ARTICLE

Blood Pressure Elevation Associated With Sleep-Related Breathing Disorder in a Community Sample of White and Hispanic Children

The Tucson Children's Assessment of Sleep Apnea Study

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Background: The Tucson Children's Assessment of Sleep Apnea study (TuCASA) was designed to investigate the prevalence and correlates of objectively measured sleep-related breathing disorder (SBD) in preadolescent Hispanic and white children.

Objective: To describe the associations of SBD and elevation in resting blood pressure in the first 239 children enrolled in TuCASA.

Design: Children between the ages of 6 and 11 years (45% girls and 51% Hispanic) from elementary schools of the Tucson Unified School District were enrolled in this prospective cohort study. Resting systolic and diastolic blood pressure, sleep symptoms, and parental smoking status were obtained during evening home visits, followed by overnight unattended home polysomnography.

Results: The mean (SD) systolic and diastolic blood pressures were 98.4 (10.6) mm Hg and 62.0 (8.9) mm Hg, respectively. Fifteen children had hypertension. The mean (SD) respiratory disturbance index (2%), defined as the number of apneas and hypopneas per hour of sleep associated with a 2% oxygen desaturation, was 2.3 (3.8) events per hour. Factors independently associated with systolic and diastolic blood pressure elevation were obesity, sleep efficiency, and respiratory disturbance index (2%).

Conclusions: In preadolescent children, elevated blood pressure is associated with SBD and obesity, as previously noted in adults. The control of obesity in childhood may be important to reduce the daytime consequences of SBD and to reduce the risks of life-long hypertension.

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THE ASSOCIATION between sleep-related breathing disorder (SBD) and hypertension has been recognized in adults since the mid 1980s.[1] The cross-sectional associations of systolic and diastolic blood pressure (BP) (and hypertension) with multiple indices of SBD were recently confirmed in a large community-based study[2] of more than 6000 adults (the Sleep Heart Health Study). Furthermore, higher mean diastolic BP during sleep was noted in a study of 41 children with clinically significant obstructive sleep apnea syndrome when compared with children with primary snoring.[3] Although factors that influence BP in children have been studied in large cohorts,[4-7] to our knowledge, there are no previous reports of the association between elevations in BP and objectively measured SBD from a community-based sample of children.

The Tucson Children's Assessment of Sleep Apnea study (TuCASA) was designed to investigate the prevalence and correlates of objectively measured SBD in a population-based cohort of preadolescent children.[8] TuCASA included BP measurements as part of its protocol and thus allowed us to investigate the relationship between BP elevation and SBD in children of this age group.

METHODS

RECRUITMENT

White and Hispanic children aged 6 to 11 years were recruited from elementary schools in Tucson, Ariz. The Tucson Unified School District (TUSD) is a large district with children representative of those living in southern Arizona. To recruit a final cohort that was approximately 50% Hispanic, we selected elementary schools with 25% to 75% Hispanic students enrolled. We sent the parents of each child a 1-page child's sleep habits questionnaire, which focused on symptoms associated with SBD (**Table 1**). The return rate of this screening instrument was approximately 31%.[9] From parents who agreed to be contacted, we re-

Table 1. Sample Questions From the Screening Questionnaire Sent to Parents*

How often does your child snore loudly?
Does your child stop breathing during sleep?
Is your child sleepy during the daytime?
Does your child fall asleep at school?
Does your child fall asleep while watching television?
Does your child have learning problems?

*Responses were checked as "don't know; never; rarely; occasionally; frequently; or almost always." Questions regarding birth date, sex, weight, height, and ethnicity were also asked.

quested permission to perform an unattended polysomnogram (PSG) on the child in their home. The TuCASA protocol was approved by the University of Arizona Human Subjects Committee and TUSD Research Committee. Informed consent was obtained from a parent or legal guardian, and a children's assent form approved by the institutional review board was completed by each child. Full details of the study design have been previously published.[8]

HOME VISITS

Visits to each child's home were scheduled to occur approximately 1 hour before the child's usual bedtime. One of the child's parents was given a self-administered questionnaire that contained items concerning the child's sleep habits, daytime activity levels, and whether either parent smoked cigarettes during the previous 2 months (parental smoking). The child's height, weight, and arm and neck circumference (size) were measured using standardized techniques. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. A categorical variable of obesity was defined as a BMI of greater than the 95th percentile standardized for age, sex, and ethnicity.[10,11]

After a few minutes of rest while seated, the child's BP was measured in triplicate from the right arm using a portable mercury sphygmomanometer and standardized techniques.[12] The appropriate BP cuff was selected according to the measured arm size (upper arm circumferences of 6-15 cm for infants, 16-22 cm for children, and 23-30 cm for regular-sized adults). The initial cuff inflation pressure was determined by adding 30 mm Hg to the palpated systolic BP. Cuff deflation was at 2 mm/s. At least 30 seconds elapsed between each of the 3 successive measurements. The mean of the final 2 of 3 BP measurements was used for the analyses for this report. We defined BP elevation as a systolic and diastolic BP above the 90th percentile when adjusted for age, height, and sex.[7]

POLYSOMNOGRAPHY

After BP was measured, the PSG procedure was explained to the parent(s) and child. The PSG electrodes and sensors were attached using a vest and a portable, battery-powered sleep recording system (PS-2 SleepWatch; Compumedics Ltd, Abbotsford, Victoria, Australia). The system consists of a patient interface box containing amplifiers and filters to which electrodes and sensors are connected. The following signals were acquired as part of the TuCASA montage: C3/A2 and C4/A1 electroencephalogram, right and left electroculogram, a bipolar submental electromyogram, thoracic and abdominal displacement (inductive plethysmography bands), airflow (nasal/oral thermistor), nasal pressure cannula, finger pulse oximetry, single-lead electrocardiogram, snoring (microphone), body position, and ambient light. The PSG signals were verified before the study team left the home. The equipment was removed the following morning, and the stored data were downloaded for review.

The software system (W-series Replay, version 2.0, release 22; Compumedics Ltd) was used to process all PSGs. Scoring procedures have been previously described.[8] Sleep stages were scored according to the criteria of Rechtschaffen and Kales.[13] Arousals were identified using criteria published by the American Academy of Sleep Medicine.[14] Sleep efficiency was expressed by the total sleep time as a percentage of the sleep period time. The arousal index was calculated as the total number of arousals divided by the total sleep time. Apneas were scored if the amplitude (peak to trough) of the airflow signal using the thermistor decreased below at least 25% of the amplitude of baseline breathing (identified during a period of regular breathing with stable oxygen levels), if this change lasted for more than 6 seconds or 2 breath cycles. Hypopneas were designated if the amplitude of any respiratory signal decreased below 70% of the amplitude of baseline and if the thermistor signal did not meet the criterion for apnea. Central events were marked if no displacement was noted on both the chest and abdominal inductance channels. Otherwise, events were scored as obstructive. For this analysis, the nasal pressure signal was not used to define SBD events. The PSGs with less than 4 hours of a valid oximetry signal were classified as failed studies.

After full scoring, analysis software was used to link each breathing event to data from the oxygen saturation and electroencephalogram channels. Respiratory events were marked independently of concomitant oxygen desaturation; this allowed characterization of events according to differing degrees of associated desaturations and arousals or various combinations of these measures. In this manner, the respiratory disturbance index (RDI) was defined as the number of respiratory events (apneas and hypopneas) per hour of the total sleep time. In addition, scoring software marked respiratory events in terms of associated desaturations (0%, 2%, 3%, or 4%, with or without arousal).

All studies were scored by a single registered PSG technologist, who was required to demonstrate a complete understanding of the study's scoring rules and to articulate reasons for assigning epoch-by-epoch codes for sleep and respiratory scoring. Approximately 5% of studies were rescored by the same scorer on a blinded basis to determine consistency in scoring. No systematic differences were observed between initial and rescored studies.

STATISTICAL ANALYSIS

All study results were entered or transferred to a computer database for data verification and cleaning. The data for this analysis were transferred to SPSS statistical software version 10 (SPSS Inc, Chicago, Ill) for statistical analyses. Descriptive statistics (distributions of continuous variables) were reviewed for normalcy and outliers. Exploratory univariate analyses of the key variables were performed using nominal/logistic regression and χ^2 analyses. Because RDI distributions were not normal, they were log transformed before analysis. Those variables associated with elevations in systolic or diastolic BP on univariate analyses were then used in multivariate nominal and logistic regression analyses. Diagnostic analyses to detect the presence of collinearity were performed for measures of body size, sleep quality, and indices of RDI.

RESULTS

Results from the first 239 study participants who completed unattended home PSGs between December 12, 2000, and January 14, 2002, are reported herein. Fifty-five percent were boys, 51% were Hispanic, 54% were in the 6-

to 8-year age group, and 12% were obese. A parent of 15% of the children reported hearing the child snoring loudly (frequently or almost always). Fifteen (6%) had hypertension, and 19% had parents who smoked cigarettes. See **Table 2** for additional participant characteristics.

Significant univariate associations were noted between elevations in systolic and diastolic BP and indices of body size, sleep fragmentation, and SBD. In exploratory analyses, we found qualitatively similar associations between systolic and diastolic BP elevation and RDI2%, RDI3%, and RDI4% but not RDI0%. However, because the absolute number of desaturation events for RDI2% was larger than for the other definitions of SBD, we elected to present only the data for RDI2% in Table 3 and to use this definition for subsequent multivariate analyses. In addition, we found that sleep efficiency and arousal index were colinear. Inasmuch as the best-fitting multivariate model incorporated sleep efficiency, but not arousal index, data using the former are presented in **Table 3**. Similarly, collinearity was observed for neck circumference, BMI, weight, and categorical obesity. Obesity was associated with the most parsimonious model and is used in Table 3 as well. For systolic BP elevation, there were significant associations with habitual loud snoring, witnessed apnea, RDI2%, and poorer sleep efficiency. For diastolic BP elevation, relationships were observed with obesity, poorer sleep efficiency, RDI2%, and arousal index. Factors not associated with either systolic or diastolic hypertension were sex, ethnicity, total sleep time, and parental smoking.

As given in Table 3, systolic BP elevation, noted in 15 of the children, was independently associated in the logistic regression model with poorer sleep efficiency and RDI2% desaturation. Diastolic BP elevation, also noted in 15 children, was independently associated with obesity, RDI2%, and poorer sleep efficiency.

Table 2. Characteristics of the 239 Tucson Children's Assessment of Sleep Apnea Study Participants

Characteristic	Mean (5th-95th Percentile)
Age, y	8.70 (6.15-11.24)
Height, cm	132 (113-152)
Weight, kg	32.6 (19.4-56.0)
Body mass index, kg/m^2	18.4 (13.5-27.9)
Neck size, cm	27.0 (22.5-33.0)
Systolic blood pressure, mm Hg	98.4 (82.0-119.0)
Diastolic blood pressure, mm Hg	62.0 (48.0-77.3)
Hours of sleep	8.15 (5.23-9.93)
RDI2%*	2.3 (0.2-5.5)
Sleep efficiency, %	90.1 (78.6-96.2)
Arousal index	3.39 (1.77-5.93)

*The respiratory disturbance index 2% (RDI2%) was defined as the number of apneas and hypopneas associated with a 2% oxygen desaturation per hour of sleep.

Table 3. Independent Factors Associated With Hypertension Using Logistic Regression

Factor	OR (95% CI)	*P* Value
Systolic hypertension		
RDI2%	4.57 (1.21-17.3)	.02
Sleep efficiency	0.92 (0.86-0.99)	.048
Diastolic hypertension		
RDI2%	4.75 (1.22-18.5)	.02
Sleep efficiency	0.92 (0.87-0.99)	.04
Obesity	4.57 (1.36-15.4)	.01

Abbreviations: CI, confidence interval; OR, odds ratio; RDI2%, respiratory disturbance index 2% (defined as the number of apneas and hypopneas associated with a 2% oxygen desaturation per hour of sleep).

COMMENT

Obesity and hypertension are becoming a significant health problem in children.[15] In this study performed in a general population sample, children with elevations in BP were more likely to be obese, have poorer sleep, and have evidence of SBD. These data provide evidence that SBD and obesity contribute to the development of hypertension in children and adults.

Our study provides evidence that SBD may be an important factor in the development of hypertension in children. To our knowledge, the only previous study of hypertension and SBD in children is that of Marcus and coworkers,[16] who studied a cohort of children referred to a sleep disorders center. These investigators found that mean diastolic BP measured automatically during both wakefulness and sleep was higher in young children with obstructive sleep apnea when compared with children with only snoring. The results of our study extend these findings by demonstrating an association between SBD and daytime hypertension in a large community-based sample of children. These findings may have significant implications for the health of children as they mature into adulthood. It is possible that children with unrecognized SBD and hypertension may eventually be those adults with severe hypertension caused by many years of untreated BP elevation. Furthermore, children without hypertension but with unrecognized SBD may be at increased risk for developing hypertension as an adult.

Elevations in BP during wakefulness were associated only with SBD events that resulted in some degree of oxygen desaturation. This observation is consistent with data from a large cohort of adults in which the risk of hypertension increased with the amount of nocturnal oxygen desaturation.[2] Furthermore, our results are consistent with data from animal models of obstructive sleep apnea. Experimentally induced chronic obstructive sleep apnea results in persistent daytime hypertension in dogs.[17] Moreover, an important factor in the development of hypertension in rats is episodic hypoxia.[18]

We observed that poorer sleep efficiency was independently associated with both systolic and diastolic BP elevation. In many cases, poorer sleep efficiency is a reflection of cortical arousals and sleep fragmentation. This is consistent with our finding that the arousal index and sleep efficiency were colinear in our study population. Acute elevations in BP occur in association with cortical arousals and sleep fragmentation and are believed to be related to an increase in sympathetic nervous system ac-

What This Study Adds

Sleep-related breathing disorders are associated with BP elevation and obesity in adults. Our study observed this association in elementary school–aged children as well.

tivity.[19,20] Thus, our data suggest that nocturnal arousals contribute to the development of daytime hypertension in children. However, they are not consistent with some experimental data in dogs[17] and adults[2] that indicate that sleep fragmentation is not important in the pathogenesis of daytime hypertension. These discrepancies may be explained by differences in the arousal response to apnea in children when compared with adults.[21]

We observed that an elevation in diastolic BP was related to obesity. The importance of obesity has been emphasized as a remedial cause of hypertension in children.[15] It is possible that the saying "The child is father of the man" is applicable because a child's body habitus (obesity and thick neck) persists into adulthood. Thus, subtle increases of BP may result in frank hypertension as the child grows into adulthood.[22] Longitudinal studies will be necessary to study this hypothesis, but meanwhile our results add to the accumulating body of evidence that childhood obesity is not benign.

A limitation of our study is the lack of recordings of leg movement. Our sleep recorder did not have enough bandwidth to add another electromyogram channel. Periodic leg movements are one mechanism known to increase the arousal index and are associated with inattention in children.[23] Differences in BP and SBD may be present in children from ethnic groups that we did not study (African American, Asian American, and American Indian, for instance). Finally, we acknowledge that our definition of BP elevation includes those children who are considered to have high normal pressures (>90th and <95th percentile) and those considered hypertensive (>95th percentile).[12] Nevertheless, our data demonstrate an association between SBD and this definition of BP elevation. Moreover, it has been recommended that children with high normal values be further observed and other risk factors evaluated.[12]

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