Out-of-Office Blood Pressure in Children and Adolescents: Disparate Findings by Using Home or Ambulatory Monitoring

George S. Stergiou, Christina V. Alamara, Chrysa B. Kalkana, Iraklis N. Vaindirlis, Constantinos J. Stefanidis, Catherine Dacou-Voutetakis, and Theodore D. Mountokalakis

Background: The validity of home blood pressure (HBP) measurements in children has not been evaluated, although in clinical practice such measurements are being used. This study compares HBP, with clinic (CBP) and daytime ambulatory blood pressure (ABP) in children and adolescents.

Methods: Fifty-five children and adolescents aged 6 to 18 years were evaluated with CBP (three visits), HBP (6 days), and daytime ABP. Mean age was 12.3 ± 2.9 (SD) years, 33 boys. According to the Task Force CBP criteria, 26 were hypertensives, 6 had high-normal BP (hypertensive group), and 23 were normotensives (normotensive group).

Results: In the hypertensive group, CBP was 130.8 ± 7.6/72.5 ± 8.1 mm Hg (systolic/diastolic), HBP 118.9 ± 6.3/73.7 ± 6.7, and ABP 130.8 ± 8.1/75.5 ± 8.3. In the normotensive group, CBP was 112.8 ± 8/63.1 ± 6.3, HBP 106.7 ± 8.4/67.2 ± 5.2, and ABP 123.9 ± 7.2/72.4 ± 4.3. Strong correlations (P < .001) were observed between CBP–HBP (r = 0.73/0.57, systolic/diastolic), CBP–ABP (r = 0.59/0.49), and HBP–ABP (r = 0.72/0.66). In normotensive subjects, ABP was higher than both CBP and HBP for systolic and diastolic BP (P < .001). Furthermore, systolic HBP was lower than CBP (P < .01), whereas the opposite was true for diastolic BP (P < .05). In hypertensive subjects systolic HBP was lower than both CBP and ABP (P < .001), whereas CBP did not differ from ABP. For diastolic BP no differences were found among measurement methods.

Conclusions: These data suggest that, in contrast to adults in whom HBP is close to the levels of daytime ABP, in children and adolescents HBP appears to be significantly lower than daytime ABP. Until more data become available, caution is needed in the interpretation of HBP in children and adolescents. Am J Hypertens 2004;17:869–875 © 2004 American Journal of Hypertension, Ltd.

Key Words: Children, adolescents, home blood pressure, ambulatory blood pressure, hypertension.
ments in normotensive and hypertensive children and adolescents in comparison with CBP and ABP measurements.

Methods

Study Participants

Children and adolescents aged 6 to 18 years old referred for elevated BP (on at least two occasions) were recruited. Participants were asked to perform BP measurements in the clinic, at home, and with ambulatory monitoring. Exclusion criteria were history of hypertension, chronic disease, and treatment with antihypertensive or other medication that might influence BP.

BP Measurements

Participants were asked to measure HBP for 2 weeks or ABP for 24 h. The alternate measurement was then performed. CBP was measured in three visits within 3 weeks when participants came to receive or to bring back the devices for home or ambulatory BP monitoring.

CBP measurements were taken by three physicians who fulfilled the British Hypertension Society Protocol criteria for observer agreement in BP measurement.7 Triplicate CBP measurements were taken at each clinic visit after 5 min of sitting rest and with at least 1 min between recordings by using a standard mercury sphygmomanometer (cuff with bladder size 9 × 18, 12 × 23, or 15 × 35 cm according to arm circumference, Korotkoff phase V for diastolic BP, or Korotkoff phase IV when sounds could be heard to 0 mm Hg).

HBP was measured using validated fully automated electronic devices Omron HEM-705CP8 (stores and prints the last 12 measurements) or Omron IC8 (stores all measurements, which can be downloaded to a computer) (Omron Healthcare GmbH, Hamburg, Germany; bladder size 12 × 23 or 14 × 28 cm where appropriate), apart from children with arm circumference <20 cm in whom the Omron 711 IS was used (bladder size 9 × 16 cm).9 Participants were trained in the conditions of HBP measurement and the use of the electronic devices and were instructed to make duplicate morning (6 to 10 AM) and evening (6 to 10 PM) self-measurements after 5 min of sitting rest and with 1 min between recordings, on 3 routine workdays per week for 2 weeks. In the younger children, HBP measurements were taken by their parents. In addition to the device memory storage and printout, a form was supplied to the participants to report all HBP values.

ABP was measured using validated noninvasive portable oscillometric devices SpaceLabs 90207 or 90217 (SpaceLabs Inc., Redmond, WA; bladder size 12 × 23 or 9 × 16 cm where appropriate).8 The recorders were programmed to measure BP at 20-min intervals for 24 h and were applied always on a routine workday before or after the HBP measurement period. Subjects were instructed to follow their usual daily activities but to remain still with the forearm extended during each BP reading. A brief diary specifying the time when they went to bed and arose was kept by the children or their parents. Before each HBP or ABP monitoring session, the accuracy of the devices was tested against a standard mercury sphygmomanometer by manual activation (Y connector; three consecutive readings).

Analysis

ABP data and additional recorded information from the report files generated by the ABP monitor were batch imported and organized in a relational database (Microsoft Access 2000, Redmond, WA) using a Visual Basic program. This program, designed by Leonidas G. Roussias (Athens, Greece) for statistical analysis of ABP-derived data, reads the ASCII text files generated by the ABP monitor and performs multiple data procedures and analyses. ABP recordings with less than 30 successful awake BP measurements or less than 12 sleeping measurements were excluded from the analysis. The BP measurements flagged by the software of the monitors as technically erroneous were excluded as were measurements with systolic BP <60 or >260 mm Hg or with diastolic BP <40 or >150 mm Hg. Early readings taken less than 20 min after the monitor was attached to patient were also excluded as these were taken in the clinic environment. Average daytime, nighttime, and 24-h ABP were calculated according to individual subjects’ sleeping hours.

Subjects who provided less than 12 valid HBP readings or readings taken on less than 4 days were excluded from the analysis. All available HBP readings were averaged to obtain the mean HBP per individual. The CBP measurements of all the three study visits were also averaged to give a single number per individual.

The criteria of 1996 Updated Task Force Report on high blood pressure in children and adolescents10 were used for the classification of hypertension (mean CBP ≥95th percentile for sex, age, and height), high-normal blood pressure (90th to 95th percentile), and normotension (<90th percentile). Diagnosis of ambulatory hypertension was based on normative values of the German Working Group on Pediatric Hypertension.11 Using these normative data, children and adolescents whose daytime ABP was below the 90th percentile of daytime systolic and diastolic BP, stratified according to gender and height were classified as normotensives.11 Because of the lack of normative data for HBP, classification of hypertension based on such measurements was not performed.

Statistical analysis was performed using the MINITAB INC Statistical Software (release 13.31) (Minitab Inc., PA). Student paired t tests were used for the comparison of CBP, HBP, and ABP measurements with Bonferroni’s correction for multiple comparisons applied where appropriate. Pearson correlations were used to investigate the association of HBP with CBP and ABP. For a more
meaningful evaluation of the differences between readings obtained by various techniques in individual subjects, the prediction error was also used as an absolute measure of the amount of error in prediction. This was calculated, for example, for HBP/CBP differences by calculating $100 \times \frac{\text{HBP} - \text{CBP}}{\text{CBP}}$. Results are expressed as mean ± standard deviation (SD). A probability value $P < .05$ was considered statistically significant.

**Results**

A total of 57 consecutive children and adolescents, referred for elevated BP from February 2000 to April 2003, were recruited. All referred children and adolescents were invited to participate, apart from those who did not fulfill the study inclusion criteria or lived a distance from Athens. Two recruited subjects were excluded because they provided inadequate HBP measurements and data from 55 subjects (33 boys and 22 girls) were analyzed (mean age 12.3 ± 2.9 [SD] years, range 6 to 18). According to the Task Force criteria for CBP measurement, 10 subjects were classified as hypertensives, of which 20 (76%) had only elevated systolic BP, 6 (24%) had elevated systolic and diastolic BP, and none had only elevated diastolic BP. Six subjects were classified as having high-normal BP due to isolated elevation of systolic BP and 23 subjects were classified as normotensives.

Comparison of CBP, HBP, and ABP revealed similar findings for subjects with high to normal blood pressure and hypertensives, which differed from normotensives. Therefore, all subjects with high-normal BP and hypertensives (CBP above the 90th percentile) are presented as one group (hypertensive group: $n = 32$, mean age $13 \pm 2.8$ [SD] years, 21 boys) and normotensives as a comparison group (normotensive group: $n = 23$, mean age $11.4 \pm 2.6$ years, 12 boys). According to United States Centers for Disease Control and Prevention growth charts, 29 subjects (12/17, normotensive/hypertensive) were obese (≥95th percentile for age and sex), 11 (6/5) overweight (85th to 95th percentile), and 15 (5/10) were normal weight (<85th percentile).

The average number of obtained HBP readings was 22.5 ± 2.2 (mean ± SD) per participant (range 12 to 24 readings). Sixty percent of recruited subjects performed all the expected HBP readings, 30% performed 80% to 95%, and 7% provided 50% to 80% of the expected readings. Two subjects (3.5%) performed fewer than 12 HBP readings and were excluded from the analysis. Comparison of HBP values stored in the memory of the devices with those reported by subjects showed small differences, probably attributed to copying errors. It should be noted that participants were aware of the storage capacity of the HBP monitors. Thus, misreporting of HBP values was prevented in this study. In 10 children with small arms, who was used the Omron 711 device (which has no storage capacity), checking for misreporting was not possible. However, in these young children, the HBP values were filled in the forms by their parents. The average difference between parallel test measurements using the HBP monitoring devices against a mercury column was $-3.6 \pm 5.1$ (SD) mm Hg. Fifteen percent of the subjects had a ≥5 mm Hg difference in diastolic BP between the HBP monitor and the mercury manometer and 20% had a difference of $10 \text{ mm } Hg$ systolic BP. A total of 85 ± 8.7 readings were obtained during the 24-h ABP monitoring. A fraction of 20% ± 8% of readings were discarded and 3.9% ± 3.6% of time points were not represented in the ABP profile, because both the initial and the automatically repeated reading 2 min later were considered erroneous.

The average CBP of all three study visits did not differ from the average CBP of visits 2 to 3 for the total group of subjects as well as for hypertensives and normotensives analyzed separately. Likewise, the average HBP of all 6 days did not differ from the average obtained after discarding measurements of the initial day and no differences in average HBP were found among days 1 to 6 (Fig. 1). This was also the case for hypertensive subjects analyzed separately. The initial reading of all morning and afternoon HBP measurements was consistently higher than the repeated one taken 1 min later (average BP decline 2.6 ± 1.2/2.1 ± 1.3 mm Hg for systolic/diastolic HBP; statistically significant in most of the days; Fig. 2). For each monitoring day the average morning HBP did not differ from those taken in the afternoon.

The average CBP, HBP, and ABP levels of all study participants and separately of hypertensive and normotensive subjects are presented in Table 1 and Fig. 3. Significant correlations were observed between CBP and HBP measurements (correlation coefficient $r = 0.73/0.57$ for systolic/diastolic BP), between CBP and 24-h ABP ($r = 0.59/0.49$), and between HBP and 24-h ABP ($r = 0.72/0.66$) ($P < .001$ for all measurements). The prediction error for the HBP/CBP difference was 7% ± 6% for systolic and 4% ± 11% for diastolic BP, for the HBP/ABP difference 11% ± 5% and 4% ± 8%, and for the ABP/CBP difference 4% ± 8% and 9% ± 11%. Hypertensive subjects had higher CBP, HBP, and ABP values than normotensives (Table 1). In normotensive subjects, sys-
Table 1. Clinic, home, and ambulatory blood pressure in all study participants and in hypertensives and normotensives analyzed separately (mm Hg ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Hypertensives (N = 32)</th>
<th>Normotensives (N = 23)</th>
<th>All (N = 55)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systolic blood pressure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic</td>
<td>130.8 ± 7.6</td>
<td>112.8 ± 8†</td>
<td>123.3 ± 11.8</td>
</tr>
<tr>
<td>Home</td>
<td>118.9 ± 6.3</td>
<td>106.7 ± 8.4†</td>
<td>113.8 ± 9.4</td>
</tr>
<tr>
<td>Ambulatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daytime</td>
<td>130.8 ± 8.1</td>
<td>123.9 ± 7.2†</td>
<td>127.9 ± 8.4</td>
</tr>
<tr>
<td>Nighttime</td>
<td>115.4 ± 7.8</td>
<td>107.0 ± 6.8‡</td>
<td>111.9 ± 8.5</td>
</tr>
<tr>
<td>24-h</td>
<td>124.9 ± 7.3</td>
<td>117.3 ± 6.3‡</td>
<td>121.7 ± 7.9</td>
</tr>
<tr>
<td><strong>Diastolic blood pressure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic</td>
<td>72.5 ± 8.1</td>
<td>63.1 ± 6.3‡</td>
<td>68.6 ± 8.7</td>
</tr>
<tr>
<td>Home</td>
<td>73.7 ± 6.7</td>
<td>67.2 ± 5.2‡</td>
<td>70.9 ± 6.9</td>
</tr>
<tr>
<td>Ambulatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daytime</td>
<td>75.5 ± 8.3</td>
<td>72 ± 4.3*</td>
<td>74 ± 7.0</td>
</tr>
<tr>
<td>Nighttime</td>
<td>61.4 ± 6.8</td>
<td>57.6 ± 4.2*</td>
<td>59.8 ± 6.1</td>
</tr>
<tr>
<td>24-h</td>
<td>70 ± 7.7</td>
<td>66.2 ± 3.7*</td>
<td>68.4 ± 6.5</td>
</tr>
</tbody>
</table>

* P < .05; † P < .01; ‡ P < .001 for difference from hypertensives.
tional stethoscopic technique and a standard mercury sphygmomanometer, as is usually the case for clinic measurements by the physicians in practice. On the other hand, out-of-office BP measurements (HBP and ABP) were measured using validated oscillometric devices, which are widely used in general practice and are recommended by official guidelines. Parallel test measurements of HBP monitoring devices against a mercury column revealed reassuring results with a difference in measured BP within the requirements of the Association for the Advancement of Medical Instrumentation protocol for device validation (mean difference $<5 \pm 8 \text{ mm Hg}$).

The compliance of study participants with HBP monitoring was excellent, probably because home monitoring was performed under the close supervision of the participants’ parents and, in the younger children, measurements were taken by their parents.

Multiple CBP and HBP measurements were obtained to allow for a progressive decline of BP, which is known to occur with repeated measurements. Because the initial clinic visit and the initial home monitoring day have been shown to provide higher and unstable values, several investigators prefer to discard these measurements. Interestingly, in this study, the exclusion of the initial clinic visit or the initial home monitoring day had little effect on average CBP or HBP. Nevertheless, these data underline the importance of multiple BP measurements on repeated visits, given that 42% of the children and the adolescents referred for elevated BP were classified as normotensives.

As is the case for adults, HBP showed a similar behavior to CBP, given that the initial HBP reading was consistently higher than the repeated one, even after several monitoring days (Fig. 2). In addition, although this is a small study group, it confirms previous reports showing that systolic hypertension is more common than diastolic hypertension among children and adolescents.

Studies in normotensive adults showed little difference between CBP and ABP, whereas in hypertensives, CBP is known to be higher than ABP, reflecting the “clinic reaction.” In contrast to the findings in adults, accumulating data suggest that in normotensive children and adolescents the ABP is by about 10 mm Hg higher than CBP. This difference, also confirmed by the findings of the present study, has been attributed to the higher level of physical activity during daytime in the young population. However, in the hypertensive group of the present study, the difference between CBP and daytime ABP was eliminated. This difference between the two groups might be attributed to the presence of the white coat effect, which is known to increase CBP, especially in subjects with elevated pressures and not in normoten-

Studies in hypertensive children showed contradictory findings (CBP was lower or exceeded daytime ABP.)
With regard to HBP, studies in adults showed lower values than for CBP and close to the levels of daytime ABP. This study showed that, in both normotensive and hypertensive children and adolescents, systolic HBP is lower than both daytime ABP and CBP and close to the levels of nighttime ABP (Fig. 3). As is the case in adults, the CBP–HBP difference was more pronounced in the hypertensive group, reflecting the clinic reaction. Diastolic BP did not show the typical white coat effect, with CBP being lower than HBP and with daytime ABP, providing the highest BP values (differences reaching statistical significance only in the normotensive group). Studies in adults also showed that systolic BP is responsible for the majority of cases with a large difference between CBP and ABP (white coat effect). In addition, systolic BP elevation is more common than diastolic BP in children and adolescents. Interestingly, in regard to pulse rate, the pattern of comparisons of BP values obtained by the different methods appear to be similar to systolic rather than diastolic BP (HBP measurements being lower than both CBP and ABP measurements; Fig. 3). These data may indicate that, in both normotensive and hypertensive children and adolescents, the sympathetic nervous system activation (which can be grossly estimated by pulse rate measurement) is a more important mechanism for the regulation of systolic BP rather than diastolic BP.

This study has several limitations regarding the methodology for BP measurement and the selection criteria for study participants. First, differences in technologies for BP measurement may be responsible, at least in part, for the observed differences in BP obtained by the three methods. Second, an important selection bias due to the inclusion of children referred for elevated BP cannot be excluded, because these children may have increased reactivity. Third, age and BP values might influence the differences in BP obtained when using different methods (auscultatory or oscillometric) and devices. Although in this study, comparison of BP values obtained using the different methods showed a similar pattern in boys and girls and in children and adolescents, a larger study sample, representative of the pediatric population stratified by age and sex is needed to confirm these preliminary findings. Finally, it should be mentioned that because of the lack of normative values for CBP and ABP in Greek children, diagnosis of hypertension in this study was based on other population norms.

The important message from these preliminary data is that, in children and adolescents, caution is needed in the interpretation of out-of-clinic BP measurements obtained using home monitoring. These data suggest that in this population HBP values are significantly lower than both clinic and ambulatory measurements. Until normative data for HBP become available, decisions for diagnosis and treatment of hypertension in children and adolescents should not be based on such measurements. Large trials relating HBP values with hypertensive target organ damage are needed to estimate diagnostic thresholds for this method in children and adolescents.

Acknowledgments

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References


