Blood Pressure Associated With Sleep-Disordered Breathing in a Population Sample of Children

Edward O. Bixler, Alexandros N. Vgontzas, Hung-Mo Lin, Duanping Liao, Susan Calhoun, Fred Fedok, Vukmir Vlasic, Gavin Graff

Abstract—The current criteria for sleep-disordered breathing (SDB) in children are not based on a clinically relevant outcome. The purpose of this study was to assess the association of blood pressure with SDB in a random sample of the local elementary school children (kindergarten through grade 5) using a 2-phased strategy. During phase 1, a brief questionnaire was completed for all of the children (N=5740) with a response rate of 78.5%. During phase 2, 700 randomly selected children from phase 1 with a response rate of 70.0% were assessed with a full polysomnograph and a history/physical, including an ECG; ear, nose, and throat; and pulmonary evaluation. We observed a significantly elevated systolic blood pressure associated with the apnea hypopnea index (AHI): AHI ≥1 (2.9 mm Hg); AHI ≥3 (7.1 mm Hg); and AHI ≥5 (12.9 mm Hg). The SDB and blood pressure association remained significant after adjusting for age, sex, race, body mass index percentile or waist circumference, sleep efficiency, percentage of rapid eye movement sleep, and snoring. In addition, older age, body mass index percentile, waist circumference, and snoring were significantly associated with blood pressure, independent of SDB. Based on these findings, our study suggests that SDB is significantly associated with higher levels of systolic blood pressure in children aged 5 to 12 years even after adjusting for the various confounding factors. Clinically, the data support the threshold of AHI ≥5 for the initiation of treatment for SDB. Additional research is indicated to assess the efficacy of SDB treatment on reducing blood pressure. (Hypertension. 2008;52:1-6.)

Key Words: blood pressure • snoring • REM AHI • children • sleep-disordered breathing

Sleep-disordered breathing (SDB) in adults has been shown to be independently associated with hypertension in population samples in cross-sectional and prospective studies.1-5 In addition, hypertension in adults has been shown to be associated with snoring in the absence of sleep apnea.3,6 It is assumed that a similar association is present in children with SDB. However, adequate data are not currently available to support this relationship in children.7-9

We have located 7 published studies that have used an objective polysomnographic (PSG) assessment of SDB as an independent predictor of elevated blood pressure.9-15 One of these studies reported that patients with an apnea index (AI) >1 compared with patients with primary snoring had elevated blood pressure.9 Another study reported that the apnea hypopnea index (AHI) was independently associated with blood pressure >90th percentile in a community sample.11 The latter study did not address a threshold, and both of these studies reported quite severe SDB. The remaining studies that did not report elevated waking blood pressure were all based on small samples (<100), and many had inadequate controls. Because the current PSG criteria for SDB in children are not based on clinically relevant outcomes, these studies used varying thresholds for SDB ranging from AI >1 to AHI >10. Thus, the objectives of this study were as follows: (1) to evaluate the association of SDB with blood pressure in a large (N=700) representative random sample of children from the general public with mild to moderate SDB; (2) to establish the AHI in children that is associated with a clinically significant increase in blood pressure; and (3) to determine the relative contribution of several potential risk factors in this association.

Methods

This study was designed as a 2-phase study with the first phase designed for collecting general information from the parents about their child’s sleep and behavioral patterns. In the second phase we collected more detailed data in our general clinical research center on a stratified sample randomly selected subset from the first phase. The study was reviewed and approved by our institutional review board, as well as by the general clinical research center review board.

In the first phase, elementary schools (kindergarten through grade 5) were selected each year so that ~1500 students were enrolled. A questionnaire with consent forms to be completed by the parent was sent home with every child. The questionnaire used was based on the survey published by Ali et al,16 validated to identify children at high risk for SDB. Over the course of 5 years, we have assessed all 18 of the public elementary schools within 3 school districts of Dauphin County, Pennsylvania. Overall, we sent home 7312 questionnaires, and 5740 were returned for a response rate of 78.5%.
In the second phase of this study, each year 200 children were selected from the questionnaires that were returned that year. Using a stratification of grade, sex, and risk for SDB (based on the parent’s response to the initial questionnaire), we randomly selected children from each stratum to maintain representativeness of the original sample. At the end of the 5-year study, we recorded 704 children for 1 night in the sleep laboratory; however, 4 children did not complete the recording. Thus, the final sample included 700 children for a response rate of 70%. All of the measures were completed by trained and certified research technicians according to standard procedures, with regular ongoing quality control assessment. We contrasted the subjects who completed the PSG recording with those who were selected but did not complete the phase 1 questionnaire. There were no significant differences between the 2 groups. During the PSG recording night, a second consent was signed by the parent and assented to by the child. Then the child completed a detailed evaluation including a physical examination and a 9-hour fixed-protocol PSG. The physical examination, which was completed in the evening before the PSG, included height, weight, waist and neck measurement, blood pressure, and a visual evaluation of the nose and throat by an ear, nose, and throat specialist, as well as an evaluation of the respiratory function by a pediatric pulmonologist. Blood pressure was measured in the seated position using an automated system (vital signs monitor 006-001-01, Welch Allyn) with the appropriately sized cuffs. The accuracy of this vital signs monitor is reported to be ±3 mm Hg for ages >3 years. In addition, the internal calibration was performed every time before using it on a participant, and the machine was checked against a mercury sphygmomanometer at least annually. The means of the final 2 of 3 blood pressure measurements were used for the analysis. Height was measured in centimeters using a stadiometer (model 242, SECA Corp), and weight was assessed using a scale (model 758c, Cardinal Scale Manufacturing Co). In the standing position, the waist was measured in centimeters at the top of the iliac crest and the neck at the corticothyroid membrane.17

For the sleep evaluation, all of the subjects in the presence of a parent spent 1 night in sound-attenuated, temperature- and light-controlled rooms in our general clinical research center. During this time, the child’s sleep was continuously monitored for 9 hours (24 analog channel and 10 dc channel TS amplifier using Gamma software, Grass-Telefactor, Inc). A 4-channel electroencephalogram, a 2-channel electro-oculogram, and a single-channel electromyogram were recorded. The sleep records were subsequently scored independently according to standardized criteria.18 Respiration was monitored throughout the night by use of thermocouple at the nose and mouth (model TCT R, Grass-Telefactor, Inc); nasal pressure (MP 45 to 871±2 cm H2O, Validyne Engineering Corp), and thoracic and abdominal strain gauges (model 1312, Sleepmate Technologies). A subjective estimate of snoring was obtained from parental report. In addition, we obtained an objective estimate of snoring during the PSG by monitoring breathing sounds with a microphone attached to the throat (model 1250, Sleepmate Technologies), as well as a separate room microphone. A single-channel ECG was also recorded. All of the night hemoglobin oxygen saturation was obtained from the finger (model 8800, Noomin Medical).

We defined sleep apnea and hypopnea using criteria that are currently used in clinical practice.19,20 All of the PSG records were double scored. An obstructive apnea was defined as a cessation of airflow with a minimum duration of 5 seconds and an out-of-phase strain gauge movement. A hypopnea was defined as a reduction of airflow of ~50%, with an associated decrease in oxygen saturation of ≥3% or an associated arousal. Based on these data, an AI (apneas per hour of sleep) and an AHI [(apneas+hypopneas)/hours of sleep] were calculated. We further defined individuals as “without SDB” if AHI was <1, as “mild SDB” if AHI was ≥1 but <5, and as “moderate SDB” if AHI was ≥5. We used this SDB definition throughout the analysis, although we also performed analysis using A1 ≥1 or ≥2 as a cutoff point to define SDB and to compare 2 definitions of SDB in our data. AHI was also analyzed as a continuous variable in the models to identify other factors that were associated with higher levels of blood pressure.

### Statistical Methods

Means and proportions of the main variables were calculated for the entire study population, as well as stratified according to SDB status. The ANCOVA was used to calculate multivariable adjusted means and the SEs of systolic, diastolic, and mean blood pressure. We accounted for the sampling probability from phase 1 to phase 2 enrollments in all of the analyses to generate population level estimates and to make inference back to the population from which the phase 2 study participants were selected. Our a priori hypothesized covariables included age, sex, race, percentage of rapid eye movement (REM) sleep, sleep efficiency, height, weight, and body mass index (BMI) percentiles adjusted for age and gender based on Centers for Disease Control and Prevention criteria.21 The effect modification of the SDB and blood pressure relationship by snoring during sleep was also tested.

### Results

The final sample that completed the sleep laboratory phase of this study included 700 subjects. The major characteristics of the study sample are presented in Table 1 for the entire population, as well as stratified according to SDB status.

#### Table 1. Characteristics of Study Population

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>No SDB</th>
<th>Mild SDB</th>
<th>Moderate SDB</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>700</td>
<td>517</td>
<td>175</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Age, mean (SD), mo</td>
<td>111 (21)</td>
<td>111 (21)</td>
<td>112 (20)</td>
<td>121 (18)</td>
<td>0.283</td>
</tr>
<tr>
<td>Male, proportion, %</td>
<td>48</td>
<td>49</td>
<td>47</td>
<td>11</td>
<td>0.120</td>
</tr>
<tr>
<td>Minority, proportion, %</td>
<td>24</td>
<td>21</td>
<td>34</td>
<td>0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI percentile, mean (SD)</td>
<td>61 (29)</td>
<td>60 (29)</td>
<td>65 (28)</td>
<td>68 (42)</td>
<td>0.072</td>
</tr>
<tr>
<td>Waist, mean (SD), cm</td>
<td>65 (10)</td>
<td>64 (10)</td>
<td>66 (11)</td>
<td>73 (15)</td>
<td>0.002</td>
</tr>
<tr>
<td>Weight, mean (SD), kg</td>
<td>35 (12)</td>
<td>34 (12)</td>
<td>37 (13)</td>
<td>46 (16)</td>
<td>0.003</td>
</tr>
<tr>
<td>Height, mean (SD), cm</td>
<td>136 (12)</td>
<td>136 (12)</td>
<td>137 (11)</td>
<td>148 (6)</td>
<td>0.013</td>
</tr>
<tr>
<td>Neck, mean (SD), cm</td>
<td>29 (5)</td>
<td>29 (5)</td>
<td>30 (4)</td>
<td>30 (2)</td>
<td>0.173</td>
</tr>
<tr>
<td>REM, mean (SD), %</td>
<td>20 (6)</td>
<td>20 (6)</td>
<td>20 (5)</td>
<td>17 (6)</td>
<td>0.193</td>
</tr>
<tr>
<td>Sleep efficiency, mean (SD), %</td>
<td>86 (12)</td>
<td>85 (9)</td>
<td>87 (8)</td>
<td>83 (9)</td>
<td>0.034</td>
</tr>
<tr>
<td>Snore, proportion, %</td>
<td>25</td>
<td>21</td>
<td>37</td>
<td>73</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Systolic blood pressure, mean (SD), mm Hg</td>
<td>111 (12)</td>
<td>110 (12)</td>
<td>112 (11)</td>
<td>126 (11)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diastolic blood pressure, mean (SD), mm Hg</td>
<td>66 (8)</td>
<td>66 (8)</td>
<td>66 (7)</td>
<td>71 (5)</td>
<td>0.131</td>
</tr>
<tr>
<td>MAP, mean (SD), mm Hg</td>
<td>81 (8)</td>
<td>80 (8)</td>
<td>81 (7)</td>
<td>89 (7)</td>
<td>0.002</td>
</tr>
</tbody>
</table>
population and according to SDB status, defined by AHI <1, AHI 1 to 5, and AHI ≥5. In this population-based sample of young children, we identified 8 individuals (1.14%) as moderate SDB, 175 individuals (25.00%) as mild SDB, and 517 individuals as without SDB (73.86%). Current clinical standards use 2 different definitions to diagnose SDB, one based on AI and the other on AHI. Neither of these criteria has been assessed based on a relevant clinical outcome. To address this issue, we assessed the association of SDB based on these 2 definitions and blood pressure, a condition associated frequently with SDB in adults. The association of AI with blood pressure was assessed by comparing those with AI <1 and subjects with AI ≥1 and AI ≥2. There was no significant association between AI and blood pressure. In the Figure we described the association of blood pressure with SDB by comparing all of the subjects with AHI <1.00 with those with AHI 1.00 to 1.99, 2.00 to 2.99, 3.00 to 3.99, 4.00 to 4.99, and ≥5.00. The strongest association with blood pressure was noted with AHI ≥5.00 (12.9 mm Hg; \( P=0.0006 \)), whereas it approached significance at AHI 3.00 to 3.99 (5.5 mm Hg; \( P=0.056 \)). The lack of significance with AHI 4.00 to 4.99 may reflect the small number of children in this category. Because we did not observe a significant association between AI and blood pressure, all of our further analyses were based on the AHI.

The mean levels and their SEs of blood pressure across SDB categories (AHI <1, AHI 1 to 5, and AHI ≥5) are presented in Table 2, from unadjusted model, basic demographic variable-adjusted model, and an extended model to include all of the major covariates. For example, in the fully adjusted model, the mean systolic blood pressure levels (±SEs) by SDB categories were 109.9 ±0.5, 111.7 ±0.8, and 123.6 ± 3.7 mm Hg (\( P=0.001 \) for trend); diastolic blood pressure means were 65.6 ±0.4, 65.5 ±0.6, and 69.9 ±2.8 mm Hg (\( P=0.136 \) for trend); and mean arterial pressure (MAP) means were 80.4 ±0.3, 80.9 ±0.6, and 87.8 ±2.7 mm Hg (\( P=0.009 \) for trend), respectively.

It has been reported that SDB in children, in contrast to adults, is an REM-related disease. To assess this hypothesis, we first evaluated the association between REM and non-REM AHI with the severity of the overall AHI. The correlation between the REM AHI and the overall AHI was markedly less than the correlation between the non-REM AHI and the overall AHI (REM AHI, \( R^2=0.112 \); non-REM AHI, \( R^2=0.947 \)). To assess the relative clinical significance of these 2 AHIs we repeated the fully adjusted model (see model 3 in Table 2) to evaluate the association between SDB and blood pressure based on the AHI observed during REM and non-REM sleep separately. These results are presented in Table 3. The average AHI observed in our sample during REM sleep was 1.12 ±0.07 (median: 0.48; interquartile range: 1.54) compared with 0.74 ±0.07 (median: 0.18; interquartile range: 0.78) during non-REM sleep (signed rank test

---

**Table 2. Mean Blood Pressure Levels (SE) by SDB Categories**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th></th>
<th>Model 2</th>
<th></th>
<th>Model 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>AHI &lt;1</td>
<td>1≤AHI&lt;5</td>
<td>AHI ≥5</td>
<td>P</td>
<td>AHI &lt;1</td>
<td>1≤AHI&lt;5</td>
</tr>
<tr>
<td></td>
<td>109.6 (0.51)</td>
<td>112.40 (0.87)</td>
<td>125.6 (3.94)</td>
<td>P1&lt;0.01</td>
<td>109.9 (0.46)</td>
<td>111.8 (0.79)</td>
</tr>
<tr>
<td>Diastolic</td>
<td>65.5 (0.36)</td>
<td>65.8 (0.61)</td>
<td>71.1 (2.77)</td>
<td>P1=0.75</td>
<td>65.6 (0.36)</td>
<td>65.5 (0.61)</td>
</tr>
<tr>
<td>MAP</td>
<td>80.2 (0.36)</td>
<td>81.3 (0.61)</td>
<td>89.3 (2.76)</td>
<td>P1=0.12</td>
<td>80.4 (0.34)</td>
<td>81.0 (0.58)</td>
</tr>
</tbody>
</table>

Model 1 was adjusted for sampling weight. Model 2 was like model 1, plus age, minority, sex, and BMI percentile. Model 3 was like model 2, plus sleep efficiency, snoring, and percentage of REM sleep. \( P \) values for testing the mean difference were as follows: P1 for comparing “non-SDB” with “mild SDB,” P2 for comparing “non-SDB” with “moderate SDB,” and P3 for comparing “mild SDB” with “moderate SDB.”
P<0.001), which supports the hypothesis that more AHI occurred in the REM than in the non-REM sleep in children. However, in terms of the relationship with the blood pressure, the non-REM AHI was significantly associated with elevated blood pressure, whereas the REM AHI was not (Table 3).

Snoring based on parent report is commonly used as a risk factor for SDB in children. In our study, snoring was identified based on 2 different methods. The first method was a subjective assessment based on the survey in the phase 1 study of snoring (moderate to severe), which was reported by the parent in 14.9% of the children. Subjective snoring was reported in 14.3% of those with an AHI <1, 15.5% of those with an AHI between 1 and 5, and 37.5% of those with an AHI ≥5 (P=0.181). The second measure of snoring was based on the objective evaluation obtained during the PSG and was present in 25.4% of the children. Objective snoring was observed in 20.9% of those with an AHI <1, 36.6% of those with an AHI between 1 and 5, and 75.0% of those with an AHI ≥5 (P<0.001). We first assessed the general agreement between these 2 measures of snoring. The κ estimate (κ=0.109) suggested a very low degree of agreement. We further assessed the association of the 2 sources of snoring with blood pressure. The parental report of snoring versus no snoring was associated with borderline significantly higher systolic blood pressure 112.3±1.1 versus 110.2±0.4 mm Hg (P=0.071), whereas the objectively measured snoring versus no snoring was associated with a significantly higher systolic blood pressure (112.2±0.8 versus 109.9±0.5 mm Hg; P=0.017). The parent’s report of snore versus no snore was not associated with an increased diastolic blood pressure (65.7±0.8 versus 65.6±0.3 mm Hg; P=0.962) in contrast to the objective estimate (66.9±0.5 versus 65.2±0.3 mm Hg; P=0.016). In a similar manner, for MAP the parental report of snore versus no snore was not significantly associated with blood pressure (81.1±0.8 versus 80.3±0.3 mm Hg; P=0.389), whereas the objective estimate of snoring was (81.8±0.6 versus 80.0±0.3 mm Hg; P=0.006). Because of the stronger association of objective snoring with blood pressure, we examined whether objectively measured snoring modifies the AHI and elevated blood pressure association.

Although the interaction between snoring and AHI was not significant, largely because of very small differences between snorers and nonsnorers in the non-SDB (AHI <1) group and very small sample size in the moderate SDB (AHI ≥5) group, we observed that, in the group with mild-SDB (AHI between 1 and 5), objectively measured snore was associated with the following: (1) a significantly higher diastolic blood pressure (mean±SE: 67.0±0.9 versus 64.8±0.7 mm Hg; P=0.049); (2) a significantly higher MAP (mean±SE: 82.5±0.9 versus 80.3±0.7 mm Hg; P=0.041); and (3) a slightly but not statistically significant higher systolic blood pressure than nonsnoring (mean±SE: 113.6±1.3 versus 111.1±1.0 mm Hg; P=0.136). These results may suggest that snoring in the presence of mild SDB may be associated with additional risk for elevated blood pressure, especially diastolic blood pressure.

Table 4 presents the regression coefficients of various factors associated with blood pressure from multivariable regression models. These factors included the following: age, sex, minority, BMI percentiles, (or waist circumference and height), REM percentage, sleep efficiency, objective snoring, and AHI. Older age, BMI percentile, waist circumference, height, and AHI were significantly associated with systolic

<table>
<thead>
<tr>
<th>Variable</th>
<th>β (SE)</th>
<th>P</th>
<th>β (SE)</th>
<th>P</th>
<th>β (SE)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mo</td>
<td>0.18 (0.02)</td>
<td>&lt;0.01</td>
<td>0.04 (0.02)</td>
<td>0.01</td>
<td>0.09 (0.02)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Male</td>
<td>0.79 (0.86)</td>
<td>0.36</td>
<td>−0.05 (0.64)</td>
<td>0.94</td>
<td>0.23 (0.62)</td>
<td>0.71</td>
</tr>
<tr>
<td>Minority</td>
<td>0.01 (0.98)</td>
<td>0.99</td>
<td>0.84 (0.72)</td>
<td>0.25</td>
<td>0.56 (0.71)</td>
<td>0.43</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>0.102 (0.02)</td>
<td>&lt;0.01</td>
<td>0.03 (0.01)</td>
<td>0.01</td>
<td>0.05 (0.01)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Waist, cm*</td>
<td>0.26 (0.05)</td>
<td>&lt;0.01</td>
<td>0.05 (0.04)</td>
<td>0.20</td>
<td>0.12 (0.04)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Height, cm*</td>
<td>0.14 (0.07)</td>
<td>&lt;0.05</td>
<td>0.12 (0.05)</td>
<td>&lt;0.01</td>
<td>0.13 (0.05)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>REM %</td>
<td>0.11 (0.08)</td>
<td>0.20</td>
<td>0.08 (0.06)</td>
<td>0.18</td>
<td>0.09 (0.06)</td>
<td>0.13</td>
</tr>
<tr>
<td>Neck, cm</td>
<td>0.16 (0.10)</td>
<td>0.11</td>
<td>0.02 (0.07)</td>
<td>0.82</td>
<td>0.06 (0.07)</td>
<td>0.37</td>
</tr>
<tr>
<td>Sleep efficiency, %</td>
<td>−0.05 (0.06)</td>
<td>0.42</td>
<td>−0.10 (0.04)</td>
<td>0.02</td>
<td>−0.08 (0.04)</td>
<td>0.04</td>
</tr>
<tr>
<td>Snoring</td>
<td>2.08 (1.02)</td>
<td>0.04</td>
<td>1.48 (0.76)</td>
<td>&lt;0.05</td>
<td>1.68 (0.74)</td>
<td>0.02</td>
</tr>
<tr>
<td>AHI, AHI per hour</td>
<td>0.58 (0.27)</td>
<td>0.03</td>
<td>0.18 (0.20)</td>
<td>0.37</td>
<td>0.31 (0.19)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Data are from linear regression models including all listed variables in the model.

*Waist replaced BMI percentile in the regression model.
blood pressure. However, only older age, BMI percentile, height, sleep efficiency, and snoring were significantly associated with diastolic blood pressure. Older age, BMI percentile, waist, height, and snoring were significantly associated with MAP. It is worth noting that the effects of these risk factors on blood pressure were modeled mathematically, adjusting for the effects of SDB, thus representing their respective effects on blood pressure independent of SDB status.

Discussion

The current study, which is the largest published population-based sample of children aged 5 to 12 years, indicates that blood pressure is strongly associated with AHI in these children. These data confirm a previous population study based on a smaller sample. The clinical relevance of elevated blood pressure in children of this age range is supported by reports of increased left ventricular mass associated with elevated blood pressure and that the presence of hypertension in children is a strong risk factor for essential hypertension in adults. Because our study shows that AHI in children makes an independent contribution to clinically significant elevated blood pressure, its detection and management may lead to a significant reduction of elevated blood pressure in children and potentially of cardiovascular risk in adults.

The observed association between AHI and systolic blood pressure appears to strongly support the critical threshold of AHI ≥5. Several thresholds have been suggested by individual investigators or committees to initiate treatment in sleep apnea, ranging from an AI >1 to AHI ≥5. Our study supports the cutoff of AHI ≥5, which is also the most commonly used in everyday practice for initiating treatment of sleep apnea. However, further investigation is needed to assess the efficacy of SDB treatment on reducing blood pressure. In addition, based on our assessment of the association of various thresholds of AHI with systolic blood pressure, an AHI ≥3, which accounted for 4% of our sample, might signal the need for more frequent monitoring of blood pressure and SDB. The use of the threshold of AI ≥1 was not supported by our data because we did not find a significant association between AI and blood pressure, which is contrary to what has been reported previously based on a relatively small clinical sample. One possible explanation for this difference is that the previous study had a mean AI of 10, suggesting that there were some subjects with very high AI, which could have influenced the result.

We assessed the relative contribution of several potential risk factors that might contribute to an elevated blood pressure. The factors included in the final multivariate model were BMI, waist, and AHI. This result held whether we included AHI as a continuous or a categorical variable. The results suggest that SDB is independent of other confounding risk factors for elevated blood pressure in children. In adults with SDB it is becoming increasingly clear that SDB is associated with metabolic changes that may play an important role in the clinical presentation. The fact that waist circumference was a strong risk factor for systolic blood pressure in our multivariate models suggests that metabolic factors may also play a contributing role for blood pressure associated with AHI within children similar to adults. This potential mechanism of SDB in children warrants further study.

Snoring in adults has been reported to be associated with an increased risk for hypertension. Similar findings have been reported in children. In children, the parental report of snoring is commonly used as a risk factor for SDB. In our study, snoring was assessed in 2 different ways. We first addressed this issue by evaluating the degree of overlap between these 2 estimates. Surprisingly, the correlation was quite weak (κ=0.109). We also observed that snoring based on parental report was only weakly associated with either AHI or blood pressure. Snoring objectively assessed during the PSG was more strongly associated with both AHI and with blood pressure. The explanation for this discrepancy is not immediately apparent. It is possible that the parent’s observations are influenced by factors such as apprehension, attitudes, education, etc. In any event, it appears that, with regard to sleep symptoms, parental reports should be confirmed with more objective data. With regard to the additional effect of snoring, we found little support for the association between primary snoring (AHI <1) and elevated blood pressure, as has been reported previously. In our data, the interaction between SDB and snoring was not significant for either systolic or diastolic blood pressure. However, there was some indication that snoring was associated with an increased diastolic blood pressure and MAP in mild SDB (AHI 1 to 5) but not in the moderate group. Several reasons can be considered for the lack of association between snoring and SDB status in relationship to blood pressure in the moderate SDB group. First, it is possible that, because snoring and AHI are highly correlated at higher levels of AHI and less correlated at lower levels of AHI, the latter may lead to the “independent statistical” effect of snoring on blood pressure, largely attributable to its relationship with blood pressure in individuals with lower AHI. Second, it is possible that snoring, which is a precursor of moderate or severe SDB, detects “preclinical/subclinical” SDB when AHI fails to do so because of night-to-night variability, a phenomenon that is stronger in mild cases. Third, it is also possible that snore and AHI measure different physiological processes in young children with a mild degree of SDB.

AHI observed during REM sleep in children has been reported to be greater than AHI observed during non-REM sleep. In contrast, in another study that experimentally induced SDB in children, there was an increase in AHI during nasal occlusion in non-REM (1.2 to 8.4; P <0.01) but not in REM (1.5 to 1.6; P value not significant) sleep. In our study, we first addressed the question of whether REM AHI or non-REM AHI better correlates with the overall AHI. The linear association between non-REM AHI and the overall AHI was quite robust (R²=0.947), whereas the REM AHI was relatively weakly associated with the overall AHI (R²=0.112). In addition, we assessed the clinical significance in terms of blood pressure of the AHI observed during REM sleep compared with the AHI observed during non-REM sleep. In our sample, AHI observed during non-REM sleep but not REM sleep was significantly associated with elevated blood pressure, especially systolic and MAP. This suggests
that REM AHI is not useful in predicting the association of SDB with blood pressure in children.

The major strength of this study is that it is representative of the underlying population. The sample was based on a 2-phase protocol with a response rate of 78.5% for the initial phase and 70.0% for the second phase. The majority of the published studies assessing the association of blood pressure and AHI in children are based on clinical samples, which may not be representative of the general public. However, this study does suffer from weaknesses. The first caveat is that statistical power in the more severe SDB subgroup was reduced because of the relatively rare prevalence within the general population. In addition, in representative samples such as this one, the severity of the SDB observed tends to be less severe than what is seen in the clinical population. In addition, the blood pressure was obtained only in the evening. Other studies have assessed blood pressure continuously over a 24-hour period or during the PSG recording. However, this degree of blood pressure assessment does carry a risk of disturbing sleep.

**Perspectives**

Our study suggests that SDB is an independent risk factor for elevated blood pressure in children aged 5 to 12 years. At a threshold of AHI ≥5, the effect on blood pressure appears to warrant therapeutic intervention for SDB. Additional research is needed to assess the efficacy of SDB treatment on reducing blood pressure. At a threshold of AHI ≥3, the assessment of the blood pressure and the AHI in regular follow-up visits may be warranted. Again, future research is indicated to validate this suggestion. Primary snoring or snoring in the moderate group does not appear to be a risk factor for blood pressure; however, snoring may be an additive factor for mild AHI. Finally, the association of waist with systolic blood pressure supports the influence of metabolic factors in childhood SDB. AHI remained significantly associated with blood pressure after adjusting for these metabolic factors. This indicates that SDB in children is independently associated with elevated blood pressure, at least partially, via some nonobesity related pathways.

**Sources of Funding**

This work was supported by National Institutes of Health grants R01 HL063772, M01 RR010732, and C06 RR016499.

**Disclosures**

None.

**References**

Blood Pressure Associated With Sleep-Disordered Breathing in a Population Sample of Children
Edward O. Bixler, Alexandros N. Vgontzas, Hung-Mo Lin, Duanping Liao, Susan Calhoun, Fred Fedok, Vukmir Vlasic and Gavin Graff

Hypertension. published online October 6, 2008;

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2008 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/early/2008/10/06/HYPERTENSIONAHA.108.116756.citation

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/