Cardiac Involvement in Adolescent Hypertension
Echocardiographic Determination of Myocardial Hypertrophy

KENNETH G. ZAHKA, M.D., CATHERINE A. NEILL, M.D., LANGFORD KIDD, M.D.,
MARIANNE A. CUTILLETTA, AND ANTHONY F. CUTILLETTA, M.D.
with the technical assistance of CATHY HENSLEY

SUMMARY We measured left ventricular chamber dimension and wall thickness using M-mode echocardiography in 61 adolescents with systolic or diastolic blood pressures above the 90th percentile for age and sex and in 49 normotensive adolescents. Left ventricular posterior wall and ventricular septal thickness indexed to body surface area were significantly greater (p < 0.001) in the hypertensive group than in the normotensive controls. Left ventricular chamber diastolic and systolic dimensions were not different in the hypertensive group when compared to normotensive adolescents with comparable body size. Left ventricular diastolic and systolic volumes as well as left ventricular function did not differ between the hypertensive and control groups. Calculated parameters of left ventricular hypertrophy, namely, the radius-to-wall-thickness ratio, cross-sectional muscle area, and left ventricular mass, in the hypertensive adolescents were all significantly different (p < 0.001) from those in the control groups. The finding of myocardial hypertrophy in young, mildly hypertensive subjects suggests early myocardial involvement in the hypertensive process.

KEY WORDS • hypertension • adolescent • hypertrophy • echocardiogram

EARLY recognition of essential hypertension in the pediatric population affords us the opportunity to study and follow asymptomatic patients in the initial and often mild stages of the hypertensive syndrome. Early evaluation of these patients may increase our understanding of the etiology, pathogenesis, and cardiovascular sequelae of essential hypertension.

Recent studies in adults with mild-to-moderate hypertension using M-mode echocardiography have shown that a majority of these hypertensive patients have increased ventricular septal or left ventricular posterior wall thickness.1 In the adolescent population, Laird et al.4 found increased posterior wall thickness in 23% of the mildly hypertensive subjects. Similarly, Nishio et al.6 demonstrated increased left ventricular mass in greater than 20% of a group of mildly hypertensive adolescents. Goldring et al.,4 however, found no difference in wall thickness between hypertensive adolescents and normal subjects.

In this study we used M-mode echocardiography to measure left ventricular chamber dimensions and wall thickness in a group of adolescents with mild to moderate hypertension. From these parameters we calculated indices of left ventricular volume, mass, and function. The purpose of this study was to determine whether alterations of left ventricular volume, mass, and function exist in this population despite the relatively brief duration and mild to moderate severity of the disease.

METHODS
We performed M-mode echocardiograms on 61 hypertensive and 49 normotensive adolescents. The hypertensive subjects were those referred to our Adolescent Blood Pressure Center and found to have mild to moderate hypertension. Forty-four of the normotensive group were adolescents referred for evaluation of functional murmurs, and five were selected at random from the general outpatient clinics. None had a history of hypertension or structural heart disease. We measured arm-cuff blood pressures in the sitting position in each hypertensive subject on two occasions during each of three clinic visits. Diastolic pressure was recorded as the fourth phase of the Korotkoff sounds. The average of the six systolic and diastolic readings was used. Systolic or diastolic blood pressure levels were above the 90th percentile for age in each of the hypertensive subjects, using the criteria established by the National, Heart, Lung, and Blood Institute.6 Blood pressures in the normotensive group were below
the 90th percentile, but otherwise normally distributed. To facilitate comparisons with the hypertensive group, a subgroup of the normotensive population was formed consisting of the 19 normotensive adolescents with the greatest body surface area (BSA). The large BSA in this group was due to obesity defined as body weight greater than the 95th percentile for age and sex. Clinical data for these three groups are summarized in Table 1. No patient was on antihypertensive medication or had a previous history of heart disease. Secondary forms of hypertension were ruled out by history, physical examination, urinalysis, serum electrolytes, urea nitrogen and creatinine determinations, and, if indicated, rapid sequence intravenous pyelograms.

Echocardiograms were performed in the supine position using a Smith-Kline Ekoeline 20A with a Honeywell 1956 recorder and a 2.25 mHz Aerotech transducer. Transducer position was adjusted along the lower left sternal border to record the left ventricular cavity, with simultaneous visualization of the posterior wall and ventricular septum just below the tips of the mitral valve. Damping was adjusted to obtain clear endocardial and epicardial echos.

Left ventricular diastolic dimension (LVDd), left ventricular systolic dimension (LVSd), interventricular septal thickness (IVSt), posterior wall thickness (PWt), aortic root dimension, and left atrial dimension were measured as described by Sahn et al.* Left ventricular end diastolic dimension, PWt, and IVSt were taken at the onset of the QRS complex on the simultaneous electrocardiogram and systolic dimensions at the point of maximum anterior excursion of the left ventricular posterior wall. All echocardiograms were read without knowledge of blood pressure.

Left ventricular systolic volume (LVSv) and left ventricular diastolic volume (LVDv) were calculated assuming the left ventricle to be a prolate ellipsoid where $LVSv = 1.047 (LVSd)^3$ and $LVDv = 1.047 (LVDd)^3$.

The LV radius-to-wall-thickness ratio $(r/t)$ was calculated using the sum of the ventricular septal and posterior wall thickness; $r/t = LVDd/(IVSt + PWt)$. Cross-sectional muscle area (CSA) was determined using the formula: $CSA = \pi (LVDd + IVSt + PWt)/2 - \pi (LVDd/2)^2$. Left ventricular mass (LVM) was estimated using a modification of the method of Troy et al.† which includes the IVSt in the determination: $LVM = 1.05 \times 1.047 (LVDd + IVSt + PWt) - (LVDd)^3$. Each parameter, with the exception of $r/t$, was indexed to body surface area. The BSA was derived from a height and weight nomogram.‡ The results were compared statistically using the two-tailed, unpaired Student $t$ test.

Heart rate (HR) was determined from the average R-R interval on the simultaneous electrocardiogram. The pre-ejection period (PEP) and ventricular ejection time (VET) were measured from the Q-wave to aortic valve opening and aortic valve opening to closure, respectively. Stroke index (SI) $[(LVDv - LVSv)/BSA]$; cardiac index (CI), $(SI \times HR)$, shortening fraction (SF), $[(LVDd - LVSd)/LVDd]$; velocity of circumferential fiber shortening (VCF), (SF/VET), and left ventricular systolic time interval (LSTI), (PEP/VET) were calculated as indices of left ventricular function.

**Results**

The mean BSA of the hypertensive group, $1.88 \pm 0.40$ $m^2$ (mean $\pm$ SD) was significantly greater than the control group, $1.62 \pm 0.27$ $m^2$ $(p < 0.001)$, as shown in Table 1. This reflects an increased incidence of obesity in the hypertensive subjects; 40% of them were above the 95th percentile for weight, age, and sex. The BSA of a subgroup of the 19 normotensive adolescents with the largest body surface area was $1.88 \pm 0.17$ $m^2$. Their ages were comparable to both the hypertensive group and the total control group.

The mean systolic and diastolic blood pressures for the hypertensive and overall control group were $141 \pm 21/94 \pm 20$ (range $136-176/82-110$) and $114 \pm 11/68 \pm 8$ (range $90-132/48-82$) mm Hg, respectively $(p < 0.001)$. Blood pressures were compared in each of three age groups, 8-12 years, 13-16 years, 17-19 years, and the differences in blood pressure remained significant in each age group. The average blood pressure of the obese normotensive group was $117 \pm 8/71 \pm 9$ mm Hg, not significantly different from the overall control group.

Echocardiographic measurements for the hypertensive, normotensive, and obese normotensive subjects are shown in Table 2. When compared to the overall control group, both the systolic and diastolic left ventricular dimensions indexed to BSA were significantly smaller in the hypertensive group. However, there were no statistical differences in the systolic or diastolic dimensions when compared to those of the obese normotensive control subgroup. Similarly, aortic and left atrial dimensions were decreased compared with the entire normotensive group. However, if the hypertensive subjects were compared to the obese normotensive adolescent subgroup, these differences in left atrial and aortic dimensions were no longer significant.

Left ventricular wall thickness and ventricular septal thickness (Table 2) were significantly greater in the hypertensive adolescents compared with those in either the entire control group or the obese normotensive subgroup. Mean posterior wall thickness was 23% greater and the mean ventricular septal thickness 20% greater in the hypertensive subjects relative to the normotensive controls. The ventricular septal to posterior wall thickness ratio was greater than 1.3 in only one hypertensive subject.

Left ventricular systolic and diastolic volumes derived from ventricular dimensions and then indexed to BSA did not differ among the groups (Table 2). Left ventricular systolic volume in the hypertensive subjects was $11.5 \pm 5.0$ $cm^3/m^2$ compared to $12.9 \pm 6.9$ $cm^3/m^2$ in the control group and $12.3 \pm 5.2$ $cm^3/m^2$ in the obese subgroup. Left ventricular diastolic volume was $59.2 \pm 20.0$ $cm^3/m^2$ in the hypertensive group,
Table 1. Clinical Data for Hypertensive Subjects (HT), Normotensive Subjects (NT), and Obese Normotensive (ONT) Subgroup Subjects

<table>
<thead>
<tr>
<th></th>
<th>Hypertensive</th>
<th>Normotensive</th>
<th>Obese normotensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>61</td>
<td>49</td>
<td>19</td>
</tr>
<tr>
<td>Male/female</td>
<td>41/20</td>
<td>25/24</td>
<td>9/10</td>
</tr>
<tr>
<td>Black/white</td>
<td>44/17</td>
<td>31/18</td>
<td>10/9</td>
</tr>
<tr>
<td>Age, yrs (range)</td>
<td>14.6 ± 3.1 (8-19)</td>
<td>14.1 ± 2.1 (9-18)</td>
<td>14.6 ± 2.2 (10-18)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>167.6 ± 12.3</td>
<td>159.8 ± 14.1</td>
<td>168.3 ± 7.8</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>80.6 ± 25*</td>
<td>60.7 ± 17</td>
<td>76.2 ± 16</td>
</tr>
<tr>
<td>Body surface area, m²</td>
<td>1.88 ± 0.40*</td>
<td>1.62 ± 0.27</td>
<td>1.88 ± 0.17</td>
</tr>
<tr>
<td>Systolic BP, mm Hg</td>
<td>141 ± 21†</td>
<td>114 ± 11</td>
<td>117 ± 8</td>
</tr>
<tr>
<td>Diastolic BP, mm Hg</td>
<td>94 ± 20‡</td>
<td>68 ± 8</td>
<td>71 ± 9</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation.

*HT vs NT, p < 0.001.
†HT vs NT, p < 0.005.
‡HT vs NT, p < 0.001; HT vs ONT, p < 0.001.
§HT vs NT, p < 0.005; NT vs ONT, p < 0.001.
||HT vs NT, p < 0.001; NT vs ONT, p < 0.005.

61.5 ± 20.3 cm²/m² in the normotensive subjects, and 58.1 ± 17.9 cm²/m² in the obese normotensive adolescent subgroup. These values were not statistically different.

Calculated indices of left ventricular mass are shown in figure 1. The mean r/t ratio of the normotensive adolescents was 3.0 ± 0.7 compared with 2.3 ± 0.5 for the hypertensive group (p < 0.001). The r/t ratio is independent of body size and was the same in both the overall control group and the obese control subgroup. Cross-sectional muscle area was significantly greater in the hypertensive adolescents when compared with either control group, 9.8 ± 1.9 cm²/m² in the hypertensive group, 7.3 ± 1.1 cm²/m² in the overall normotensive subgroup, and 6.8 ± 1.0 cm²/m² in the obese normotensive controls (p < 0.001). Left ventricular mass in the hypertensive group was 45% greater than that of either the overall or obese control subgroup, 113.8 ± 30.6 vs 78.3 ± 20.5 g/m² (p < 0.001). The radius-to-thickness ratio is independent of body size and was the same in both the overall control group and the obese control subgroup. Cross-sectional muscle area was significantly greater in the hypertensive adolescents when compared with either control group, 9.8 ± 1.9 cm²/m² in the hypertensive group, 7.3 ± 1.1 cm²/m² in the overall normotensive subgroup, and 6.8 ± 1.0 cm²/m² in the obese normotensive controls (p < 0.001). Left ventricular mass in the hypertensive group was 45% greater than that of either the overall or obese control subgroup, 113.8 ± 30.6 vs 78.3 ± 20.5 g/m² (p < 0.001).

Table 2. Echocardiographic Dimensions and Volumes for Hypertensive Subjects (HT), Normotensive Subjects (NT), and Obese Normotensive (ONT) Subgroup Subjects

<table>
<thead>
<tr>
<th></th>
<th>Hypertensive</th>
<th>Normotensive</th>
<th>Obese normotensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>61</td>
<td>49</td>
<td>19</td>
</tr>
<tr>
<td>Left ventricular diastolic dimension, cm/m²</td>
<td>2.52 ± 0.42*</td>
<td>2.81 ± 0.41</td>
<td>2.48 ± 0.32</td>
</tr>
<tr>
<td>Left ventricular systolic dimension, cm/m²</td>
<td>1.45 ± 0.26*</td>
<td>1.63 ± 0.29</td>
<td>1.47 ± 0.19</td>
</tr>
<tr>
<td>Diastolic ventricular septal thickness, cm/m²</td>
<td>0.53 ± 0.11†</td>
<td>0.44 ± 0.09</td>
<td>0.39 ± 0.07</td>
</tr>
<tr>
<td>Diastolic posterior wall thickness, cm/m²</td>
<td>0.58 ± 0.13‡</td>
<td>0.47 ± 0.09</td>
<td>0.42 ± 0.08</td>
</tr>
<tr>
<td>Left atrial diastolic dimension, cm/m²</td>
<td>1.63 ± 0.34§</td>
<td>1.77 ± 0.26</td>
<td>1.61 ± 0.20</td>
</tr>
<tr>
<td>Aortic root diastolic dimension, cm/m²</td>
<td>1.49 ± 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left atrial/aortic ratio</td>
<td>1.11 ± 0.17</td>
<td>1.09 ± 0.03</td>
<td>1.11 ± 0.21</td>
</tr>
<tr>
<td>Left ventricular systolic volume, cm³/m²</td>
<td>11.5 ± 5.0</td>
<td>12.9 ± 6.9</td>
<td>12.3 ± 5.2</td>
</tr>
<tr>
<td>Left ventricular diastolic volume, cm³/m²</td>
<td>59.2 ± 20.0</td>
<td>61.5 ± 20.3</td>
<td>58.1 ± 17.9</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation.

*HT vs NT, p < 0.001; NT vs ONT, p < 0.001.
†HT vs NT, p < 0.005; HT vs ONT, p < 0.001.
‡HT vs NT, p < 0.001; NT vs ONT, p < 0.001.
§HT vs NT, p < 0.005; NT vs ONT, p < 0.001.
||HT vs NT, p < 0.001; NT vs ONT, p < 0.005.

Figure 1. Calculated parameters of left ventricular hypertrophy are shown for the hypertensive (HT), normotensive (NT), and obese normotensive subgroup (ONT) subjects. Bars represent mean ± 1 standard deviation. CSA = cross-sectional muscle area/m²; LVM = left ventricular mass/m²; r/t = radius-to-thickness ratio.
from the observations of Goldring et al.\textsuperscript{4} in adolescents. They found a significantly decreased left ventricular diastolic volume when indexed to body surface area. Although not specifically stated, this would imply decreased left ventricular diastolic dimension, as well. This difference may reflect the greater BSA in their hypertensive adolescents. We found a similarly decreased left ventricular diastolic dimension indexed to BSA in our

Left ventricular hypertrophy is frequently found in adolescents. We found a similarly decreased left ventricular diastolic dimension indexed to BSA in our

Discussion

Left ventricular hypertrophy is frequently found in adults with established, severe essential hypertension and is usually attributed to chronic increased afterload. Recent echocardiographic studies, however, have suggested that adults may have left ventricular hypertrophy with only mild to moderate elevations of blood pressure. Savage et al.\textsuperscript{1} found that 61\% of a group of adults with mean blood pressures of 144 ± 23/94 ± 12 mm Hg had increased left ventricular mass and 50\% had elevated ventricular septal thickness. Left ventricular diastolic and left atrial dimensions were abnormal in only 5\% of the group. Analysis of age showed that increased ventricular septal thickness was present even in the 20- to 30-year age group. Slchant et al.\textsuperscript{4} evaluated 83 adults with mild to moderate hypertension (diastolic blood pressure, 90-115 mm Hg) and found significantly greater posterior wall thickness in the hypertensive group than in the normotensive controls. Ventricular septal thickness, however, was not statistically different. Both investigators concluded that compared with electrocardiography or chest X-ray, echocardiography provides the most sensitive non-invasive assessment of left ventricular hypertrophy. Dunn et al.,\textsuperscript{16} using echocardiography, evaluated a group of young hypertensive adults with an average mean blood pressure of 123 mm Hg, normal chest x-ray, and electrocardiogram. They found no significant difference in ventricular septal and posterior wall thickness or ventricular mass compared to control values. Those patients, however, with the additional findings of left atrial hypertrophy on the electrocardiogram did have increased posterior wall and ventricular septal thickness.

In the mildly hypertensive adolescent, Goldring et al.\textsuperscript{4} did not find an increased ventricular septal or posterior wall thickness, although left ventricular diastolic volumes were decreased. Nishio et al.\textsuperscript{8} demonstrated an increase in left ventricular mass in five of 22 children with mild hypertension. Similarly, Laird et al.\textsuperscript{2} showed increased posterior wall thickness in 23\% of a group of hypertensive adolescents.

In the present study, we evaluated a group of mildly to moderately hypertensive adolescents with M-mode echocardiograms. In addition to left ventricular anatomical measurements, we have calculated three parameters of left ventricular hypertrophy: the radius-to-thickness ratio, cross-sectional muscle area, and left ventricular muscle mass. Since the mean BSA of the hypertensive adolescents was greater than that of the normotensive control group, we also compared the hypertensive group with a subset of the control adolescents in which the BSA was not different than the hypertensive group. Several investigators have found a nonlinear relationship between BSA and a number of echocardiographic parameters in normal subjects,\textsuperscript{11-13} supporting the importance of a comparable BSA in the control and hypertensive group. Left ventricular posterior wall and ventricular septal thickness, and cross-sectional muscle area and mass, were significantly increased and the r/t ratio significantly decreased in the hypertensive subjects. Diastolic and systolic chamber dimensions and volumes in the hypertensive group were not different from those of the control subjects with similar BSA.

Although our finding of similar left ventricular systolic and diastolic chamber dimensions and volumes in hypertensive and control subjects of comparable BSA supports the findings of previous studies in adults,\textsuperscript{1,4} it differs from the observations of Goldring et al.\textsuperscript{4} in adolescents. They found a significantly decreased left ventricular diastolic volume when indexed to body surface area. Although not specifically stated, this would imply decreased left ventricular diastolic dimension, as well. This difference may reflect the greater BSA in their hypertensive adolescents.

<table>
<thead>
<tr>
<th>Left Ventricular Function for Hypertensive Subjects, Normotensive Subjects, and Obese Normotensive Subgroup Subjects</th>
<th>Hypertensive</th>
<th>Normotensive</th>
<th>Obese normotensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate, bpm</td>
<td>75.5 ± 17.2</td>
<td>72.9 ± 10.7</td>
<td>71.1 ± 11.1</td>
</tr>
<tr>
<td>Stroke index, cm³/m²</td>
<td>47.0 ± 17.5</td>
<td>47.4 ± 13.0</td>
<td>45.8 ± 15.0</td>
</tr>
<tr>
<td>Cardiac index, l/min/m²</td>
<td>3.51 ± 1.39</td>
<td>3.43 ± 1.03</td>
<td>3.19 ± 0.96</td>
</tr>
<tr>
<td>Shortening fraction, %</td>
<td>0.42 ± 0.07</td>
<td>0.42 ± 0.07</td>
<td>0.41 ± 0.06</td>
</tr>
<tr>
<td>Left ventricular time intervals</td>
<td>0.34 ± 0.04</td>
<td>0.33 ± 0.03</td>
<td>0.33 ± 0.03</td>
</tr>
<tr>
<td>Velocity of circumferential fiber shortening, circ/sec</td>
<td>1.54 ± 0.29</td>
<td>1.46 ± 0.24</td>
<td>1.42 ± 0.21</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation.
hypertensive group when compared to that of a control group with a smaller mean BSA. However, this difference was no longer apparent when left ventricular dimensions were compared in patients of similar BSA.

Increased posterior wall and ventricular septal thickness in hypertensive adolescents compared to that found in control groups suggests left ventricular hypertrophy. This is further supported by a decreased r/t ratio. The r/t ratio reflects relative wall thickness and has been used to assess left ventricular hypertrophy in adults and children with aortic stenosis, aortic regurgitation and hypertrophic cardiomyopathy. In patients with aortic stenosis, an increase in the relative wall thickness correlates well with the severity of the obstruction as assessed by left ventricular pressure. It has the advantage that, unlike other parameters of left ventricular hypertrophy, it is independent of body size. The decreased r/t ratio in our hypertensive subjects suggests that relative to the diastolic dimension of the left ventricle there is an increase in muscle thickness. Although Goldring et al. did not find an increased posterior wall or ventricular septal thickness in their hypertensive subjects, the decreased volume in the hypertensive group may imply a decrease in the r/t ratio, suggesting left ventricular hypertrophy.

Cross-sectional muscle area has been used by some investigators to assess left ventricular hypertrophy. It is less affected by ventricular geometry than ventricular mass calculations. This parameter is significantly greater in our hypertensive group than in the normotensive subjects. Left ventricular mass calculated from M-mode echocardiograms has been used extensively as an index of ventricular hypertrophy. The finding of significantly increased muscle mass in our hypertensive adolescents supports the results of Nishio et al. and Laird et al., and is consistent with the other parameters of left ventricular hypertrophy found in these subjects.

Despite the alterations in the indices of left ventricular mass, no significant abnormalities of left ventricular function could be determined echocardiographically. This may suggest preservation of ventricular function or an insensitivity of the echocardiogram to minor changes in ventricular function.

Although left ventricular hypertrophy is associated with conditions of increased afterload, we have found a significant degree of hypertrophy in young adolescents with mild elevations in blood pressure. In the spontaneously hypertensive rat, an animal model used extensively in the study of essential hypertension, similar discrepancies between left ventricular hypertrophy and blood pressure have been described. Our finding of left ventricular hypertrophy in these young mildly hypertensive subjects suggests early myocardial involvement in the hypertensive syndrome.

References

Cardiac involvement in adolescent hypertension. Echocardiographic determination of myocardial hypertrophy.
K G Zahka, C A Neill, L Kidd, M A Cutilletta and A F Cutilletta

Hypertension. 1981;3:664-668
doi: 10.1161/01.HYP.3.6.664

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1981 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/3/6/664

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/