Validation of a Suprasternal Pressure Sensor for Sleep Apnea Classification in Children

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Study Objectives: The recognition and characterization of respiratory events is crucial when interpreting sleep studies. The aim of the study was to validate the PneaVoX sensor, which integrates the recording of respiratory effort by means of suprasternal pressure (SSP), respiratory flow, and snoring for the classification of sleep apneas in children.

Methods: Sleep recordings of 20 children with a median age of 7.5 (0.5–16.5) years were analyzed. Scoring of apneas according to the American Academy of Sleep Medicine (AASM) guidelines using nasal pressure, oronasal thermal sensor and respiratory efforts by means of respiratory inductance plethysmography (RIP), was compared to a scoring using the PneaVoX sensor and nasal pressure, without the oronasal thermal sensor nor RIP, during a dual blind study.

Results: The percentage of sleep time recording without artifacts was 97%, 97%, 87%, 65%, and 98% for the respiratory flow and SSP from the PneaVoX sensor, oronasal thermal sensor, nasal pressure, and RIP, respectively. As compared to the AASM scoring with RIP, sensitivity and specificity of the SSP for the scoring of central apneas were 75% and 99% for the first reader, and 70% and 100% for the second reader, respectively. Sensitivity and specificity for the scoring of obstructive apneas were 98% and 75%, and 100% and 70%, respectively. A significant number of apneas scored as central by RIP were scored as obstructive by the SSP.

Conclusions: The PneaVoX sensor has a high degree of scorability in children. The PneaVoX sensor is a useful adjunct for characterizing apneas.

Keywords: polygraphy, respiratory effort, suprasternal pressure, respiratory inductance plethysmography, central apnea, obstructive apnea, child


INTRODUCTION

The recognition and characterization of respiratory events is crucial when interpreting sleep studies. According to the 2012 recommendations of the American Academy of Sleep Medicine (AASM), the standard sensor for apnea detection is an oronasal thermal sensor whereas a nasal pressure transducer is recommended for the scoring of hypopneas.\textsuperscript{1}

Monitoring of respiratory effort is paramount in the classification of respiratory events as obstructive, central, or mixed. Increased respiratory effort is a sign of obstructive sleep-disordered breathing and may be recorded from mechanical, electrical, and electromechanical signals.\textsuperscript{2} Monitoring of esophageal pressure is the gold standard, as the pressure signal directly reflects the respiratory muscle force,\textsuperscript{2} but this method is invasive and usually poorly tolerated and may cause sleep disturbances.\textsuperscript{3} Characterization of respiratory efforts by means of esophageal pressure is thus not used in routine care. Respiratory inductance plethysmography (RIP) is used as an alternative method to detect respiratory efforts but underestimation of obstructive events is possible. Indeed, in 9% of a study population of 54 adult patients, chest wall motion evaluated by RIP suggested central apneas but esophageal swings revealed obstructive apneas.\textsuperscript{4} In another study which analyzed data from 22 adult patients, re-scoring with esophageal pressure led to a decrease in central apneas (10 vs. 6 events/h), an increase in obstructive apneas (34 vs. 42 events/h), and a moderate increase in mixed apneas (4 vs. 5.5 events/h).\textsuperscript{5} More recently, approximately 30% of apneic events considered to be central using data generated by uncalibrated RIP were classified differently when examined using diaphragmatic electromyography and esophageal pressure.\textsuperscript{6}

Acceptance and tolerance of sensors is an important practical issue of sleep studies in children. Airflow sensors have been shown to have the poorest tolerance with the lowest hours of scorable signal free from artifact and the highest equipment discomfort.\textsuperscript{7} Sensors that are minimally invasive and the least
uncomfortable are thus preferred. In order to overcome the removal of sensors or signal artifacts, the use of well-tolerated, stable, and different sensors that may give additional and/or complementary information on airflow and respiratory effort is recommended.1

A sensor placed over the trachea in the sternal notch (PneaVoX), which enables the recording of suprasternal inspiratory pressure related to inspiratory effort (SSP), but also of tracheal sounds and snoring, has been shown to have a good sensitivity (99.4%) and specificity (93.6%) for the evaluation of respiratory efforts in adults when compared to esophageal pressure.8 However, this PneaVoX sensor has never been validated in children.

The aim of the present study was to compare a similar PneaVoX sensor to the oronasal thermal sensor with RIP for the characterization of sleep apneas in children.

**METHODS**

**Patients**

The study was conducted at the noninvasive ventilation and sleep unit at Necker university Hospital in consecutive children who underwent a polygraphy (PG) for a suspicion of obstructive sleep apnea syndrome (OSA). The protocol was approved by the local ethical committee (CPP Ile de France II, n° 2014-03-09 SC).

**Sleep Recordings and the PneaVoX Sensor**

PGs were performed using CID 102* (Cidelec, Angers, France). The recorded data included airflow via a nasal pressure transducer and an oronasal thermal sensor, body position, actigraphy, thoracic and abdominal movements assessed with RIP, and pulse oximetry (SpO₂). Each study was performed with the PneaVoX sensor (Figure 1). The PneaVoX sensor was placed above the sternal notch, over the trachea. The transducer was attached to the skin by an adhesive tape and then secured with an adhesive band. Incorrect application of the transducer, not ensuring an airtight cavity between the skin and the transducer, resulted in the absence of the suprasternal negative pressure signal; therefore, the quality and amplitude of the signal was verified before starting the recording.

The PneaVoX sensor consists of a microphone and a pressure sensor inserted inside a 28-mm diameter and 15-mm thick protective housing. The surface of the transducer attached to the skin comprises a 2 mm-thick cuff, designed to ensure an airtight cavity between the skin and the transducers (Figure 1). Sounds in the cavity related to respiratory flow and snoring are recorded by the microphone. Static pressure variations in this cavity, related to increasing deformation of the suprasternal notch during obstructed inspirations, are measured by the SSP. According to the intensity and frequency, three different signals are therefore recorded from the PneaVoX sensor:

- Respiratory effort is recorded from the SSP with a frequency range between 0.02 and 20 Hz;
- Snoring is recorded from the microphone with a frequency range between 20 Hz and 200 Hz and is defined by an acoustic intensity greater than 76 decibels in the transducer chamber;
- Respiratory flow (in- and outflows) is recorded from the microphone with a frequency range between 200 and 2000 Hz during inspiration and expiration.

**Validation of the PneaVoX Sensor for the Classification of Apneas**

In the absence of the esophageal pressure, the SSP was compared to RIP which was considered as the “gold standard” for the classification of sleep apneas. A dual blind analysis of each anonymized PG was performed by two independent experienced readers. The dual blind analysis consisted of:

1. one scoring using the oronasal thermal sensor, the nasal pressure transducer and RIP, without the PneaVoX, (Therm-RIP scoring), representing

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**Figure 1**—The PneaVoX sensor.

![Diagram of the PneaVoX sensor](image)
A Suprasternal Pressure Sensor for Sleep Apnea

the reference sensor set according to the AASM recommendations. 1
2. another scoring using the PneaVoX sensor, including the SSP, tracheal sounds and snoring, respiratory flow, and the nasal pressure transducer, without the oronasal thermal sensor nor RIP (PneaVoX scoring).

For the Therm-RIP scoring, an obstructive apnea was defined as ≥ 90% reduction of oronasal thermal sensor for a duration > 2 breaths with the persistence of respiratory efforts on the RIP (Figure S1 in the supplemental material). Central apnea was defined as ≥ 90% reduction of oronasal thermal sensor for a duration > 2 breaths without any respiratory efforts on RIP, associated with an oxygen desaturation of ≥ 3% or with an event duration > 20 seconds (Figure S2 in the supplemental material).

For the PneaVoX scoring, an obstructive apnea was defined as ≥ 90% reduction of tracheal sounds for a duration > 2 breaths with the persistence of respiratory efforts on the SSP (Figure 2). Central apnea was defined as ≥ 90% reduction of tracheal sounds for a duration > 2 breaths without any respiratory efforts on the SSP, associated with an oxygen desaturation of ≥ 3% or with an event duration > 20 seconds (Figure 3).

Each PG was prepared for the Therm-RIP scoring and PneaVoX scoring by a third examiner who was not involved in the scoring of the PGs (GB). GB prepared the anonymized PG and selected the sleep periods for the scoring by the two readers. Each reader then scored the anonymized Therm-RIP scoring and PneaVoX scoring in a random order. The comparison of the results obtained with the two scorings was performed by the third blind-examiner (GB). Three examples of agreement or non-agreement between the Therm-RIP scoring and PneaVoX scoring are shown on Figure 4, Figure 5 and Figure 6, respectively.

Statistical Analysis

Data are presented as median and range. The sensitivity and specificity of the PneaVoX sensor to detect obstructive or central apneas, compared to RIP (considered as the reference method) were calculated according to the following formulas:
• Sensitivity = [true positives] / [true positives + false negatives] * 100;
• Specificity = [true negatives] / [true negatives + false positives] * 100.

RESULTS

The PGs of 20 children with a median age of 7.5 (0.5–16.5) years were analyzed. Median total recording time was 6.6 hours. Percentages of total sleep time with a scorable signal free of artifacts were 97%, 97%, 87%, 65%, and 98% for the respiratory flow and SSP from the PneaVoX sensor, the oronasal thermal sensor, the nasal pressure, and RIP, respectively. No differences according to age were observed.

The concordance between the Therm-RIP scoring and the PneaVoX scoring for the first and second reader are shown on Table 1. A total number of 563 apneic events were scored by the first reader, and 596 by the second reader. For the first reader, the sensitivity of the SSP was 75% for central apneas, and 98% for obstructive apneas. The specificity for detecting these two types of apneas was 98% and 75%, respectively. For the second reader, the sensitivity of the SSP was 70% for central apneas, and 100% for obstructive apneas. The specificity for the detection of these two types of apneas was 100% and 70%, respectively.

For the first reader, 16 of the apneas classified as central on the Therm-RIP scoring were apneas with persistence of respiratory effort on the suprasternal pressure sensor. This number increased to 29 for the second reader. On the contrary, only 10 of the apneas classified as...
obstructive on the Therm-RIP scoring were classified as central based on the SSP by the first reader, and 1 by the second reader.

**DISCUSSION**

Our study is the first to evaluate the usefulness of a PneaVoX sensor integrating respiratory effort, in- and outflows, and snoring in children. The PneaVoX sensor showed a high degree of scorability and was very well tolerated and accepted by the children regardless of their age. The agreement between the PneaVoX sensor and the sensors recommended by the AASM, i.e., oronasal thermal sensor and RIP, was good with high levels of sensitivity and specificity for the classification of apneas. However, a significant number of apneas scored as central by the oronasal thermal sensor and RIP were scored...
as obstructive by the PneaVoX, as observed previously in adult patients.

Qualification of respiratory events as obstructive or central is of major importance for the analysis of sleep studies in children. Chest and abdominal chest wall movements recorded by RIP are usually taken as surrogates of respiratory effort for diagnostic purposes. However, RIP can underestimate respiratory effort because chest and abdominal wall motion may be influenced by lung volume and posture. The sensor bands on the chest and the abdomen may move up or down during
the night, leading to an overestimation of central sleep apnea events. RIP may also be unreliable when the amplitude of the chest wall movements is small, which may be the case in very young children or older children with truncal obesity. Monitoring of movements of the suprasternal fossa has previously been proposed as a noninvasive method for the estimation of pleural pressure, showing that pressure variations in the suprasternal area reflect esophageal pressure. When using the PneuVox sensor, we also found that the SSP showed a good agreement with RIP for apnea classification. And importantly, the scoring with the SSP increased the number of obstructive apneas, similarly to previous studies that used the esophageal pressure.

The PneuVox sensor also comprised a microphone that records in- and outflows. The recording of tracheal sounds for the detection of apneas in children is not new. Indeed, more than 30 years ago, Beckerman and Wegmann used a miniature microphone/amplifier system to sense breath sounds over the trachea in order to detect central and obstructive apnea episodes in infants and children. In a later study, they used a microphone breath sound detector, coupled to the analysis of chest wall motion by transthoracic impedance in 10 sleeping infants and children for the detection of normal respirations, and central and obstructive apneas. However, they did not observe any statistically significant difference between breath sounds and airflow in the ability to detect obstructive apnea.

The acceptability and the scorability of the different sensors used during sleep studies in children are important issues. Indeed, technical problems such as displacement or refusal of sensors by a restless, irritable or non-cooperative child are common, especially for the airflow sensors. Studies analyzing the comfort and hours of artifact-free signal for different respiratory sensors showed that airflow sensors were associated with the lowest tolerance and “scorability.” The PneuVox sensor has the advantage over other devices that sense airflow (thermists, carbon dioxide sampling catheters) that it is not easily dislodged during restless sleep. This sensor is also less sensitive to position and remains reliable even in the prone position.

The major limitation of our study is that we did not measure the esophageal pressure for the characterization of apneas because of its discomfort and poor acceptance. As the PneuVox sensor used in the present study is similar to the sensor used in comparison to the esophageal pressure in adult patients, in the study by Meslier et al., we may reasonably assume that the agreement between the SSP and the esophageal pressure is similar in children. The difference in the number of events scored by the two readers may be explained by an inter-scorer variability, as recently assessed in large study by Rosenberg et al. As the PneuVox sensor has not been validated for detecting hypopneas; therefore, we only included apneic events in our analysis.

In conclusion, the SSP of the PneuVox sensor is useful for the classification of apneas in children. This sensor is also well accepted and associated with a high scorability. As such, the PneuVox sensor is a useful adjunct for detecting airflow and obstructive apneas in children.

### ABBREVIATIONS

- AASM, American Academy of Sleep Medicine
- abdo belt, abdominal belt
- cen apn, central apnea
- HR, heart rate
- obs apn, obstructive apnea
- OSA, obstructive sleep apnea
- PG, polygraphy
- pleth, pulse wave plethysmography
- SpO₂, pulse oximetry
- RIP, respiratory inductance plethysmography
- SSP, suprasternal inspiratory pressure
- therm, oronasal thermal sensor
- trach pre, suprasternal pressure
- tho belt, thoracic belt
- trach obs, suprasternal pressure sensor analysis

### REFERENCES


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DISCLOSURE STATEMENT
Dr. Baffet is fully employed by Cidelec and contributed to the study design, the preparation of the anonymized data and the manuscript with regard to the description of the PneaVox sensor, he was not involved in the analysis of the data and the conclusions of the study which are the full responsibility of the other authors. The authors have indicated no financial conflicts of interest.