Comparison of Nasal Pressure Transducer and Thermistor for Detection of Respiratory Events During Polysomnography in Children

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Study Objectives: The results of small studies have suggested that a nasal-cannula pressure transducer has a higher sensitivity than a thermistor in detecting hypopneas and diagnosing sleep-disordered breathing in both adults and children. We compared a thermistor alone, and in conjunction with a pressure transducer, for detection of sleep-disordered breathing in children during in-home polysomnography.
Design: Retrospective analysis of a subsample of a prospective cohort study.
Setting: Students attending elementary school in the Tucson Unified School District.
Participants: A subsample of the Tucson Children's Assessment of Sleep Apnea study population.
Measurements and Results: Polysomnographic recordings of 40 children (24 girls and 16 boys, mean age 9.2±1.7 years; range 6-11 years) were analyzed to compare the detection of sleep-disordered breathing events by 2 different methods of measuring airflow: thermistor alone and thermistor with nasal-cannula pressure transducer (transducer) used simultaneously. The transducer detected all the respiratory events detected by the thermistor, but the thermistor detected only 84% of the transducer-defined events. Consequently, the transducer-derived mean respiratory disturbance index was higher than that detected by the thermistor (7.0±3.8 vs 5.9±3.4, P<.001). The bias error between transducer respiratory disturbance index and thermistor respiratory disturbance index on a Bland-Altman plot was 1.08 (95% confidence interval, 0.8-1.4). There was good agreement between the thermistor and the transducer for making the diagnosis of sleep apnea using a cutoff of a respiratory disturbance index greater than 5 (κ=0.69). The quality of the tracings with the transducer was comparable to that of the thermistor, but the transducer dislodged more frequently.
Conclusion: The use of a nasal transducer in conjunction with a thermistor was more sensitive than the thermistor alone in detecting sleep-disordered breathing in children during unattended polysomnography.
Keywords: Sleep, children, sleep-disordered breathing, transducer, thermistor
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INTRODUCTION

THERE IS INCREASING EVIDENCE SUGGESTING A FREQUENT OCCURRENCE OF OBSTRUCTIVE SLEEP APNEA (OSA) IN CHILDREN. THE PREVALENCE OF OSA in preschool population is estimated at 1% to 3%.[1-3] Adenotonsillar hypertrophy is hypothesized to be the primary etiology of this disorder at this age. However, other structural and neuromotor abnormalities may play a contributory role.[4] OSA in children is associated with excessive daytime sleepiness,[5] systemic hypertension,[6,7] impaired academic performance,[5,8,9] behavioral problems,[10] and increased healthcare utilization.[11] Treatment of childhood OSA results in improvement in daytime functioning,[12] long-term quality of life,[13] and academic performance[9] and reduces healthcare utilization.[14]

Polysomnography (PSG) continues to be the gold standard for the diagnosis of OSA. Thermistors utilizing change in temperature of exhaled air to assess the airflow have been traditionally used to detect apneas and hypopneas during PSG recording. However, thermistors may fail to detect minor but significant changes in airflow and may underestimate hypopneas.

Nasal pressure transducers have been suggested to be equivalent to invasive determination of inspiratory pressure using a supraglottic or an esophageal catheter in assessing flow limitation.[15] While the transducer has been shown to be superior to the thermistor in diagnosing hypopneas in adults,[16] similar data in children are scant.[17] As in adults,[18] the consequences of hypopneas in children may be the same as those of apneas. Thus, it is important to confirm whether a relatively noninvasive technique such as the nasal pressure transducer is a more sensitive method than the thermistor for detecting hypopneas in children. In this study, we compared the detection of airflow-limitation events by nasal transducer with that by thermistor in children undergoing unattended home PSG.

METHODS

Population

We performed a retrospective analysis of nocturnal PSG recordings obtained on 40 children as a part of the Tucson Children's Assessment of Sleep Apnea (TuCASA) study. The objectives and design of the TuCASA study have been reported previously.[19] Briefly, TuCASA is a prospective cohort study of children aged 6 to 11 years, intended to assess the prevalence, risk factors, and outcomes of SDB in this age group. Participants were recruited through the Tucson Unified School District; 504 children under-

went PSG as a part of the TuCASA study and the measurements of airflow were performed using both a thermistor and a transducer simultaneously. A sample of studies providing excellent technical quality (vide infra) for both thermistor and transducer tracings were selected. Of these excellent tracings, those with the longest sleep hours and maximum number of respiratory events (n=40) were used to maximize the reviewable data for this study. Consequently, the hours of sleep in this subsample were higher than those of the entire cohort.

Polysomnography

Children underwent unattended home PSG using the Compumedics PS-2 system (Abbotsford, Victoria, Australia).[19] The following signals were acquired as part of the TuCASA montage: C_3/A_2 and C_4/A_1 electroencephalogram, right and left electrooculogram, a bipolar submental electromyogram, thoracic and abdominal displacement (inductive plethysmography bands), airflow (nasal/oral thermocouple), nasal pressure cannula, oximetry (finger pulse oximeter, Nonin, Minneapolis, Minn), electrocardiogram (single bipolar lead), snoring (microphone attached to the vest), body position (mercury gauge sensor), and ambient light (sensor attached to the vest to record on/off). The thermistor and transducer signals were collected simultaneously by taping a nasal/oral thermocouple (Protec, Woodinville, Wash) on the superior surface of a nasal cannula (Salter Labs, Arvin, Calif). The filter settings for the thermistor and the transducer channels were 5 Hz for the high-frequency filter and 0.05 Hz for the low-frequency filter.

Each PSG record was manually scored on 3 passes through the recording by a single trained and certified registered polysomnographic technologist. During the first pass, sleep stages were marked manually on a 30-second, epoch-by-epoch basis. During the second pass, respiratory signals were displayed in 2- or 5-minute epochs, and respiratory events were manually marked using effort tracings and thermistor signal but without visualizing the nasal pressure monitor. During the third pass, respiratory signals were displayed in 2- or 5-minute epochs, and respiratory events were manually marked using all respiratory monitors, including nasal pressure and thermistor signal.[19]

A PSG was considered adequate if the total duration of sleep was more than 4 hours. PSGs with less than 4 hours of scorable oximetry were classified as failed studies and were repeated, subject to participant consent. All nonfailed PSGs in the TuCASA study were assigned by the scorer an overall quality grade of excellent (at least 1 electroencephalogram channel, 1 electrooculogram channel, chin electromyogram, oximetry, airflow, thoracic, and abdominal bands good for >5 hours), good (respiratory channels [airflow or either band], oximetry, and 1 electroencephalogram channel good for >5 hours), or fair (respiratory channels [airflow or either band], oximetry, and 1 electroencephalogram channel good for >4 hours but < 5 hours). Sleep was manually staged according to Rechtschaffen and Kales criteria[20] using proprietary software (Compumedics W-Series Replay, v 2.0, release 22).

The respiratory disturbance index (RDI) was defined as the number of respiratory events (apneas and hypopneas) per hour of the total sleep time irrespective of any associated oxygen desaturation or arousal. Obstructive apneas were identified if the magnitude of any ventilation signal decreased to below 25% of the baseline amplitude for at least 6 seconds or 2 or more consecutive breaths. Hypopneas were scored if the magnitude of any ventilation signal decreased to below approximately 70% of the baseline amplitude for at least 6 seconds or for 2 or more consecutive breaths. Central apneas were scored if both airflow and thoracoabdominal effort were absent.

Event Comparison

Respiratory events in all studies were scored twice by the sleep technologist—initially using only the thermistor ($RDI_{thermistor}$) tracing to evaluate the airflow and a second time with inclusion of the nasal transducer ($RDI_{transducer}$) signal. The event sheets were then collated, and the presence of discrepant events detected by only 1 method was confirmed by 1 of the investigators (RB). This was done by first identifying the event detected by only 1 method and then looking for evidence of a change in the waveform in the other tracing. If there was a change in waveform that met the above criteria for a hypopnea, the scoring was changed accordingly.

Quality of Nasal Transducer and Thermistor Tracings

Hours of data collection that were free of artifact were determined for both transducer- and thermistor-based airflow tracings and classified into 1 of the 4 groups: more than 6 hours, 4 to 6 hours, 2 to 4 hours, and less than 2 hours. The proportion of "artifact-free" time during the entire sleep study for pressure- and thermistor-based measurement of airflow was compared.

Statistical Analysis

All categorical variables were analyzed by χ^2 tests. Since RDI measurements were nonparametric, log transformation was performed before testing the difference between means using Student t test. Bland Altman plots were constructed to compare the agreement between respiratory events detected by nasal transducer and thermistor. Intraclass correlation coefficients were also calculated. Linear regression was used to determine whether bias between $RDI_{thermistor}$ and $RDI_{transducer}$ was related to severity of RDI. Agreement between different quartiles of $RDI_{thermistor}$ and $RDI_{transducer}$ was calculated using Cohen's κ statistic, where a κ of 1.0 implies perfect agreement and a κ of 0 indicates agreement no better than chance. We used the following interpretation of κ: < 0.20, poor; 0.2-0.39, fair; 0.4-0.59, moderate; 0.60-0.79, good; and 0.80-1, excellent agreement. Agreement for a diagnosis of OSA was also measured using Cohen κ, applying different RDI cutoffs (5/hour, 10/hour, and 15/hour) to make such diagnoses. All hypotheses were 2-tailed. Statistical significance was considered at P < .05. Statistical analysis was carried out using SPSS 10.0 (SPSS, Inc, Chicago, IL).

RESULTS

Study Population

The characteristics of the study sample and the overall TuCASA cohort are presented in Table 1. The study sample was slightly older than the overall TuCASA cohort. The total sleep time, as expected on the basis of selection criteria, was slightly greater in the study sample.

Detection of Events

Transducer Versus Thermistor for Assessing RDI in Children—Budhiraja et al

Table 1—Sample Characteristics

Characteristic	Study Sample (n=40)	Entire TuCASA study (n=504)	P value
Age, y	9.2±1.7	8.3±1.6	.002
Girls, %	60	50.2	.15
Total sleep time, min.	543±42	504±72	.001

Data are presented as mean±SD, unless otherwise indicated.

The nasal transducer detected all (100%) of the events detected by the thermistor, whereas the thermistor detected only 85% of the transducer-defined events. Consequently, $RDI_{transducer}$ was significantly higher than $RDI_{thermistor}$ (P<.001) (Table 2). Overall, the transducer identified 2532 events and the thermistor identified 2142 events. There were no sex-related differences in RDIthermistor and $RDI_{transducer}$ between these 2 techniques. Hypopneas, even when the transducer and thermistor methods were in agreement, usually resulted in a better-defined and more easily perceptible change in the nasal transducer tracing than in the thermistor tracing.

Agreement Between Thermistor and Transducer

The intraclass correlation coefficient for the RDI obtained by the 2 techniques was 0.96 (95% confidence interval [CI], 0.92-0.98). A Bland-Altman plot was constructed for paired comparison of $RDI_{transducer}$ and $RDI_{thermistor}$. The plot of the difference between RDItransducer and RDIthermistor against the mean RDI from 2 methods showed a bias of 1.08 (95% CI, 0.8-1.4) (Figure). The lower limit of agreement was -0.81 (95% CI, -1.35 to -0.30), and the upper limit of agreement was 2.96 (95% CI, 2.5 to 3. 5). The square of the difference between the RDI was tested for association with the mean RDI score using regression analysis and was found to be statistically significant (P= .037). This suggests that the difference in RDI scores between the 2 scoring methods was related to the severity of sleep apnea and was greater at a higher mean RDI.

The distribution of $RDI_{transducer}$ as a function of quartiles of $RDI_{thermistor}$ is shown in Table 3. A κ of 0.50 suggested a moderate agreement between quartile distribution of $RDI_{transducer}$ and the $RDI_{thermistor}$.

There was good agreement between thermistor and transducer for diagnosis of sleep apnea using a cutoff of an RDI greater than 10 per hour (κ=0.63, P<.001) or an RDI greater than 5 per hour (κ=0.69, P<.001). Table 4 shows the number of children diagnosed with OSA using these cutoffs by the 2 diagnostic modalities.

Quality of Flow Tracings

Of the 504 studies performed, 446 had acceptable respiratory and thermistor channels and were scored for SDB. The proportion of studies graded by hours of scorable signal for the thermistor and nasal transducer tracings in these 446 studies are shown in Table 5. Overall, 61% of thermistor tracings and 52% of transducer tracings had signal mostly free of artifact for 4 hours or more (P=.055). In many of these studies, the nasal cannula was displaced or removed by the child in the night and was not replaced. Eventually, only 214 studies had both thermistor and pressure signals available for interpretation. In such studies, the mean scorable time was higher in the nasal transducer tracings than in

Table 2—Comparison of Thermistor- and Transducer-Derived Respiratory Disturbance Index in 40 Children

	$RDI_{thermistor}$	$RDI_{transducer}$	% difference*	% thermistor†
Mean	5.95	7.03	20	85
SD	3.42	3.81		
Percentile				
25th	3.34	4.24	6	77
50th	5.40	5.98	15	87
75th	6.88	8.51	30	94

*Increased events detected by transducer expressed as a percentage of events detected by thermistor
†Percentage of transducer-detected events that were detected by thermistor

Mean of RDIThermistor and RDItransducer
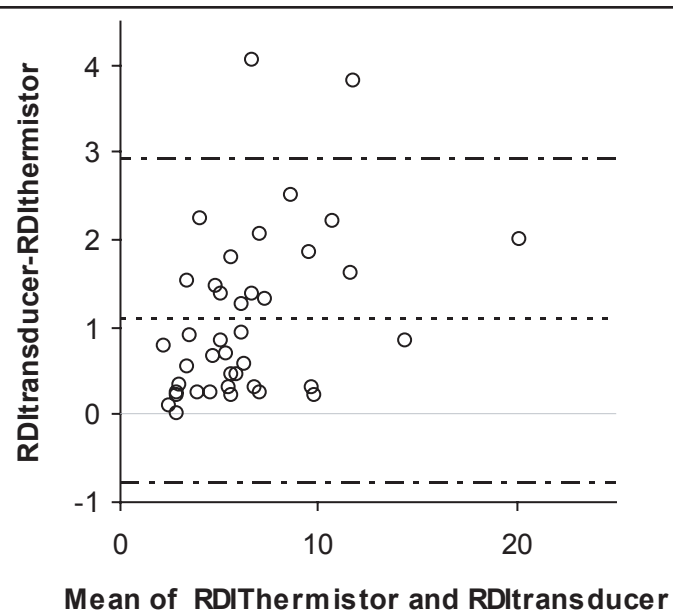
Figure—Bland-Altman plots of difference in the transducer respiratory disturbance index (RDI) (RDItransducer) and the thermistor RDI (RDIthermistor)as a function of the mean RDI derived from the 2 methods. Linear regression (not shown in Figure) revealed an increase in the difference between RDItransducer and RDIthermistor with increasing mean RDI (y=0.11x+0.37, R2=0.17)

the thermistor tracing (7.2±1.8 hours vs 6.8±2.4 hours, P=.04).

DISCUSSION

Our study demonstrates that the use of a nasal pressure transducer in conjunction with a thermistor is more sensitive than thermistor alone in detecting airflow limitation in children. The results also suggest that thermistor alone may be inadequate to define the whole range of sleep-related respiratory abnormalities and may possibly result in some patients being left untreated as the result of some respiratory events not being detected.

While pneumotachography is the gold standard for quantifying reductions in airflow,[18] the requirement of a snugly fitting mask makes it uncomfortable and inappropriate for regular use. This has prompted the use of more practical surrogates for detecting airflow limitation. Thermistors rely on temperature changes in the expired air for this purpose and have been traditionally used as a standard component of PSG for airflow assessment. A nasal transducer detects variations in nasal pressure resulting from changes in inspiratory and expiratory airflow and, thus, may be

Table 3—Agreement Between Thermistor- and Transducer-Derived Respiratory Disturbance Index Based on Thermistor Respiratory Disturbance Index Quartiles

$RDI_{thermistor}$	$RDI_{transducer}$				
	0-3.34	3.35-5.40	5.41-6.88	>6.89	Total N
0-3.34 (0-25th percentile)	*6 (15.0)*	4 (10)	0 (0)	0 (0)	10
3.35-5.40 (25th-50th percentile)	0 (0)	*3 (7.5)*	6 (15)	1 (2.5)	10
5.41-6.88 (50th-75th percentile)	0 (0)	0 (0)	*6 (15)*	4 (10)	10
>6.89 (75th-100th percentile)	0 (0)	0 (0)	0 (0)	*10 (25)*	10
Total, no. (%)	6 (15.0)	7 (17.5)	12 (30.0)	15 (37.5)	*40 (100)*

Data are presented using quartiles of RDI obtained from the thermistor ($RDI_{thermistor}$) shown in the rows. The frequency (percentage in parenthesis) distribution for subjects with transducer RDI ($RDI_{transducer}$) corresponding to the thermistor RDI quartile is shown in the columns. An N of 10 in each of the italics would have represented a perfect congruence between $RDI_{thermistor}$ and $RDI_{transducer}$. Columns above and to the right of this diagonal row suggest overestimation of RDI by the transducer compared with the thermistor and cells below and to the left suggest underestimation.

Table 4—Diagnostic Agreement Between Thermistor and Transducer Using Random Cutoffs for the Diagnosis of Obstructive Sleep Apnea

Technique	Diagnostic Criteria	
	AHI>5	AHI>10
Cases detected by transducer, no.	28	6
Cases detected by thermistor, no.	22	3
Sensitivity of thermistor for diagnosis of OSA, %	79	50

Table 5—Proportion of Studies Graded by Hours of Scorable Tracing

Technique	Scorable tracings, h			
	≥6	≥4 but <6	≥ 2 but <4	<2
Thermistor (N=446)	44	17	18	21
Nasal Transducer (N=446)	36	16	20	28

Data are presented as percentages.

a sensitive method for detecting airflow limitation. Our results validate the use of this technique for detecting SDB in children.

To our knowledge, this study is the first to compare thermistor and transducer for airflow assessment during unattended in-home polysomnography in a large number of children. Our results suggest that addition of a nasal transducer is more sensitive for detecting sleep-disordered breathing compared to thermistor alone. Moreover, the quality of tracings obtained by the transducer, as defined by the hours of scorable and artifact-free signal, was comparable with, and, in some cases, better than that obtained by only a thermistor.

Our results are generally consistent with those reported in earlier studies. Norman et al detected only 52% of the transducer-characterized respiratory events when using thermistor in 11 adults with OSA.[16] The detection rate with a thermistor was abysmal (17% of the nasal transducer-detected events) in patients with upper airway resistance syndrome.[16] Another study found a 25% increase in respiratory arousal index with transducer compared with thermistor in adults with OSA.[21] Data in children are more limited. However, Trang et al compared the 2 techniques in 14 infants and 16 children with suspected OSA and found that 48% of the apneas and only 14% of the obstructive hypopneas detected by nasal pressure monitoring were detected by the thermistor.[17] The discrepancy in the event measurement between the 2 techniques is much greater in the study by Trang and coworkers than that in our study. Possible explanations for this discrepancy could include the following: First, the age of subjects was lower in their study (median age, 5.5 years; range, 1.4-14.8) than ours (median age, 9 years; range, 6-11). In their study, infants were noted to have greater discrepancy in RDI detected by the 2 techniques than were older children. Second, the total number of participants in our study in this age group was larger (40 versus 16). Third, we compared thermistor scoring to thermistor plus nasal transducer scoring. In contrast, Trang et al scored the thermistor and the nasal transducer tracings independently.[17] However, we do not believe

this explains the difference between the observations by Trang et al and our data, as one would expect that use of greater amounts of information would result in a larger number of identified events with transducer.

Unlike other studies, we observed that the difference between the transducer and thermistor tracings increased at higher levels of RDI. The explanation for this finding is not readily apparent. However, this would suggest that clinicians should be cognizant of possibly underestimating the magnitude of SDB in children with more-severe disease.

The results herein should be viewed with certain caveats. First, in many children, the cannula was displaced or removed by the child during sleep and was not replaced. This resulted in scorable data for the nasal pressure transducer not being available for many children. This may be a limitation of this technique in unattended settings. However, in attended settings during in-laboratory PSG, this is less of a problem. Second, the effect of predominant mouth breathing on the nasal-transducer recording is unclear. Third, although the transducer detected more events, the clinical implications of such detection are yet to be elucidated. The physiologic correlates of the changes in the pressure waveform have been studied by Hosselet and colleagues.[15] In that study, the investigators noted that nasal pressure tracings were associated with invasively determined supraglottic pressure swings.[15] Another study revealed that inspiratory flow limitation detected by nasal pressure wave contour detected 90% of the epochs classified as abnormal based on esophageal catheter recording in children.[22] Trang and coworkers found all events detected by the nasal cannula pressure transducer to be associated with changes in esophageal pressure.[17] As discussed in their study and others, however, nasal secretions and mouth-breathing, as well as resistance due to the physical presence of cannula in the nares, may limit the usefulness of the nasal pressure transducer in children.[23] Fourth, our study was recruited from the general population and may not be comparable with a more symptomatic clinic-derived cohort. However, because we chose recordings with greater numbers of SDB events, it is likely that our data are applicable to PSGs performed for clinical indications.

In our study, respiratory events were scored using the thermistor alone for all sleep studies and then combining the thermistor

and nasal pressure. Although it is conceivable that this may have introduced a bias in the findings, the fact that the thermistor tracings were carefully assessed for any corresponding changes in the airflow when extra events were detected in the transducer tracings, should negate such bias. Finally, we also focused primarily on flow reduction rather than a mere flattening of the waveform. It is possible that flattening of the waveform, even in the absence of a decrease in the amplitude, may represent either hypopneas or respiratory effort-related arousals, thus leading to an underestimation of the actual sleep-related respiratory abnormalities in our study. Serebrisky et al have shown that the flattened nasal-cannula contour correlates with an increased intrathoracic pressure.[24] However, whether such events result in adverse clinical outcomes is still not known.

Arousals are uncommon in children with OSA[4] and were not included in our diagnostic criteria. Use of cutoffs for oxygen desaturation to define hypopneas has also been questioned in both adults and in children. An earlier study showed that clinical symptoms correlated with increasing RDI even when respiratory events were not associated with desaturation.[5] Hence, oxygen desaturation was not considered a prerequisite to define hypopneas in our study. Since there is no well-defined cutoff to diagnose SDB in children, we empirically used different RDI cutoffs to assess the agreement between the thermistor and the transducer for making such diagnoses. We found a moderate correlation between these 2 approaches.

In conclusion, we have demonstrated a higher sensitivity for the combination of a nasal-cannula pressure transducer and a thermistor in comparison with the thermistor alone for detection of sleep-related breathing abnormalities in children undergoing in-home PSG. We have also found the quality of transducer tracings to be comparable with those by thermistor, although there was frequent dislodgement of the nasal cannula. Larger studies need to be conducted comparing cohorts with and without nasal cannulae to assess any discomfort or physical obstruction as the result of the presence of the cannula. Furthermore, the clinical implications of transducer-defined events need to be better elucidated prior to embracing this technique as a routine component of screening PSG in children.

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