Cardiovascular Response to Isometric Exercise
in Normal Adolescents

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SUMMARY The purpose of this study was to document the cardiovascular response to submaximal isometric handgrip (IHG) exercise in 32 normal adolescents. Left ventricular (LV) dimensions and systolic time intervals were recorded using echocardiography; blood pressure was measured by sphygmomanometry both at rest and during IHG exercise at 25% maximum contraction. This level of isometric exercise produced significant \( p < 0.001 \) increases in mean heart rate, systolic, diastolic and mean blood pressures. Despite this response LV diastolic and systolic dimensions remained unchanged during exercise; hence, stroke volume remained constant. Cardiac index increased by \( 22\% \) \( p < 0.001 \) due to the increase in heart rate. Systemic vascular resistance did not change significantly. LV ejection indices, including shortening fraction, mean Vcf and systolic time intervals also remained unchanged, except for an increase in LV ejection time index \( p < 0.025 \). These data indicate that the cardiovascular response to submaximal isometric exercise in normal adolescents is similar to that reported in adults. This study demonstrates that sustained isometric stress testing in adolescents is safe and provides normal hemodynamic values.

EVALUATION OF CIRCULATORY ALTERATIONS during sustained isometric muscle contraction is a useful method to assess cardiac function. The hemodynamic responses of this provocative test have been well-documented in adults. Characteristically, there is an increase in cardiac output and blood pressure, but little change in total peripheral resistance.\(^1\) Among adults, there appear to be age-related differences in the response, whether evoked at submaximal\(^2\) or near-maximal\(^3\) exertion.

No information is available describing the cardiovascular effects of static muscular contraction in normal adolescents. We undertook a noninvasive study using echocardiographic determinations of left ventricular (LV) function and systolic time intervals to document in normal, young adolescents the cardiovascular responses to submaximal isometric exercise.

Materials and Methods

The study population included 32 healthy volunteers (10 female and 22 male) ages 14–16 years, with an average age of 14.7 years. All were considered normal on the basis of history, physical examination, ECG and chest x-ray. A handgrip dynamometer (Stoelting Co., Chicago, Illinois) was used to determine maximum voluntary isometric contraction at least 15 minutes before the study. The average maximum contraction was calculated from three consecutive maximal handgrip attempts. Subjects were instructed not to perform a Valsalva maneuver during the exercise period, and were carefully observed for this during the isometric exercise.

Data were obtained just before and in the third and fourth minute of handgrip exercise at 25% maximum voluntary contraction (MVC). Arterial blood pressure was measured in the non-exercising arm using a mercury sphygmomanometer. LV echocardiograms were recorded during exercise at 3 minutes; systolic time intervals were determined from the aortic valve echocardiogram during the fourth minute.

All echocardiograms were obtained using an Ekoine 20 ultrasonicoscope interfaced to an Ekoine 21 strip chart recorder. Studies were performed from the third or fourth intercostal space at the left parasternal edge with the subject in the supine position. Occasionally a slight left lateral decubitus position was required to record the ventricular septum clearly.

Dimensions of the left ventricle were obtained with the ultrasound beam passing through the left ventricle at the tips of the mitral valve leaflets.\(^4\) Once this position was obtained and baseline recordings made with the subject at rest, the transducer was not removed from the chest wall and we attempted to maintain the transducer beam in the same direction during the isometric exercise. End-diastolic diameter (LVID\(d\)) was measured at the onset of the QRS complex. End-systolic diameter (LVID\(s\)) was measured at the point in late systole when the septum and LV posterior wall were in closest apposition (fig. 1). Near the end of the third minute of exercise, LV dimensions were recorded. In the fourth minute, LV systolic time intervals were determined using the aortic valve echo recorded at 100 mm/sec paper speed (fig. 2).\(^5\) The aortic valve signal was visualized by angling the ultrasound beam in a medial and cephalad direction from the mitral valve.\(^7\) For both LV dimensions and systolic time intervals, five consecutive complexes were measured and averaged. We obtained recordings satisfactory for measuring systolic time intervals in 18 of 32 subjects (56%).

From these echocardiographic recordings, we determined LV end-diastolic and end-systolic volumes,\(^6\) stroke volume and cardiac index,\(^8\) shortening fraction (SF),\(^10, 11\) and mean velocity of circumferential fiber shortening (Vcf).\(^10-12\) The cardiac index and calculated mean blood pressure\(^13\) were used to estimate systemic vascular resistance.\(^14\) LV ejection time index (LVETI) was calculated using data from normal pediatric sub-

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From the Department of Pediatrics, University of Texas Health Science Center, Southwestern Medical School, Dallas, Texas. Supported by grant HL-18456-01 from the NHLBI. Address for reprints: W. Pennock Laird, M.D., Children's Medical Center, 1935 Amelia Street, Dallas, Texas 75235. Received June 5, 1978; revision accepted November 8, 1978. Circulation 59, No. 4, 1979.
jects. Statistical analysis of the results was done using the t test for paired data.

Results

The results are summarized in tables 1-3. In the adolescents isometric handgrip contraction at 25% MVC produced a significant \( p < 0.001 \) elevation in mean heart rate, systolic, diastolic, and mean blood pressures. Despite this response, LV diastolic and systolic dimensions were unchanged during exercise. Stroke volume remained constant. Therefore, the observed increase \( p < 0.001 \) in cardiac index was due to the increase in heart rate. Systemic vascular resistance index did not change significantly. With this degree of isometric exercise LV ejection indices including SF, mean Vcf, and systolic time intervals also remained unchanged, except for LVETI, which increased \( p < 0.025 \).

![Figure 1. Echocardiogram showing method by which left ventricular (LV) dimensions were determined. End-diastolic diameter \( (LVID_d) \) was measured between the endocardial surfaces of the interventricular septum (IVS) and the left ventricular posterior wall \( (LVPW) \) at the onset of the QRS complex of the ECG. End-systolic diameter \( (LVID_s) \) was measured at the point in late systole when the septum and posterior wall were in closest apposition. Portions of mitral valve \( (MV) \) are recorded.](image)

![Figure 2. Aortic valve echocardiogram demonstrating method by which left ventricular systolic time intervals were determined. Paper speed 100 mm/sec; time dots 0.1 sec. PEP = pre-ejection period; LVET = left ventricular ejection time; Ao = aorta; LA = left atrium.](image)

Discussion

We chose adolescents as subjects to provide a younger population distinct from adults. To some extent, this relatively narrow age range may limit the applicability of the findings.

For these adolescents we set the level of isometric exercise at 25% of a MVC held for 4 minutes. We had several reasons for using this relatively low level of

| Table 1. Hemodynamic Changes During Isometric Exercise in Normal Adolescents (n = 33) |
|-----------------------------------------------|-----------------|
|                                | Rest            | Isometric exercise |
| Heart rate (beats/min)           | 70 ± 9 \( (p < 0.001) \) | 88 ± 11          |
| Systolic pressure (mm Hg)        | 110 ± 7 \( (p < 0.001) \) | 124 ± 10         |
| Diastolic pressure (mm Hg)       | 61 ± 8 \( (p < 0.001) \) | 76 ± 8           |
| Mean pressure (mm Hg)            | 78 ± 7 \( (p < 0.001) \) | 92 ± 7           |
| Cardiac index \( (l/min/m^2) \)  | 3.1 ± 0.7 \( (p < 0.001) \) | 3.8 ± 0.8       |
| Systemic vascular resistance \( (mm Hg/min/l^-1) \) | 27 ± 7 \( (NS) \) | 25 ± 5          |

Values are mean ± sd.
exertion. Since our protocol called for high-quality echocardiograms to first record ventricular dimensions and then systolic time intervals from the aortic valve, sufficient recording time of 1–2 minutes during exertion was required. We began to record after 2 minutes of exercise, since that amount of time may be necessary before a significant effect is observed in some subjects. Accordingly, a test period of 4 minutes was necessary.

Our preliminary work with the adolescents indicated that at 25% MVC, virtually all would cooperate and maintain the desired level of contraction for 4 minutes without performing a Valsalva maneuver, excessive body movements, or stopping to rest. We felt that a 25% MVC effort would be sufficient to induce hemodynamic effects in the children, since information in the literature indicates that in normal adults, a response will be produced as long as a fatiguing load greater than 20% MVC is maintained. However, it seems clear that higher work levels will induce greater responses.

The circulatory effects of sustained isometric contraction have been well studied in healthy adult subjects. Using either catheterization techniques or more recently, noninvasive methods such as echocardiography, the findings have been consistent. The normal response includes an elevation of arterial blood pressure which is primarily due to an increase in cardiac output, with little or no change in systemic vascular resistance. The augmented cardiac output results from an increase in heart rate, since stroke volume remains relatively unchanged.

The results of our study indicate that the response in adolescents is remarkably similar to that found in adults. The actual percent increases with exercise in mean heart rate (26%) and cardiac index (22%) among our subjects are in agreement with published data in adults. Blood pressure elevations in normal adults (systolic, diastolic or mean) appear to vary in relation to the magnitude of the work load involved. At 30–33% MVC a 14–25% increase in mean arterial blood pressure was recorded, while at 50% MVC substantially higher blood pressure elevations have been noted. The 18% rise in mean blood pressure in the adolescents seems in line with the adult response, considering the level of exertion. It has been suggested that there may be age-related differences in the effect of isometric exercise on systemic vascular resistance with younger subjects possibly experiencing a fall in resistance. Our findings do not support such conclusions. We found that in the adolescents systemic vascular resistance did not change significantly during the exercise period.

In recent years echocardiography has been shown to be a reliable noninvasive method to assess LV performance both at rest and during exercise. The commonly used indices include the percent shortening of the LV lateral minor axis during systole (SF), the mean Vcf and systolic time intervals.

The LV SF has been proven a useful measure of ventricular function, since normal values are similar for both children and adults despite differences in resting heart rates. In the present study the resting values for SF were in agreement with published normals. During isometric exercise the SF did not change significantly, a finding similar to that reported in adults.

The mean Vcf has been suggested as a more sensitive index of LV function, since it adds an element of time to the measurement of change in LV dimensions. However, this results in a direct relation between mean Vcf and heart rate. In our subjects, despite an increase in heart rate with isometric exercise, the average values for mean Vcf remained unchanged, which is the response reported in adults. This failure for the Vcf to increase might have been due to the acute rise in blood pressure.

Hirschliefer et al. found mean Vcf fell after phenylephrine increased blood pressure in normal adults whose heart rates were controlled. In our subjects the tachycardia during isometric exercise may have enhanced myocardial contractility sufficiently to maintain Vcf even with an increased afterload.

Systolic time intervals have been extensively studied in both adults and children in various clinical situations, and are generally felt to correlate well with ventricular hemodynamics. Several studies in healthy adults indicate that systolic time intervals are sensitive enough to detect changes in ventricular performance during isometric exercise. The ratio of pre-ejection period (PEP) to LV ejection time (LVET) is par-

### Table 2. Echographic Findings During Isometric Exercise in Normal Adolescents (n = 38)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rest</th>
<th>Isometric exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVIDd (cm)</td>
<td>4.72 ± 0.34 (NS)</td>
<td>4.74 ± 0.32</td>
</tr>
<tr>
<td>LVIDs (cm)</td>
<td>3.06 ± 0.23 (NS)</td>
<td>3.10 ± 0.29</td>
</tr>
<tr>
<td>LV shortening fraction (%)</td>
<td>35 ± 3 (NS)</td>
<td>34 ± 4</td>
</tr>
<tr>
<td>Left atrial diameter (cm)</td>
<td>2.7 ± 0.4 (NS)</td>
<td>2.8 ± 0.4</td>
</tr>
</tbody>
</table>

Values are mean ± sd.

Abbreviations: LVIDd and LVIDs = end-diastolic and end-systolic internal minor dimensions of the left ventricle.

### Table 3. Indices of Left Ventricular Function During Isometric Exercise in Normal Adolescents (n = 18)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rest</th>
<th>Isometric exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection time (msec)</td>
<td>284 ± 16 (NS)</td>
<td>275 ± 15</td>
</tr>
<tr>
<td>Preejection period (msec)</td>
<td>84 ± 13 (NS)</td>
<td>82 ± 11</td>
</tr>
<tr>
<td>PEP/ET</td>
<td>0.297 ± 0.054 (NS)</td>
<td>0.299 ± 0.045</td>
</tr>
<tr>
<td>Ejection time index (msec)</td>
<td>373 ± 12 (p &lt;0.025)</td>
<td>386 ± 14</td>
</tr>
<tr>
<td>Mean Vcf (circ/sec)</td>
<td>1.29 ± 0.12 (NS)</td>
<td>1.32 ± 0.14</td>
</tr>
</tbody>
</table>

Values are mean ± sd.

Abbreviations: PEP = preejection period; ET = ejection time; Vcf = velocity of circumferential fiber shortening.
particularly useful as an expression of LV performance, since it appears to correlate closely with other indices of LV function and is not influenced by a wide variation in heart rate. Furthermore, the ratio tends to reflect abnormalities in both intervals when neither measurement appears abnormal.

In the present investigation the average PEP/LVET at rest was similar to normal values previously reported in pediatric studies. With isometric exercise at 25% MVC, we found a tendency for LVET to shorten, with even less shortening of the PEP. However, the ratio PEP/LVET did not change significantly with isometric exercise. The results of studies in normal adults using similar isometric work loads have been variable. Although most reports describe a shortening of LVET, changes in PEP/LVET have been inconsistent, either increasing or showing no change with submaximal isometric exercise.

In order to correct for the effect of heart rate on LVET, we calculated the LVETI on each subject both at rest and with isometric exercise. The results indicate that the isometric exercise produced prolongation of the LVETI in these adolescents. Since stroke volume was unchanged and correction was made for the effect of heart rate, presumably this response was a result of increased arterial pressure. However, Quarry and Spodick did not come to this conclusion in their studies on normal adults. They found that in adults, moderate isometric handgrip exercise produced a prolonged LVETI only with upright posture, not in the supine position. They theorized that stroke volume changes were responsible for these findings, since pressure changes were similar in each group.

Further investigation will be necessary to determine the significance of these apparently different responses in adults and adolescents. It would also be appropriate to evaluate the effects on systolic time intervals in adolescents produced by higher levels of isometric exertion, since adult studies have demonstrated that increased exertion will produce greater alteration of systolic time intervals.

This study demonstrates that sustained isometric exercise is a safe technique which is well-tolerated by adolescents. Noninvasive evaluation of cardiac function during isometric exercise can be accomplished using echocardiography. The data obtained in these normal subjects provide control values which may be used in studies of adolescents with known or suspected cardiovascular disease. The technique would be especially useful in assessing LV function in young patients with abnormalities of the left heart, such as pre- or postoperative aortic stenosis, coarctation of the aorta or systemic hypertension.

References

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