

# Feasibility of Using Unattended Polysomnography in Children for Research— Report of the Tucson Children's Assessment of Sleep Apnea Study (TuCASA)

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**Study Objectives:** The Tucson Children's Assessment of Sleep Apnea study (TuCASA) is designed to investigate the prevalence and correlates of objectively measured sleep-disordered breathing in pre-adolescent children. This paper documents the methods and feasibility of attaining quality unattended polysomnograms in the first 162 TuCASA children recruited.

**Design:** A prospective cohort study projected to enroll 500 children between 5 and 12 years of age who will undergo unattended polysomnography, neurocognitive evaluation, and physiological and anatomical measurements thought to be associated with sleep-disordered breathing.

**Setting:** Children are recruited through the Tucson Unified School District. Polysomnograms and anthropometric measurements are completed in the child's home.

**Participants:** Of the 157 children enrolled in TuCASA, there were 100 children (64%) between 5–8 years old and 57 children (36%) between the ages of 9 to 12. There were 74 (47%) Hispanic children, and 68 (43%) female participants.

**Interventions:** N/A

**Measurements & Results:** Technically acceptable studies were obtained

in 157 children (97%). The initial pass rate was 91%, which improved to 97% when 9 children who failed on the first night of recording completed a second study which was acceptable. In 152 studies (97%), greater than 5 hours of interpretable respiratory, electroencephalographic, and oximetry signals were obtained. The poorest signal quality was obtained from the chin electromyogram and from the combination thermister/nasal cannula. Parents reported that 54% of children slept as well as, or better than usual, while 40% reported that their child slept somewhat worse than usual. Only 6% were observed to sleep much worse than usual. Night-to-night variability in key polysomnographic parameters (n=10) showed a high degree of reproducibility on 2 different nights of study using identical protocols in the same child. In 5 children, polysomnograms done in the home were comparable to those recorded in a sleep laboratory.

**Conclusions:** The high quality of data collected in TuCASA demonstrates that multi-channel polysomnography data can be successfully obtained in children aged 5–12 years in an unattended setting under a research protocol.

**Key words:** Sleep; polysomnography; children; obstructive sleep apnea; sleep-disordered breathing

## INTRODUCTION

SLEEP-DISORDERED BREATHING (SDB) INCLUDING OBSTRUCTIVE SLEEP APNEA SYNDROME (OSAS) IS INCREASINGLY RECOGNIZED AS AN IMPORTANT CAUSE OF MORBIDITY IN CHILDREN. Clinical symptoms of OSAS in children include snoring, nocturnal arousals, restlessness during sleep, enuresis, daytime sleepiness, and hyperactivity.<sup>1-4</sup> Evidence also suggests that the adverse effects of frequent nocturnal arousals include behavioral, learning, and personality problems.<sup>5-7</sup> While estimates indicate that the prevalence of OSAS is approximately 4% in adult men and 2% in adult women,<sup>8</sup> no large epidemiological study using polysomnography has been conducted to determine the prevalence of SDB in young children.

Polysomnography in adults with OSAS commonly demonstrates episodes of frank apnea although there is increasing

recognition that hypopneas and episodes of elevation in upper-airway resistance are important as well.<sup>9-11</sup> In contrast, polysomnography in children with OSAS frequently is characterized by hypopneas and periods of obstructive hypoventilation, with frank apnea found less commonly.<sup>12,13</sup> Therefore, polysomnographic monitoring techniques and criteria used to define the presence of SDB developed for adults are not necessarily applicable to children. Recent interest in childhood OSAS has led to an increase in the number of polysomnograms performed in children. However, normal values for indices of SDB severity are not well defined, and it is unknown whether proposed abnormal values correlate with clinical outcomes. Although one study in a small number of children proposed normative ranges for apnea in children,<sup>14</sup> similar guidelines for hypopnea and upper-airway resistance events in children have not been clearly established. To determine the level of severity of SDB which correlates with abnormal clinical outcomes, polysomnographic recordings are required from a large number of children with no clinical symptoms of OSAS and those with symptoms consistent with OSAS. It is quite expensive to study a large population of normal children with laboratory polysomnography due to the cost of laboratory time and the need to compensate families for their participation. Additionally, parents and their young children without known sleep problems often hesitate to spend a night in the unfamiliar setting of a sleep laboratory (particularly school aged children). Therefore, there is a need to develop techniques to perform unattended home polysomnographic recordings in children to accurately determine

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the prevalence of SDB in children and to correlate severity levels of SDB with abnormal clinical outcomes.

The Tucson Children's Assessment of Sleep Apnea study (TuCASA) is a prospective cohort study designed to determine the prevalence rate of objectively documented SDB in pre-adolescent children and to investigate its relationship to symptoms, performance on neurobehavioral measures, and physiologic and anatomic risk factors. Up to 500 Caucasian and Hispanic children aged 5–12 years will undergo unattended polysomnography over the course of the four-year study. This report describes the methods used for obtaining and analyzing unattended home polysomnography data for the first 157 children enrolled in the TuCASA study.

## METHODS

### Selection of Participants

Hispanic and Caucasian children aged 5 to 12 years were recruited to participate in the TuCASA study by soliciting the cooperation of selected elementary schools in the Tucson Unified School District (TUSD). TUSD is a very large district with an elementary school population representative of children living in Southern Arizona. To assure that an adequate mix of Hispanic and Caucasian children were recruited, elementary school populations were pre-screened so that at least 25%, but no more than 75% of children attending the school were of self-reported Hispanic ethnicity. A short sleep habits questionnaire was sent home with children in a "notes home" folder. Parents were asked to complete the questions and provide some demographic information at a minimum, and to provide their contact information if they would allow study personnel to call them for screening. Incentives were provided to classrooms and schools in order to increase participation. The polysomnography testing protocol used in the TuCASA study was approved both by the University of Arizona Human Subjects and the TUSD Research Committees.

### Home Polysomnography

An unattended home polysomnogram was scheduled as soon as possible after recruitment. A two-person, mixed gender team arrived at the home approximately one hour prior to the child's normal bedtime. During the home visit, the following data were collected in addition to polysomnography: anthropometric measurements (height, weight, and neck circumference), a digital photograph of the oropharynx and tonsils, visual oropharynx inspection, seated blood pressure, and a more extensive sleep habits questionnaire. A morning survey was completed by the caregiver the following morning.

Polysomnograms were obtained using the Compumedics PS-2 system (Abbotsford, Victoria, Australia). This monitor was chosen because of its portability, capability to record a full polysomnographic montage, flexibility of software, and successful use during other studies of home-based polysomnography.<sup>15</sup> Prior to implementing the TuCASA protocol, a feasibility study of 10 children with similar characteristics to those being studied in TuCASA demonstrated that the Compumedics system could be satisfactorily used in children. The system consists of a patient interface box (PIB) containing amplifiers and filters to which

electrodes and sensors are connected. The PIB is attached by cable to the data acquisition recorder which contains a 40MB PCMCIA card, a 15-hour rechargeable battery, and an oximeter. The PIB, loose electrode wires, and sensor cables are secured inside a loose fitting vest which is worn by the child over his or her pajamas. The vest is a variation of the Compumedics adult vest, with modifications made specifically for studies of young children. The system contains a liquid crystal display (LCD) for visualizing signals after hook-up, and an internal impedance meter to verify electrode attachments.

Sensors were placed and the equipment was calibrated by technicians during the evening home visit. Gauze, tape, water-soluble pastes, and conductive gels were used to secure sensors and electrodes. The following signals were acquired as part of the TuCASA montage: C<sub>3</sub>/A<sub>2</sub> and C<sub>4</sub>/A<sub>1</sub> electroencephalogram (EEG), right and left electrooculogram (EOG), a bipolar submental electromyogram (EMG), thoracic and abdominal displacement (inductive plethysmography bands), airflow (nasal/oral thermister), nasal pressure cannula, oximetry (finger pulse oximeter, Nonin, Minneapolis, MN), ECG (single bipolar lead), snoring (microphone attached to the vest), body position (Hg gauge sensor), and ambient light (sensor attached to the vest to record on/off). The nasal pressure cannula was employed in an attempt to capture subtle SDB events related to elevations in upper airway resistance which otherwise might have been undetected. The thermister and nasal pressure signals were collected simultaneously by taping a nasal/oral thermister (Protec, Woodinville, WA) on the superior surface of a nasal cannula (Salter Labs, Arvin, CA).

All signals were verified using the LCD, and impedances were checked to insure that values were <5 kohms. A written verification form was used to annotate impedances, any adverse environmental conditions, or any medical conditions requiring notification of a physician. The equipment was removed the following morning by a research technician or a parent.

### Data Handling

Once the equipment was retrieved and cleaned, data stored in real time on a 40MB PCMCIA flashcard was downloaded for review. A preliminary examination of the raw data determined if artifact free signals were present for sufficient duration to allow scoring of the polysomnogram. Studies with <4 hours of oximetry, insufficient duration or quality of signal, or equipment malfunction during the night were marked as "failed." Raw data from passing studies were immediately backed up to Zip Disk™ for storage, then transferred to a hard drive for scoring. Once scoring was completed, a copy of the raw data and a copy of each hypnogram generated from different scoring passes was archived onto a CD-RW disk. As a courtesy to parents of those children participating, a brief summary of anthropometric measurements and sleep characteristics was sent to the family within three weeks of the home visit.

### Scoring

The Compumedics software system was used to process all polysomnograms (W-Series Replay, v 2.0, release 22). The scorer reviewed the record as shown on the computer monitor in three passes. During the first pass, sleep stages and arousals were

marked manually on a 30-second, epoch by epoch basis. During the second pass, respiratory signals were displayed in two or five minute epochs, and respiratory events were manually marked without visualizing the nasal pressure monitor. During the third pass, respiratory signals were displayed in two or five minute epochs, and respiratory events were manually marked using all respiratory monitors including nasal pressure.

Sleep stages were scored according to Rechtschaffen and Kales criteria.<sup>16</sup> Arousals were identified using criteria published by the American Academy of Sleep Medicine.<sup>17</sup> Apneas were scored if the amplitude (peak to trough) of the airflow signal using the thermister 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 >6 seconds or two breath cycles. Hypopneas were designated if the amplitude of any respiratory signal decreased below (approximately) 70% of the amplitude of “baseline” and if the thermister signal did not meet the criterion for apnea. If the thermister signal was not scorable, then the event was scored as a hypopnea. Upper-Airway events were identified if criteria for apnea/hypopnea were not met, but there was flattening of the contour of the nasal pressure signal<sup>18</sup> lasting for  $\geq 6$  seconds or two breaths. “Central” events were marked if no displacement was noted on both the chest and abdominal inductance channels. Otherwise, events were scored as “obstructive.” Although desirable, we made no attempt to distinguish between central and obstructive hypopnea because reliable classification was not possible. In the absence of an esophageal balloon, paradox of the chest and abdominal inductance bands would be suggestive of an obstructive component to a hypopnea. While the scorable duration of these signals in our study was high (*vide infra*, Table 2), their quality was not adequate to distinguish between obstructive and central hypopnea on a consistent basis.

After full scoring, analysis software was used to link each event to data from the oxygen saturation and EEG channels. 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. The Sleep Disordered Breathing index (SDBI) was defined as the number of apneas, hypopneas and upper airway events per hour of total sleep time. Compumedics software calculated these indices separately for REM and NREM sleep, and for different body positions. Summary measures of desaturation, sleep stages, arousal frequencies, and heart rate variation also were computed.

The scorer assigned an overall quality grade of excellent (at least one EEG channel, one EOG channel, chin EMG, oximetry, airflow, thoracic, and abdominal bands good for >5 hours), good (at least two respiratory channels [airflow, thoracic or abdominal bands], oximetry, and one EEG good for >5 hours), or fair (respiratory channels [airflow or either band], oximetry, and one EEG were good for >4 hours but <5 hours). To receive the passing grade of fair, the EEG signal must have been of sufficient quality to determine sleep from wake. Any other problems with scoring that could affect reliability were annotated, as well as potential medical alerts such as heart rate >150 or <30 beats per minute for longer than 2 minutes, O<sub>2</sub> saturation <75% for >10% of total sleep time, or RDI >25.

All studies were scored by a single registered polysomnographic 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. This was judged by a review of records with one of the investigators. Subsequently, the scorer periodically reviewed selected records with one of the investigators. Studies posing difficulties in scoring or interesting problems were reviewed by the scorer and other investigators during quality assurance meetings.

Approximately 5% of studies were re-scored by the same scorer on a blinded basis to determine consistency in scoring. No systematic differences were observed between initial and re-scored studies. Comparison of some key parameters on blind studies scored using the nasal thermister (RDI, total sleep time, and sleep efficiency) were highly correlated ( $p < .01$ ). Similar results were found in studies scored with the addition of the nasal pressure cannula. Also, 12 children were asked to complete a second night of unattended polysomnography under conditions similar to the first recording in order to validate the reproducibility of major polysomnographic outcomes. A representative range of children were selected with respect to age, gender, and ethnicity. Children were only selected if the overall quality of the first PSG was excellent ( $n=10$ ) or good ( $n=2$ ), and both thermister and nasal pressure signals were of quality sufficient to score respiratory events.

To compare the quality of TuCASA polysomnograms to those performed in a sleep laboratory, a small study was conducted with a sample of five children who had both a polysomnogram recorded at home and one recorded at the University of Arizona Sleep Disorders Center. Four children were selected from the TuCASA cohort to have a repeat study in the sleep laboratory within approximately seven weeks of their home polysomnogram. Children were selected for laboratory polysomnography if their home study was of excellent quality and the parent agreed to spend the night in the lab. One child was not a member of the TuCASA cohort, but had undergone a polysomnogram in the sleep laboratory for the diagnosis of sleep apnea. This child was studied in the home seven weeks after the laboratory polysomnogram. Studies acquired in the sleep laboratory used a Grass Heritage™ digital acquisition system (Astro-Med, Warwick, RI) but the same montage as that employed in the home polysomnograms. These lab studies were scored using the same criteria as those performed in the home.

Statistical analysis was performed using STATA 6.0 for Windows (STATA Corporation, College Station, TX). The Wilcoxon signed-rank test was used to compare the distributions of key sleep parameters in the night-to-night and lab vs. home studies due to small sample sizes of ten and five respectively. Spearman rank correlation was used to compare variables for the blinded scoring studies. The Wilcoxon signed-rank test was also used to compare the median RDI in samples scored with thermister versus nasal pressure due to skewness in the distribution of RDI. The Bland-Altman procedure was used to visually compare the difference in means for the night-to-night variability study.<sup>19</sup>

**Table 1**—Baseline characteristics

		Male (n=89)	Female (n=68)	Total (n=157)
Age (years)	5—8	62 (40%)	38 (24%)	100 (64%)
	9—12	27 (17%)	30 (19%)	57 (36%)
Ethnicity	Cau	43 (27%)	40 (26%)	83 (53%)
	Hisp	46 (29%)	28 (18%)	74 (47%)
BMI > 95 percentile	Yes	18 (12%)	8 (5%)	26 (17%)
	No	71 (45%)	60 (38%)	131 (83%)
Snore*	Yes	29 (19%)	24 (15%)	53 (34%)
	No	60 (38%)	44 (28%)	104 (66%)
EDS†	Yes	25 (16%)	22 (14%)	47 (30%)
	No	64 (41%)	46 (29%)	110 (70%)

BMI=Body Mass Index (kg/m<sup>2</sup>); EDS=Excessive Daytime Sleepiness; Cau=Caucasian; Hisp=Hispanic  
 Response by parent to "How often does your child snore loudly?"\* and "Is your child sleepy during the daytime?"† was occasionally, frequently, or almost always.

**Table 2**—Quality of polysomnography

Hours of Scorable Signal Mostly Free from Artifact (%)

	Hours Scorable Signal (mean, SD)	≥6 hours	≥4 but < 6 hours	≥2 but < 4 hours	< 2 hours
Abdominal Band	8.6 (1.3)	97%	3%	0%	1%
Chest Band	8.6 (1.6)	94%	3%	1%	1%
EOG	8.4 (1.5)	92%	6%	1%	1%
Oximeter	8.3 (1.5)	92%	7%	1%	0%
ECG	8.3 (1.5)	92%	7%	1%	0%
EEG	8.1 (2.2)	89%	5%	3%	4%
Chin EMG	7.7 (2.8)	84%	4%	3%	9%
Thermister	6.1 (2.7)	59%	17%	16%	8%
Nasal Cannula	5.6 (3.0)	52%	18%	15%	15%

## RESULTS

### Baseline Characteristics

The baseline characteristics of the 157 children enrolled in TuCASA are shown in Table 1. There were 100 children (64%) between five to eight years old and 57 children (36%) between the ages of 9 to 12. The Hispanic population was well represented with 74 children (47%). There were 68 female participants (43%) and 89 males (57%). A snoring prevalence of 34% (n=53) was found in this sample, and 30% (n=47) of parents reported their child had daytime sleepiness of occasionally to almost always. Using the standardized data for body mass index reported by Rosner et al,<sup>20</sup> 26 children (17%) exceeded the 95th percentile of BMI for gender, ethnicity, and age, and were classified as obese.

### Feasibility

Between February 2000 and March 2001, 162 children underwent unattended home polysomnography. Sufficient sleep data was collected on 147 subjects, for an initial failure rate of 9%

(n=15). Six of these 15 failures were due to oximetry <4 hours (the oximeter became wet or detached from the finger), five were due to equipment failure (such as a disconnected cable or battery failure), and on four occasions the child or parent removed the monitor prior to completion of at least four hours of sleep (child refused to sleep with equipment). Of the initial failures, nine out of ten children had a successful second study with the only failure due to oximetry <4 hours. This subject had a third study completed, which was successful. The overall number of successful sleep studies was 157 out of 162 children attempted, for an overall failure rate of 3%.

### Study Quality and Recording Times

Study quality grades and length of scorable signal for the 157 studies are shown in Table 2. Overall, there were 61% (n=95) studies of excellent quality, 36% (n=57) studies of good quality and 3% (n=5) of these studies were of fair quality. The highest quality signals were found on respiratory bands and EOG, and the lowest quality signals were found on chin EMG and airflow channels. There were no trends in signal quality over the course of data collection. The mean recording time was 569 minutes

**Table 3**—Equipment discomfort

	None	Very Little	Moderate	A great deal
Vest	60%	30%	7%	3%
Oximeter	59%	27%	10%	4%
Respiratory				
Bands	56%	29%	11%	4%
ECG	53%	30%	15%	2%
EEG	53%	31%	14%	2%
EOG	42%	30%	21%	7%
Thermister/ Cannula	35%	31%	17%	17%

**Table 4**—Distribution of RDI

RDI	N	Mean	SD	%
0 - 4.9	65	2.87	.81	41.4
5 - 9.9	72	5.35	.83	45.9
10 - 14.9	14	8.06	.85	8.9
15 - 19.9	4	11.07	1.35	2.5
> 20	2	29.52	22.04	1.3

RDI = number of respiratory events (apneas and hypopneas) per hour of the total sleep time

(range 324–740), with a mean sleep period of 512 minutes (range 301–662.5), and mean sleep efficiency of 89.4% (range 72.8%–97.2%).

### Participant Burden

A short questionnaire completed by parents on the morning after the sleep study ascertained that 54% of subjects slept as well as or better than usual, 40% of the parents said that their child slept somewhat worse than usual, and 6% slept much worse than usual. The thermister/nasal cannula combination was the sensor which received the most complaint of discomfort with 34% of parents reporting that their child had a moderate to a great deal of discomfort (Table 3). Other sensors which caused at least moderate discomfort were the EOG electrodes (28%) and the EEG electrodes (17%). The respiratory bands, vest, and oximeter received very few discomfort complaints. Of all subjects, 24% (n=37) of parents reported that their child had difficulty falling asleep on the night of the study.

### Respiratory Disturbance Index

The distribution of RDI calculated from events scored without visualization of the nasal pressure signal is skewed towards lower RDI values (Table 4). Most events were hypopneic, and little oxygen desaturation was noted in most participants. The overall mean RDI value was 6.6 with a standard deviation of 6.6 and a range from 0.6 to 72.4 events per hour (this high value was confirmed by laboratory polysomnography). An RDI of > 10 was found in 12.7% (n=20) of children.

The third pass of polysomnogram scoring included nasal pressure in conjunction with other respiratory signals to detect more subtle changes in upper airway resistance. In general, more

events were detected when using the nasal pressure signal. Out of 157 children studied, 66% (n=103) had a nasal pressure signal of sufficient duration and quality to assist in scoring. Using this signal, the mean overall RDI increased to 7.8 with a standard deviation of 6.9 and range of 2 to 69.2 ( $p < .001$  vs RDI without nasal pressure cannula). An RDI > 10 now was found in 18% (n=18) of children.

### Night to Night Variability

Of the 12 children who were asked to undergo a second night of polysomnography, one of the studies failed due to equipment malfunction (main cable disconnect), and one study failed because there was less than four hours of oximetry (loose oximeter). Of the ten remaining studies, six were of excellent quality, three were of good quality, and one was fair. The mean time between the two recordings was 23.8 days, with a range of 7 to 50 days. Sufficient nasal pressure signal to accurately score upper-airway events was available in eight of the ten studies.

The RDI calculated without use of the nasal pressure signal was not statistically significantly different between the two studies ( $p > .79$ ). The mean RDI for the first study was  $4.4 \pm 1.6$  (SD); for the second study the mean RDI was  $4.3 \pm 1.8$ . Total mean sleep time was  $530 \pm 69$  and  $507 \pm 76$  minutes, respectively ( $p > .65$ ). Sleep efficiency was 90% on the first night of study and 89% on the second night ( $p > .51$ ). Using RDI as the comparison measure between the two nights of study, a Bland Altman plot (Figure 1) shows good agreement between the two separate nights of study with a mean difference of 1.16. Similar analyses using the RDI calculated with the nasal pressure signal showed no significant difference between the first and second nights of study ( $p > .62$ ).

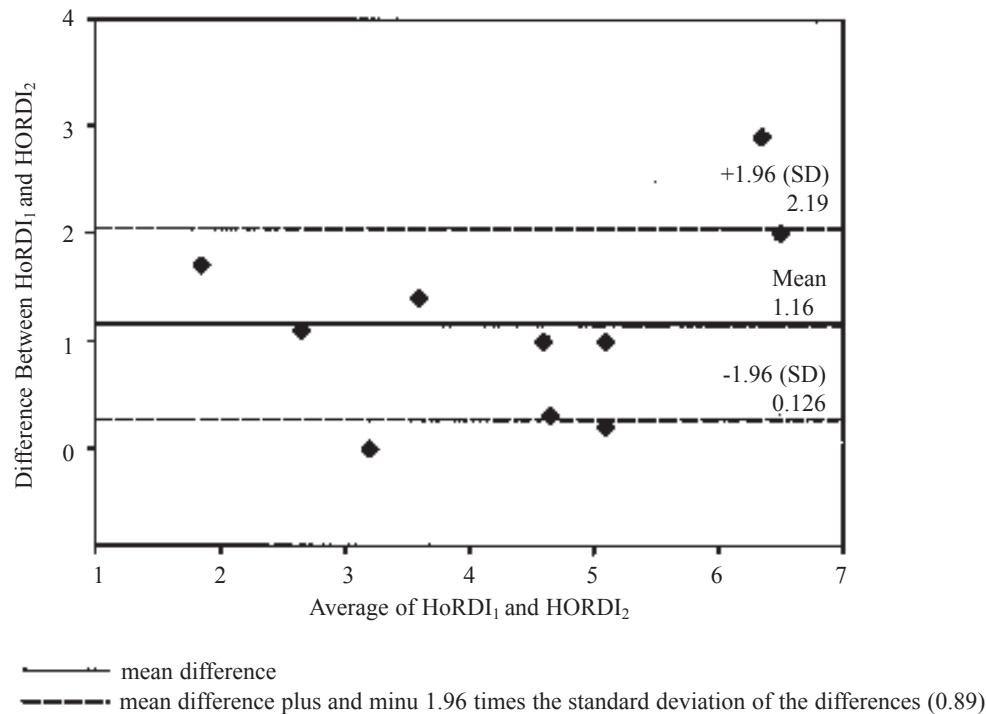
### Comparison to Laboratory Polysomnography

In the five children who were asked to complete a polysomnogram in the University of Arizona Sleep Disorders Center, one child had the clinical study done first and four children completed the home study first. In these five children, there was no statistically significant difference in RDI between the two methods ( $p > .13$ ). The sleep architecture between the lab and home studies showed consistently similar results in these children.

### DISCUSSION

The TuCASA study demonstrates that high quality unattended multi-channel polysomnography can be performed on children aged 5–12 years in a research protocol with a high rate of success. Moreover, parental assessment indicates that the monitoring equipment had only a small effect on sleep quality in the majority of children studied. Although addition of a nasal pressure cannula identified a slightly greater number of SDB events, it was associated with a higher failure rate. Repeat studies showed little night to night variability. Furthermore, unattended polysomnography using this protocol compared favorably to attended studies in a sleep laboratory.

In TuCASA, we performed unattended polysomnography in the home and acquired high quality sleep data in children with a >90% success rate. There have been several previous reports of home sleep recordings in children; however, none have used full



**Figure 1**—Bland-Altman plot of RDI night-to-night variability. HoRDI1=RDI on first night of polysomnography. HoRDI2=RDI on second night of polysomnography. N=10.

polysomnography.<sup>21,22</sup> Most of these studies have monitored a limited number of respiratory channels using a variety of sensors to record airflow, thoracic and abdominal movement, and oxygen saturation. To better define sleep, video camera monitoring, in conjunction with partial polysomnography, has also been proposed.<sup>23</sup> Although SDB can be assessed with a reasonable degree of certainty with such methods, accurate measurement of the amount and quality of sleep is not possible. The full neurocognitive impact of SDB in children may require an assessment of the quantity and quality of sleep, especially in those without severe disease. Such recordings can be obtained in a sleep laboratory with attended polysomnography; however, the cost of recording a large number of children would be quite expensive, and the burden on families could be significant. Therefore, for clinical research, the capability to perform full unattended polysomnography in the home is essential to understand the neurocognitive impact of SDB in children.

We found that the polysomnogram montage used in our study has only a modest impact on parental assessment of sleep quality. The majority of children slept as well as, or better than, usual and only a small number slept poorly. The primary sensor causing discomfort was the combination thermister/cannula, which consists of a pediatric oxygen nasal cannula with a three-pronged thermister laying on its top surface. This finding is consistent with our observation that both airflow sensors also had the highest rates of signal duration less than four hours. The level of participant burden in TuCASA children is very similar to that found in the Sleep Heart Health Study (a large cohort study using unattended polysomnography in over 6,000 adults), with 30% of those adults having a moderate to great deal of discomfort caused by the thermister alone.<sup>15</sup>

When using nasal pressure to assist in the identification of hypopneas, we observed a higher RDI (or SDBI) than with only the thermister as an airflow signal. In adults, recording of nasal pressure has been advocated as a method of detecting subtle periodic elevations in upper airway resistance that is less invasive than esophageal manometry.<sup>24</sup> These events frequently are associated with microarousals from sleep and may have the same clinical impact as frank hypopneas and apneas.<sup>25</sup> Unfortunately, the nasal pressure signal had an even higher failure rate than the thermister. The explanation for this finding is unclear. However, because both sensors tend to cause some irritation in many of the children, we believe that the children tend to inadvertently manipulate them after the sleep recording has started. We speculate that the signal derived from the nasal pressure cannula is more position sensitive than the signal from the thermister resulting in greater signal loss when inadvertently moved. Thus, our data suggest that the nasal pressure cannula should not be used by itself as a marker of airflow during unattended polysomnography in children. Additionally, it is uncertain whether unattended polysomnography would be feasible in the pre-school age group as signal quality decreased in the younger children in our study.

In a limited sample of children, we found that the results from a second unattended polysomnogram were comparable to the first night of recording. There have been several studies of night-to-night variability in adults performed using laboratory polysomnography.<sup>26-30</sup> In general, the RDI on one night is comparable to another, although variability may be slightly greater when the RDI is low.<sup>26,30</sup> No studies of night to night variability have been performed using unattended polysomnography in children. However, our findings are comparable to a larger study performed in adults as part of the Sleep Heart Health Study in which

night-to-night variation also was small.<sup>31</sup>

A potential problem of laboratory polysomnography in young children is the inability to sleep well in an unfamiliar environment, surrounded by strangers and monitoring equipment. By recording sleep in the familiar home setting, children should be less apprehensive and have a more normal night of sleep. While we did not perform an extensive comparison of home to laboratory polysomnography (n=5), we obtained reasonably similar data in these participants. These statistical similarities are accepted with the limitations normally found in samples of such small size. Although we cannot infer that our home recordings were more representative of a child's sleep than recordings performed in a laboratory, they appear to be at least comparable.

A potential limitation of our findings is the exclusion of end-tidal PCO<sub>2</sub> or TcPCO<sub>2</sub> as part of our TuCASA recording montage. Use of end-tidal PCO<sub>2</sub> or TcPCO<sub>2</sub> has been recommended in children for detecting obstructive hypoventilation.<sup>32-34</sup> Unfortunately, it is not feasible to perform either end-tidal PCO<sub>2</sub> or TcPCO<sub>2</sub> measurements in the home environment. However, subtle changes in flow limitation indicative of increased upper airway resistance can be identified by the use of pressure changes measured with a nasal cannula.<sup>18,25</sup> We believe that it is possible to identify episodes of obstructive hypoventilation using this signal, although we have no confirmatory data. Furthermore, it is likely that episodes of hypoventilation become less prevalent in older preadolescents, which comprise 35% of our cohort.

Another possible limitation of our study is the potential for selection bias. If parents of children with a sleep problem preferentially returned the screening questionnaire, a greater number of participants with a high RDI would have been studied. Unfortunately, this bias may be present in any prospective cohort study.

In conclusion, the TuCASA study has demonstrated the feasibility of collecting high quality unattended multi-channel polysomnography in children ages 5 to 12 years. Participant burden has been acceptable in the majority of children and has had only a modest effect on subjective sleep quality. Therefore, the polysomnographic recording techniques that we have outlined should prove useful in our current and other future epidemiological studies of sleep in children.

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## ABBREVIATIONS

BMI—body mass index; ECG—electrocardiogram; EEG—electroencephalogram; EMG—electromyogram; EOG—electrooculogram; LCD—liquid crystal display; HoRDI<sub>1</sub>—value of RDI on first night of home polysomnography; HoRDI<sub>2</sub>—value of RDI on second night of home polysomnography; NREM—non-REM sleep; OSAS—obstructive sleep apnea syndrome; PCM-CIA—personal computer memory card international association; PCO<sub>2</sub>—pressure of carbon dioxide; PIB—patient interface box; PSG—polysomnogram; REM—rapid eye movement sleep; RDI—respiratory disturbance index; SDB—sleep-disordered breathing; SDBI—sleep-disordered breathing index; TcPCO<sub>2</sub>—transcutaneous carbon dioxide; TuCASA—Tucson Children's Assessment of Sleep Apnea; TUSD—Tucson Unified School District