Thirty to 60 min later, after interview and following an electrocardiogram taken while the subject was at rest, the subjects maintained 50% of the maximal force for 90 s. Electrocardiographic monitoring was performed during the study. Measurement of heart rate, cuff arm blood pressure, and heart rate systolic blood pressure product were obtained. Complete Doppler echocardiographic studies, using an Aloka SSD-730 machine equipped with 2 and 3 MHz transducers, were performed with the subjects at rest. Using two-dimensionally directed M-mode echocardiographic recordings, the diameters of the left ventricle at end-diastole and end-systole were measured at the level of the tips of the mitral leaflets. Left ventricular septal and posterior wall end-systolic and end-diastolic thickness was measured from the parasternal short axial views just below the level of the mitral valve, according to the recommendations of the American Society of Echocardiography.[9]

Left ventricular mass and mass index were calculated using the formula of Devereux and Reichek.[10]

\[
\text{Mass} = 1.04 \left(\text{LVIDD} + 2 \times \text{LVWTD}\right)^3 - \text{LVIDD}^3 - 14 \text{ g}
\]

where LVIDD is left ventricular end-diastolic diameter and LVWTD wall thickness in end-diastole. Mass index was calculated by dividing mass by body surface area. Peak meridional systolic wall stress was assessed as:

\[
\text{Stress} = \left[0.334 \times \text{SBP} \times \text{LVIDD}\right]/\left(\text{LVWTD} \times (1 + \text{LVWTD}/\text{LVIDD})\right) \text{ dynes/cm}^2 \times 1000
\]

where SBP=systolic arterial blood pressure in mmHg, LVWTD and LVIDD as above.[11]

Pulsed Doppler interrogation was performed from the apical four chamber view with a 5 mm sample volume at the level of the mitral annulus, while a less than 10° angle between the Doppler cursor line and the long axis of the left ventricle was maintained. Peak blood velocity through the mitral valve during early diastole (E) and pre-systole (A), as well as the E/A peak velocity ratio, the time velocity integral (TVI) of the whole inflow period (total TVI), the E-TVI, A-TVI, and the atrial filling fraction (AFF%) were measured by a blinded observer. Left ventricular isovolumic times, from aortic valve closure to the beginning of mitral flow, were measured from Doppler sampling of inflow-outflow regions from the apical five-chamber view.[12] The Doppler parameters at left ventricular inflow, blood pressure, and the heart rate systolic blood pressure product were measured at rest and at the end of 90 s of isometric stress testing.

Echocardiographic and Doppler measurements were performed by two observers (E.G.A. 20 subjects and D.S. 18 subjects). Three consecutive beats were analysed by each observer, and the averages calculated. Measurements were repeated by the two observers in 10 subjects at different times to calculate variability of the measurements. Inter- and intra-observer variability was expressed as the ratio of the difference between measurements, divided by the mean of measurements. For time velocity integral measurements, inter- and intra-observer variability were 4 and 6%, while for peak velocity measurements were 2 and 3%, respectively.

**Statistical analysis**

Two-way analysis of variance with repeated measures was employed to detect any possible changes in each variable as a result of isometric stress. The Student–Neuman–Kuels post-hoc procedure was used for specific comparison, with the level of statistical significance at P<0·05. In order to compare the descriptive data of the groups, one-way analysis of variance was used, and the Tukey post-hoc procedure applied for assessing significance at a level of P<0·05. Multiple regression analysis (stepwise variable selection) was performed with blood pressure, heart rate, left ventricular mass, wall thicknesses and peak meridional wall stress (as independent parameters) affecting ventricular filling (as a dependent parameter).

**Results**

Mean descriptive data of the athletic, hypertensive and normal groups are presented in Table 1. No significant differences were found between the groups as regards age, height, body weight or surface area. Left ventricular end-systolic diameters were smaller in weight-lifters than in the other groups, while left ventricular end-diastolic diameter, 48 ± 2 mm, and fractional shortening, 36 ± 3% in runners, were higher than in the other groups, P<0·05. The end-diastolic thickness of the inter-ventricular septum and left ventricular posterior wall were similar in the runners, weight-lifters and hypertensive groups and were higher than in normal subjects. Left ventricular mass and mass index were highest in hypertensive and weight-lifters, P<0·05. Thus, the runners had left ventricular hypertrophy with a larger end-diastolic diameter and when corrected for body surface area, while weight-lifters had ventricular hypertrophy and a smaller end-diastolic diameter. Resting peak meridional wall stress was highest in hypertensive patients and lowest in weight-lifters, P<0·01.

Maximal voluntary contractions in kg were similar in controls (52·6 ± 7·8 kg), runners (55·4 ± 7·2 kg) and hypertensive subjects (53·4 ± 8 kg) and
Ventricular filling in athletes and hypertensives 459

Table 1 Resting characteristics of the study population

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Runners</th>
<th>Weight-lifters</th>
<th>Hypertensives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>31 ± 7</td>
<td>38 ± 9</td>
<td>30 ± 10</td>
<td>40 ± 10</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78 ± 7</td>
<td>68 ± 7</td>
<td>70 ± 10</td>
<td>73 ± 10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176 ± 6</td>
<td>174 ± 7</td>
<td>168 ± 11</td>
<td>168 ± 12</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1-9 ± 0-1</td>
<td>1-8 ± 0-1</td>
<td>1-8 ± 0-2</td>
<td>2-0 ± 0-1</td>
</tr>
<tr>
<td>IVS (mm)</td>
<td>10 ± 2</td>
<td>13 ± 2</td>
<td>13 ± 2</td>
<td>13 ± 3</td>
</tr>
<tr>
<td>LPW (mm)</td>
<td>45 ± 3</td>
<td>49 ± 5</td>
<td>43 ± 3</td>
<td>44 ± 5</td>
</tr>
<tr>
<td>LVEDD (mm)</td>
<td>33 ± 2</td>
<td>31 ± 5</td>
<td>28 ± 2</td>
<td>33 ± 2</td>
</tr>
<tr>
<td>LVESD (mm)</td>
<td>32 ± 4</td>
<td>36 ± 5</td>
<td>34 ± 3</td>
<td>31 ± 3</td>
</tr>
<tr>
<td>FS %</td>
<td>165 ± 23</td>
<td>289 ± 51</td>
<td>280 ± 66</td>
<td>251 ± 91</td>
</tr>
<tr>
<td>LV mass (g)</td>
<td>84 ± 7</td>
<td>166 ± 25</td>
<td>158 ± 37</td>
<td>135 ± 53</td>
</tr>
<tr>
<td>Mass index (g . m⁻²)</td>
<td>145 ± 32</td>
<td>118 ± 16</td>
<td>94 ± 13</td>
<td>153 ± 29</td>
</tr>
<tr>
<td>Peak M stress</td>
<td>145 ± 32</td>
<td>118 ± 16</td>
<td>94 ± 13</td>
<td>153 ± 29</td>
</tr>
<tr>
<td>(dynes . cm⁻²) × 1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BSA = body surface area; FS = fractional shortening; IVS and LPW = thickness of interventricular septum and left ventricular posterior wall; LV = left ventricle; LVEDD and LVESD = left ventricular end-diastolic and systolic diameters. Peak M stress = peak meridional wall stress.

Table 2 Heart rate and blood pressure measurements at rest and during stress

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Stress</th>
<th>Rest</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats . min⁻¹)</td>
<td>70 ± 11</td>
<td>88 ± 12</td>
<td>117 ± 18/73 ± 9</td>
<td>138 ± 8/85 ± 6</td>
</tr>
<tr>
<td>Blood pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td>53 ± 6</td>
<td>68 ± 6</td>
<td>116 ± 12/69 ± 6</td>
<td>136 ± 8/84 ± 7</td>
</tr>
<tr>
<td>Runners</td>
<td>66 ± 6</td>
<td>89 ± 11</td>
<td>121 ± 8/69 ± 11</td>
<td>170 ± 14/99 ± 4</td>
</tr>
<tr>
<td>Hypertension</td>
<td>77 ± 11</td>
<td>95 ± 17</td>
<td>155 ± 20/92 ± 7</td>
<td>177 ± 20/100 ± 5</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0-01</td>
<td>&lt;0-01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

higher in weight-lifters (62-3 ± 6-1 kg), P<0-05. All subjects completed the isometric stress test without adverse effects and their heart rate and blood pressure increased, P<0-01. Heart rates in runners at rest (53 ± 6 beats . min⁻¹) and during isometric stress (68 ± 6 beats . min⁻¹) were significantly lower than in the other groups, P<0-05 (Table 2). Blood pressure was highest at rest in hypertensive patients, while during isometric stress weight-lifters achieved similar blood pressures as in the hypertensive group, P<0-01 (Table 2). Thus runners had left ventricular hypertrophy associated with larger end-diastolic diameters and low resting peak meridional wall stress while weight-lifters had left ventricular hypertrophy, normal end-diastolic diameters and the lowest peak meridional wall stress.

Auscultation and Doppler studies revealed no valvular regurgitation in any subject. Table 3 shows the diastolic filling parameters of the study groups at rest and during isometric stress.

### Left ventricular filling at rest

Both athletic groups had normal resting left ventricular filling parameters, as reflected by normal E/A peak velocity ratios and atrial filling fractions, without any statistical difference (Table 3). Hypertensive subjects had smaller E peak velocities, P<0-05, and integrals, P<0-05, and larger A velocities, P<0-01 and integrals, P<0-05, with smaller E/A peak velocity ratios, P<0-05, and larger atrial filling fractions, P<0-05 (Table 3).

### Isometric stress

The E wave did not change significantly in normals and runners (P not significant), while their A wave velocities and integrals increased, P<0-05 (Table 3). Runners had a smaller atrial filling fraction compared to normals during stress, P<0-05. Weight-lifters had a reduction in E velocity, P<0-05, and integral, P<0-05, and marked increases in A velocity, P<0-01, and integral, P<0-01, with a decrease in the E/A velocity ratio, P<0-05, and a marked increase in the atrial filling fraction, P<0-05, compared to resting values, and were similar to those in hypertensive subjects during isometric stress testing, P not significant (Table 3). Hypertensive subjects retained their abnormal filling pattern, with a reduction in E and an increase in A waves during isometric stress, P<0-05 (Table 3).

Isovolumic relaxation times were similar in the four groups and did not change significantly during isometric stress testing (Table 3). Left ventricular filling at rest and during isometric stress testing correlated with

Eur Heart J, Vol. 17, March 1996
systolic blood pressure. Thus, atrial filling fraction had a linear relationship with systolic blood pressure, \( r = 0.86 \) (\( P < 0.05 \)). The increase in systolic blood pressure was associated mainly with augmentation of the pre-systolic A-wave peak velocity and integral, \( r = 0.83 \) (\( P < 0.05 \)) and 0.73 (\( P < 0.05 \)), respectively, and a reduction in the early diastolic E-wave integral, \( r = -0.55 \), and E/A velocity ratio, \( r = -0.81 \). The multiple regression model at rest had \( r^2 = 0.977 \) (\( F = 331.85, P = 0.00001 \)), showing the atrial filling fraction to be affected primarily by left ventricular mass, heart rate and diastolic pressure, with a coefficient of regression of 0.026, 0.242, 0.2, a standard error of 0.0098, 0.077, 0.077 and a \( P \) value of 0.0012, 0.0038 and 0.0161, respectively. During isometric stress testing, the multiple regression model was \( r^2 = 0.954 \) (\( F = 97.623, P = 0.00001 \)), with the atrial filling fraction affected mostly by left ventricular mass, peak meridional stress, systolic blood pressure with a coefficient of regression of -0.089, -0.123, 0.0255, a standard error of 0.033, 0.06, 0.13 and a \( P \) value of 0.0149, 0.05 and 0.06, respectively.

**Discussion**

Left ventricular hypertrophy in athletes has been studied using echocardiography in subjects while they were at rest\(^{6,13,14}\). However, haemodynamic abnormalities usually appear during stress. The haemodynamic effects in athletes consist of intermittent pressure and/or volume overload, and thus, during strenuous exercise, cardiac output increases fourfold; mean arterial blood pressure and left ventricular filling pressure increase by 20% and 70%, respectively\(^{15}\). Since, diastolic dysfunction often precedes systolic dysfunction\(^{16,17}\), the present study assessed left ventricular filling parameters both at rest and during isometric stress, which predominantly increases left ventricular afterload. In runners, left ventricular hypertrophy was associated with larger end-diastolic diameters, while in weight-lifters, the hypertrophy was associated with normal end-diastolic diameters. Left ventricular masses and mass indices were similar in runners and weight-lifters and were significantly higher in athletic subjects than in hypertensive patients and normal subjects. Peak meridional wall stress was lowest in weight-lifters, while in hypertensive patients it was similar to normal controls.

In contrast to our experience in hypertensive patients with ventricular hypertrophy, in whom increased reliance on atrial contribution to ventricular filling was demonstrated\(^{10}\), the present study revealed normal resting filling parameters in athletes, inspite of ventricular hypertrophy. Although the normal resting ventricular filling patterns in athletes confirm the 'physiological' nature of hypertrophy in these subjects, they may be related to the associated low resting afterload, as expressed by peak meridional wall stress. During isometric stress, the systemic blood pressure in weight-lifters rose to levels similar to those in hypertensive patients, while runners maintained a normal blood pressure response. This abnormal reaction to the stress in weight-lifters was associated with pathological left ventricular filling, resembling the hypertensive filling pattern. On the other hand, filling patterns in runners were similar to normal subjects during isometric stress.

The diastolic left ventricular filling pattern is determined by the instantaneous pressure gradient between the left atrium and the left ventricle. This gradient is influenced by loading conditions, ventricular geometry and mass, heart rate, age, ventricular and myocardial relaxation, stiffness and ischaemia\(^{18,19}\). The age was similar in both athletic groups, and factors such as myocardial ischaemia and fibrosis are unlikely in these subjects because they were healthy young males with normal resting filling patterns. Left ventricular isovolumic periods at rest were similar in the four groups and, as others found, were not affected by hypertension\(^{6}\). Furthermore isovolumic periods during isometric stress did not change, as Ludbrook et al. found\(^{20}\), suggesting that the change in left ventricular filling was not related to a change in relaxation. Since heart rates were higher in weight-lifters compared to runners, both at rest and during isometric stress, it cannot explain the difference in filling pattern, which occurred only during stress. Although multiple regression analysis revealed that ventricular filling was dependent on ventricular
mass, peak meridional wall stress blood pressure and heart rate, systolic blood pressure was the parameter which differed markedly and it seems to be the most plausible factor to explain the differences in ventricular filling in weight-lifters and runners.

References