Blood-Pressure Categories in Adolescence Predict Development of Hypertension in Accordance with the European Guidelines

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Background: It is estimated that by 2025, >1.5 billion adults worldwide will be hypertensive. Early identification of the population at risk would lead to improved utilization of preventive measures. We aimed to evaluate whether baseline body mass index (BMI) and blood-pressure (BP) values during adolescence (categorized according to the guidelines of the European Society of Hypertension–European Society of Cardiology) are of use in predicting the development of hypertension in young adulthood.

Methods: The study population consisted of 18,513 male regular army personnel who were initially recruited at 16.5 and 19 years of age between 1976 and 1996. The main outcome was the percentage of subjects who developed hypertension (≥140 systolic and ≥90 diastolic) at ages 26 to 45 years.

Results: At baseline, BP categories were: optimal, 5961 (32.2%); normal, 7998 (43.2%); and high normal, 4554 (24.6%). Moreover, 1377 (7.4%) were overweight (BMI 25–30 kg/m²), and 199 (1.1%) were obese (BMI ≥30 kg/m²). At follow-up, 2277 (12.3%) subjects developed hypertension. The percentages progressing to hypertension were 9.46%, 11.99%, and 16.56% for optimal, normal, and high-normal categories, respectively (P < .01). Odds ratios (OR) for the development of hypertension in the normal and high-normal categories versus optimal were 1.30 (95% confidence interval [CI], 1.22–1.39) and 1.79 (95% CI, 1.67–1.93), respectively, adjusted for age and BMI. The ORs for hypertension in overweight and obese versus normal BMI were 1.75 (95% CI, 1.66–1.86) and 3.75 (95% CI, 3.45–4.07), adjusted for age and BP. Of 9762 remaining at ideal BMI at follow-up, the percentages progressing to hypertension were 5.3%, 6.4%, and 9.5% for optimal, normal, and high normal (at baseline) (P < .01).


Key Words: Adolescence, blood pressure, BMI, classification, guidelines, hypertension.

Blood pressure (BP) is a well-known, modifiable risk factor for cardiovascular disease. The relationship between BP values and the risk of cardiovascular morbidity and mortality is consistent and continuous.1 The higher the BP, the greater the chance of myocardial infarction, heart failure, stroke, and renal disease across the entire BP range.2 Hence, the dividing line between normal and high BP is arbitrary. It is based on epidemiologic data, and, as Kaplan proposed, should actually be the level of BP at which the benefits of action exceed the risks and costs of inaction.3 Recently updated BP classification guidelines1,4 defined hypertension as a systolic blood pressure (SBP) ≥140 mm Hg and a diastolic blood pressure (DBP) ≥90 mm Hg.

The seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure1 introduced the concept of the prehypertensive stage of blood pressure (systolic, 120–139 mm Hg; diastolic, 80–89 mm Hg). The recent guidelines of the European Society of Hypertension–European Society of Cardiology (ESH–ESC)4 further subdivided this “prehypertensive stage” into categories of normal (systolic, 120–129 mm Hg; diastolic, 80–84 mm Hg) and high normal (systolic, 130–139 mm Hg; diastolic, 85–89 mm Hg).
Both guidelines address the need to label individuals with nonoptimal BP as a signal to institute healthful lifestyle changes that might avert the development of frank hypertension and cardiovascular disease. Nonetheless, the differences between the European and American guidelines emphasize the lack of wide agreement on who should be labeled as being at high risk.

For individuals 40 to 70 years of age, Lewington et al\textsuperscript{2} showed that each increment of 20 mm Hg in SBP or 10 mm Hg in DBP doubles the risk of cardiovascular disease across the entire BP range from 115/75 to 185/115 mm Hg. Whether this also holds true for younger age groups is not as well established. Although it was previously shown that BP levels may “track” from childhood to adulthood,\textsuperscript{5–9} these data were published before the currently accepted BP categories of optimal, normal, and high normal or prehypertension were introduced. The associated risk for hypertension according to the recent categories cannot be inferred from these studies.

We recently demonstrated that prehypertension is extremely prevalent in the adolescent population (56.8\% of men aged 16.5–19 years).\textsuperscript{10} Designating a large proportion of adolescents as being at high risk for the development of hypertension potentially carries an enormous impact for the individual as well as for the health system. The stratification of risk according to the European guidelines may help target the most appropriate group.

Obesity is another well-known risk factor for hypertension. Obese children are at an approximately threefold higher risk for hypertension than nonobese children.\textsuperscript{11} Obesity per se was associated with prehypertension. Greenlund et al\textsuperscript{12} reported that among persons with prehypertension, 64\% were either overweight or obese. Adolescent obesity is rapidly emerging as a global epidemic that has profound public health consequences.\textsuperscript{13,14}

The aim of the present study was to assess the risk for the development of hypertension in young adulthood according to adolescent BP categories (the European guidelines) and body mass index (BMI).

**Subjects and Methods**

This study was conducted in the Israeli Defense Forces Staff Periodic Examination Center (SPEC, Tel-Aviv, Israel), to which all career service personnel >25 years of age are referred every 3 to 5 years. The computerized SPEC database was established in 1992 and includes data on 20,212 men. All subjects were initially examined before compulsory military service at 16.5 to 19 years of age between 1976 and 1996. Subjects were excluded from the study if no information on BP or BMI at this initial examination was available. Additional exclusion criteria at this stage were: (1) a known history of kidney disease; (2) hypertension or the use of antihypertensive medications; and (3) an abnormal urinalysis (proteinuria and/or hematuria). After exclusion, our study population consisted of 18,513 men. Apart from a minute number of individuals, the population is all Caucasian.

Data abstracted from the database included BP values and BMI at two points: the initial examination (baseline) and the last recorded SPEC examination (follow-up). According to the subject’s age at follow-up, the study population was subdivided into four age groups: 26 to 30, 31 to 35, 36 to 40, and 41 to 45 years.

Overweight was defined as a BMI of 25 to 30 kg/m\textsuperscript{2}, and obese as a BMI >30 kg/m\textsuperscript{2}. Blood-pressure values at baseline and at follow-up were categorized according to the European guidelines.\textsuperscript{4}

Baseline examination was performed in the army recruitment centers. Evaluation is principally aimed at ruling out major disease or physical disability. Smoking history and alcoholic consumption were not an obligatory requirement. No routine blood tests were performed. Follow-up examinations were performed in the SPEC.

Blood pressure is measured by a physician, in the seated position, using a mercury sphygmomanometer. The right upper arm is used for all measurements. For the 30 min prior to measurement, subjects are asked to refrain from smoking, eating, and exercise. Measurements are always performed at room temperature (20–25\textdegree C) in the morning. If systolic or diastolic measurements are \(\geq 140\) or \(\geq 90\) mm Hg, respectively, then the mean of 10 BP measurements, performed over a period of several weeks, is entered into the database. Weight and height are measured with a standard scaling procedure: standing height is entered into the database. Weight and height are measured with a standard scaling procedure: standing height taken to the nearest centimeter using a fixed stadiometer, and weight measured by a Health O Meter scale (Health O Meter, Inc., Bridgeview, IL). The reliability of the measuring devices is periodically assessed according to the manufacturer’s recommendations. All medical data of each subject are independently reviewed and certified by a senior physician.

At the last recorded SPEC examination (follow-up), the presence or absence of hypertension was defined. Subjects were categorized as hypertensive when at least one of the following criteria was met: (1) a documented history of hypertension; (2) administration of antihypertensive medications; and (3) a BP measurement \(\geq 140\) mm Hg (systolic) or \(\geq 90\) mm Hg (diastolic), in which case, the protocol regarding multiple BP measurements as outlined above was followed. The BP measurements of subjects on antihypertensive therapy were excluded from analysis of the mean BP values specific to age groups. This study was approved by the Israel Defense Forces (IDF) Institutional Review Board.

**Statistical Analysis**

Descriptive statistics included mean ± SD and proportions (%). For comparison of systolic BP, diastolic BP, and BMI between age groups, an ANOVA model was used. For multiple comparisons, we applied the Tukey correction. We performed logistic regression analysis for comparison...
of the proportion of subjects who developed hypertension in each age group according to the baseline category of BP. We then calculated the odds ratio (OR) for the appearance of hypertension for each baseline BP and BMI category, using optimal BP and normal-weight categories as reference. All statistical analyses were performed with SAS for Windows statistical software, version 9.1 (SAS Institute, Cary, NC). *P < .05 was considered significant.

### Results

Altogether, 18,513 subjects were enrolled. Table 1 shows the mean BMI, systolic blood pressure (SBP), and diastolic blood pressure (DBP) at baseline, at follow-up for the group as a whole, and for the age subdivisions as described in Subjects and Methods. Mean BMI was higher for the whole group (21.1–25.6) and progressively increased with each advancing age group. At baseline, 7.4% and 1.1% were found to be overweight and obese, respectively. Corresponding numbers for the whole group at follow-up were 35.2% and 11.2%.

Mean SBP was found to decrease from baseline to follow-up in the whole group and in the age subdivisions 26 to 30 years and 31 to 35 years. It increased in the 36 to 40-year and 41-to-45-year age groups. In contrast, DBP increased in the whole group, along with a progressive elevation in the incremental age groups. Overall, 12.3% of subjects developed hypertension, ranging from 10.5%, 12.6%, and 16.8% to 18.9% for the respective age groups.

At baseline, BP categories were: optimal, 5967 (32.2%); normal, 7987 (43.2%); and high normal, 4559 (24.6%). Table 2 shows the percentages of subjects who at baseline were categorized into optimal, normal, and high normal, and who went on to develop hypertension at follow-up in the different age groups. In all age groups, a statistically significant increase in percentage was noted upon going from the optimal to normal to high-normal categories. This increase was particularly striking in the younger age group (age 26–30 years), who at baseline were normal compared with high normal (8.8% vs. 14.3%, *P < .0001). With advancing age, the delta percentage rise was diminished (20.1% vs. 21.2%, *P = .0054, normal to high normal in the 41-to-45-year age group).

The ORs for the development of hypertension in the baseline categories of normal and high normal versus optimal were 1.30 (95% confidence interval [CI], 1.22–1.39) and 1.79 (95% CI, 1.67–1.93), respectively, adjusted for age and BMI. At baseline, the ORs for hypertension in overweight and obese versus normal BMIs were 1.75 (95% CI, 1.66–1.86) and 3.75 (95% CI, 3.45–4.07), respectively, adjusted for age and BP category. Table 3 gives the ORs for the development of hypertension at follow-up for the different BP and BMI categories at baseline compared with the BMI >25/optimal BP category (corrected for age).

The influence of baseline BP category on the development of hypertension, irrespective of a change of BMI, is shown in Table 4. Overall, 9762 subjects had a normal

### Table 1. Blood pressure and BMI values at baseline and at follow-up for the age-group subdivisions and the cohort as a whole

<table>
<thead>
<tr>
<th>Age groups at follow-up (y)</th>
<th>26–30</th>
<th>31–35</th>
<th>36–40</th>
<th>41–45</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td>18,513</td>
<td>8841</td>
<td>4904</td>
<td>3638</td>
<td>1130</td>
</tr>
<tr>
<td><strong>SBP</strong></td>
<td>118 ± 10</td>
<td>115 ± 12</td>
<td>116 ± 12</td>
<td>117 ± 12</td>
<td>120 ± 12</td>
</tr>
<tr>
<td><strong>DBP</strong></td>
<td>73 ± 7</td>
<td>73 ± 9</td>
<td>74 ± 9</td>
<td>76 ± 10</td>
<td>78 ± 9</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td>21.1 ± 2.8</td>
<td>24.6 ± 3.7</td>
<td>26.3 ± 4.1</td>
<td>26.7 ± 4.1</td>
<td>27.3 ± 4.2</td>
</tr>
</tbody>
</table>

BMI = body mass index (kg/m²); DBP = diastolic blood pressure (mm Hg); N = number of subjects; SBP = systolic blood pressure (mm Hg). Values are mean ± SD.

*P < .001 for each age group vs all others; †P < .001 for each BP category vs all others.

### Table 2. Number and percentage of subjects who developed hypertension at follow-up in each age group according to BP category at baseline

<table>
<thead>
<tr>
<th>BP category at baseline</th>
<th>26–30† (8841)</th>
<th>31–35† (4904)</th>
<th>36–40† (3638)</th>
<th>41–45† (1130)</th>
<th>All† (18,513)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optimal</strong></td>
<td>6.3 (162/2565)</td>
<td>10.1 (168/1663)</td>
<td>13.0 (174/1339)</td>
<td>15.8 (63/400)</td>
<td>9.5 (567/5967)</td>
</tr>
<tr>
<td><strong>Normal</strong></td>
<td>8.8 (353/2642)</td>
<td>12.0 (249/2071)</td>
<td>18.2 (269/1479)</td>
<td>20.1 (89/442)</td>
<td>12.0 (960/7987)</td>
</tr>
<tr>
<td><strong>High normal</strong></td>
<td>14.3 (326/2281)</td>
<td>17.1 (200/1170)</td>
<td>20.5 (168/820)</td>
<td>21.2 (61/288)</td>
<td>16.6 (755/4559)</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>9.5 (841/8841)</td>
<td>12.6 (617/4904)</td>
<td>16.8 (611/3638)</td>
<td>18.9 (213/1130)</td>
<td>12.3 (2282/18,513)</td>
</tr>
</tbody>
</table>

*P < .001 for each age group vs all others; †P < .001 for each BP category vs all others.
BMI at baseline and also had a normal BMI at follow-up. Similarly, 541 and 143 subjects remained overweight and obese, respectively. Of those remaining at a normal BMI, the percentages progressing to hypertension were 5.3%, 6.4%, and 9.5% for optimal, normal, and high-normal baseline categories (P < .001 for optimal v normal and high normal, and normal v high normal). Similarly, a statistically significant gradation in numbers was seen for those remaining overweight or obese. The percentage developing hypertension was much more marked in those who remained obese.

### Discussion

Our study involved a large cohort of men, screened at adolescence (ages 16.5–19 years) and followed into adulthood. Exclusion criteria ascertained that the study population at baseline was entirely composed of subjects of either optimal BP or in the “prehypertensive” phase. Both BMI and BP category (optimal, normal, and high normal), as defined by European classification guidelines, each on its own and independent of each other, were risk factors for the development of hypertension. While mean DBP increased with age, an unexpected finding was that mean SBP at follow-up decreased. This decrease resulted from the reduction in SBP in the age groups 26 to 30 years and 31 to 35 years, which quantitatively constituted the majority of subjects. A possible explanation is that from the recruitment stage until age 35 years, these regular military personnel were in an improved state of physical fitness. The limitations of the present study should be noted. First, our study population includes only male subjects. We specifically excluded women because, during the study years (1976–1996), the number of female regular army personnel was considerably lower than that of men, and was therefore not representative of the female Israeli population at large. Second, BP values at baseline were based on only one BP measurement, whereas guidelines.

#### Table 3. Odds ratios for the development of hypertension for the different BP and BMI categories at baseline versus optimal BP and normal weight category

<table>
<thead>
<tr>
<th>BP category at baseline</th>
<th>Weight category at baseline</th>
<th>Odds ratio (95% confidence interval)</th>
</tr>
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<tbody>
<tr>
<td>Normal</td>
<td>Overweight</td>
<td>2.28 (2.08–2.51)</td>
</tr>
<tr>
<td>Normal</td>
<td>Obese</td>
<td>5.45 (4.75–6.24)</td>
</tr>
<tr>
<td>High normal</td>
<td>Overweight</td>
<td>3.10 (2.78–3.46)</td>
</tr>
<tr>
<td>High normal</td>
<td>Obese</td>
<td>6.45 (5.53–7.53)</td>
</tr>
</tbody>
</table>

#### Table 4. Percentages of subjects according to BP categories at baseline who developed hypertension at follow-up while remaining in their respective BMI categories

<table>
<thead>
<tr>
<th>BP category at baseline</th>
<th>BMI category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal (BMI &lt;25)† (N = 9762)</td>
</tr>
<tr>
<td>Optimal*</td>
<td>5.3</td>
</tr>
<tr>
<td>Normal*</td>
<td>6.4</td>
</tr>
<tr>
<td>High normal*</td>
<td>9.5</td>
</tr>
</tbody>
</table>

* P < .001 for each BP group v all others; † P < .001 for each BMI category v all others.
require the mean of BP recordings from two or more office visits. However, because BP measurements were grouped into categories, the potential variation induced by a single BP determination in such a large cohort is probably of minor importance. Finally, apart from obesity, our study cannot relate to other adverse risk factors for hypertension such as smoking or alcoholic consumption, as these data were not consistently obtained during the recruitment phase.

In conclusion, this study focused on the importance of adolescent BP and BMI as a risk factor for the development of hypertension. Its findings emphasize the significance of the European classification guidelines of BP and, specifically, the subdivision of the “prehypertensive” phase into normal and high-normal categories. Although lifestyle modifications should be encouraged throughout the population with the aim of maintaining an optimal BP and BMI range, the European guidelines permit the identification of high-risk groups. Because the global burden of hypertension is predicted to burgeon to an estimated 1.56 billion adults in 2025, in this age of limited resources, it is financially sound to focus on high-risk groups. As our data suggest, the foremost group of adolescents at whom direct intervention should be aimed is the high-normal BP group, particularly when combined with a BMI >25. Our data do not permit financial evaluation of the proposed intervention. Prospective studies should be performed to address both the clinical and economic aspects delineated by our retrospective study.

References


