Comparison of Apnea Detection Using Oronasal Thermal Airflow Sensor, Nasal Pressure Transducer, Respiratory Inductance Plethysmography and Tracheal Sound Sensor

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Conflict of interest

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Abstract

Objective: Evaluation of apneas detection using tracheal sounds (TS) during sleep in patients with Obstructive sleep apnea (OSA).

Methods: Polysomnographic recordings of 32 patients (25 male, mean age 66.7±15.3 years, and mean BMI 30.1±4.5 kg/m$^2$) were analyzed to compare the detection of apneas by 4 different methods of airflow signals: oronasal thermal airflow sensor (Therm), nasal pressure transducer (NP), respiratory inductance plethysmography (RIPsum) and TS. The four used signals were scored randomly and independently form each other according to AASM rules. Results of apnea detection using NP, RIPsum and TS signals were compared to those obtained by Therm as a reference signal.

Results: The number of apneas detected by the Therm was 4167. The number of apneas detected using the NP was 5416 (+29.97%), using the RIPsum was 2959 (-29.71%) and using the TS was 5019 (+20.45%). The Kappa statistics were 0.72 (95% confidence interval 0.71 to 0.74) for TS, 0.69 (95% confidence interval 0.67 to 0.70) for NP, and 0.57 (95% confidence interval 0.55 to 0.59) for RIPsum. The sensitivity/specificity with respect to the Therm were 99.23% / 69.27%, 64.07 / 93.06 and 96.06 / 76.07 for the NP, RIPsum and TS respectively.

Conclusions: With the sensor placed properly on the suprasternal notch, tracheal sounds could help detecting apneas that are underscored by the RIPsum and identify apneas that may be over scored by the nasal pressure due to mouth breathing. In the absence of thermistor, tracheal sound sensors can be used for apnea detection.

Keywords: obstructive sleep apnea; flow measurement; tracheal sounds; polysomnography home sleep apnea testing; sleep disordered breathing

Clinical trial registration: DRKS00012795
Brief summary

Current Knowledge/Study Rationale: Reliable recording of respiratory flow is needed for apnea detection. In patients with obstructive sleep apnea syndrome, tracheal sound monitoring by the PneaVox® sensor was tested and its performance was compared to those of the nasal pressure and RIP belts with respect to the Thermistor.

Study Impact: Associated with NP, TS meet the oronasal flow evaluation required by the AASM for apnea detection. TS can be used as a substitute for oral thermistors to reliably detect apneas.
Introduction

Obstructive sleep apnea (OSA) is the most common sleep-related breathing disorder. OSA is characterized by repetitive closure of the upper airway during sleep and it affects between 6 and 13% of the adult population.\textsuperscript{1,2} Polysomnographic diagnosis and assessment of severity of OSA depend on accurate measurement of respiratory airflow and reliable detection of respiratory events.

In adults, apneas are defined as a decrease of airflow by more than 90% from baseline over a period of more than 10 seconds.\textsuperscript{3} Pneumotachography has traditionally been considered the gold standard for flow measurement and detection of apneas.\textsuperscript{3} However, this technique is not suitable for routine sleep studies with a polysomnography (PSG) or a polygraphy. Alternative techniques to measure airflow include oronasal thermal airflow sensors (thermistors or thermocouples), nasal cannulas and respiratory inductance plethysmography (RIP).

Thermal airflow sensors use the difference between the temperature of exhaled and ambient air to estimate airflow and detect mouth breathing. The use of temperature as a surrogate for measurement of airflow works well for detecting apnea because it has the advantage to detect both nasal and oral airflow. Nasal cannulas are pressure sensors capable of detecting pressure changes during inspiration and expiration. Most sleep laboratories use signals from both a thermistor (Therm) and a nasal pressure (NP) to assure an oronasal flow measurement. This sensor combination improves the identification of apneas that are missed by thermistors or overestimated by the nasal pressure in the case of mouth breathing, for example. However, these two sensors can cause patients much discomfort and even affect their sleep\textsuperscript{4}. They are therefore often displaced or even removed by the patients during recording at night and their signals become then unusable. The validity of Therm and NP signals for more than 6 hours of recording is satisfactory for less than 60% for both children\textsuperscript{4} and adults.\textsuperscript{5}
When the nasal pressure and the thermistor signals are missing or of bad quality, the RIP sum signal can be used as a surrogate respiratory flow. The RIP method uses two belts placed around the thorax and the abdomen and these sensors allow semi-quantitative assessment of volume changes through the measurement of thoracic and abdominal movements.

Recordings of tracheal sounds (TS) correlate well with respiratory flow, with no significant difference in the number of apneas detected with TS or reference sensors. Tracheal sounds, recorded at the sternal notch, reflect the superficial vibrations of the body set in motion by pressure fluctuations. Placed on the sternal notch, the TS sensors can detect these vibrations and thus, measure tracheal flow sound as well as snoring.

Our study aimed to evaluate the use of a TS sensor, PneaVoX® (Cidelec, France), for apnea detection. The results were compared to those obtained with Therm, NP and RIPsum signals.
Material and methods

Patients

Thirty-five recordings from 32 patients (25 male) with a clinical suspicion of OSA were included in the study. Patients were admitted to the Charité-Universitätsmedizin certified sleep laboratory. The study was approved by the local Ethics Committee (application number: EA1/009/13) of the university hospital in Berlin, and patients gave their written consent for participation in the study. Inclusion criteria were patients between 18 and 80 years old with either suspected OSA after clinical evaluation and before a sleep study or patients who had already been diagnosed with OSA, but who were readmitted to the sleep laboratory for control PSG. Exclusion criteria were drug use and excessive alcohol consumption, any medication intake that could influence sleep, the presence of any sleep disorder other than OSA, clinically unstable respiratory and patients who were incapable to read and understand the consent statement for any reason. Age, height, weight and neck circumference as well as medication and diagnoses of the patients were recorded.

Data acquisition

After signing written consent for participation in the study, patients underwent PSG recordings using the SOMNOscreen plus system (SOMNOmedics GmbH, Randersacker, Germany). Recorded data included all electrophysiological signals for sleep evaluation as well as airflow by thermistor and nasal cannula, RIP belts, pulse oximetry, body position, limb movements, actigraphy and light. In addition to the laboratory routine, esophageal pressure (Pes) probe (Gaeltec, Isle of Sky, Scotland) as well as TS using the PneaVoX® sensor with the CID-LXe polygraph (CIDELEC, Angers, France) were recorded.

The following specifications for recording of the respiratory signals were applied:
1) Thermistor: oronasal sensor from Somnomedics, effective range = ±80mV, frequency range = 0.1Hz – 1kHz, sampling rate = 32Hz and software low-pass (LP) filtering at 1Hz.

2) Nasal flow: nasal pressure transducer built-in device from Somnomedics, effective range = ±48mV, no square transformation, frequency range = 0.023Hz – 1kHz, sampling rate = 256Hz and software LP filtering at 1Hz.

3) Effort: RIP sensors from Somnomedics, effective range = ±170mV, uncalibrated, frequency range = 0.2Hz – 35Hz, sampling rate = 32Hz and no software filtering. The Somnomedics software provides the sum signal of thoracic and abdominal signals (RIPsum) which was used according to AASM for the apnea detection.

The PneaVoX® sensor was placed on the skin above the sternal notch and then secured in place using a double-sided ring tape and an adhesive tape. Correct positioning of 1 cm right above the sternal notch with a well-sealed contact surface of the transducer is an essential element to obtain a good quality signal. For later synchronization of recordings, the nasal pressure sensor was connected to both systems using a Y-piece connector so that both the SOMNOscreen system and the CIDELEC system share the same NP signal. Thus, accurate synchronization of the separate recordings was made possible. The presence and quality of all signals were monitored throughout the night.

All respiratory signals from the SOMNOscreen system were imported into the CIDELEC system in European Data Format (EDF) and a new anonymized polygraph file was created for each patient. Sections where respiratory signals necessary to the scoring were missing or of poor quality and sections which could not be synchronized via the NP signal were not validated. Each synchronized recording was then visualized and scored using the CIDELEC software.
**Tracheal sounds**

The TS sensor used in our study, the PneaVoX®, is a stethoscope-like transducer with an acoustic sensor 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 contains a 2 mm-thick cuff, designed to ensure an airtight cavity between the skin and the transducers (Figure 1).\textsuperscript{12-15} Filtering techniques are used to separate the high pitch (200 to 2000 Hz) tracheal flow sound from the low pitch (20 to 200 Hz) snoring sound.\textsuperscript{16} The intensity of the tracheal sound at high pitch allows the measurement of respiratory flow and the detection of apneas.\textsuperscript{17} When the signal’s amplitude is decreased to more than 90% or in the absence of flow for more than 10 seconds, it can be assumed that there is no airflow through the trachea and therefore an apnea can be scored.

**Data analysis**

For the detection of apneas, only one of the four respiratory flow signals was displayed and analyzed at a time, while the other flow signals were masked. The American Academy of Sleep Medicine (AASM) definition of apnea in terms of signal amplitude decrease and duration was applied to all 4 signals (Figure 2). Four apnea scorings were performed, using each of the following signals separately and in random order: Therm, NP, RIPsum or the TS signals. The four scorings were performed sequentially for each study. The number of detected events and the duration of each event was measured and compared for the 4 signals. The apnea detection results using the NP, RIPsum and TS were compared to those of the Therm being the reference sensor.

**Statistical analysis**

Statistical analysis was performed using IBM SPSS Statistics V22.0 (IBM, USA). Values are presented as mean ± standard deviation (SD). The Cohen’s Kappa, sensitivity and
specificity, as well as positive predictive and negative predictive values (PPV, NPV) for apnea detection were calculated for all patients using Therm as a reference signal. Bland-Altman analysis was also performed for this study.
Results

Patients

Patients had a mean age of 66.7 ± 15.3 years, a mean BMI of 30.1 ± 4.6 kg/m² and a mean neck circumference of 42.8 ± 4.1 cm. The Apnea Hypopnea Index (AHI) was 36.1 ± 25.1 events/h with an apnea index (AI) of 25.7 ± 24.3 events/h. The mean TST was 317.4 ± 77.5 min. Five patients had mild OSA (5 ≤ AHI ≤ 15 /h), 12 patients had moderate OSA (5< AHI <30 /h) and 18 patients had severe OSA (AHI ≥30 /h).

Detection of apneas with TS, NP, Therm and RIPsum

The total number of apneas detected using NP was the highest, with 5416 apneas. We detected 5019 apneas with TS, 4167 apneas with Therm and only 2959 apneas using RIPsum. There were 5 patients with relatively few apneas. This patient to patient variability is because there was no minimum AHI imposed in the exclusion criteria. These patients have an AHI < 5 with more hypopneas than apneas.

The number of common apneas with the Therm was 4135 events for the NP, 2670 events for the RIPsum and 4022 events for the TS. However, in comparison with the Therm as a reference sensor, the NP and TS had an over detection of 1281 and 997 apneas respectively while the RIPsum had an under-detection of 1497 events. For each patient, the sensitivity, specificity, positive predicted values and negative predictive values for apnea detection were calculated using the Therm signal as a reference. The results are presented for each sensor (TS, NP and RIPsum) in table 1. With the Therm as a reference detection, the Kappa statistics were 0.69 (95% confidence interval 0.67 to 0.70) for NP, 0.57 (95% confidence interval 0.55 to 0.59) for RIPsum and 0.72 (95% confidence interval 0.71 to 0.74) for TS. The results of the Pearson correlation analysis for apnea detection using the four different sensors are presented in table 2. There was a strong positive correlation between Therm and NP (r = .968, N=35, p < .001)
and between Therm and TS (r = .972, N=35, p < .001); and a less important correlation between Therm and RIPsum (r = .879, N=35, p < .001).

Figure 3 displays the results of the Bland-Altman analysis for apnea detection outcomes considering the Therm method as the reference. The mean difference value of the number of detected apneas between the Therm and the TS was smaller than between the Therm and the NP and between the Therm and the RIPsum. However, for all recordings, both the NP and TS overestimated the number of events in average by 35.7 and 24.3 apneas respectively with the limits of agreements from -99.72 to 28.35 events for NP and from -80.82 to 32.13 events for TS. In the contrary, the RIPsum underestimated the number of events in average by 34.5 apneas with limits of agreement from -75.98 to 145.01 events.

Finally, the average duration of apneas detected with NP was the longest with 21.0 ± 7.2 seconds. It was slightly lower for the TS, 19.4 ± 5.9 seconds and the Therm, 18.7 ± 5.9 seconds. The duration of apneas detected using the RIPsum was the lowest with 17.6 ± 4.8 seconds. The results of the Pearson correlation analysis for apnea duration using the four different sensors are presented in table 3.
Discussion

This is the first study to compare, in an adult population, the detection of apneas using four different signals: the thermistor, the nasal pressure, the thoracoabdominal RIPsum and the tracheal sounds. Provided that the TS sensor is well placed and that the scorer is familiar with the tracheal flow sound signal, the intensity of the TS at high pitch allows the detection of apneas.

As expected, the NP signal detected the largest number of apneas (7.3% less with TS, 23.1% less with Therm and 45.4% less with RIPsum). Previous studies comparing different sensors show that NP identifies more apneas than Therm signal, as it may overestimate the extent of airflow amplitude reduction and classify certain hypopneas as apneas. Oral respiration, especially in pediatric patients and in case of nasal obstruction, can have a significant impact on the classification of respiratory events when using a NP signal. However, our data shows that most apneas detected by the other three sensors were also detected by NP (99.9% for Therm, 99.2% for RIPsum, and 96.4% for TS). These results confirm that the NP is a very sensitive sensor for apnea detection.

The RIPsum signal detected the least apneas with 29% less than Therm. Furthermore, almost all the central and mixed apneas and only a third of obstructive apneas were detected by RIPsum when compared to the Therm detection. These results suggest that the RIPsum signal is excellent for detecting central apneas but not suitable for detecting obstructive and mixed apneas. The excursions of the RIPsum and RIPflow signals usually have minimal amplitude during apnea. However, during an obstructive apnea, significant excursions in the RIPsum or RIPflow signals may be seen if the thorax and abdominal belt signals do not exactly sum up to zero (Figure 4a). This problem is minimized by calibration of the RIP signals; however, even the calibrated RIPsum may not remain accurate overnight due to changes in patient position.
and/or belt movements. Detecting apneas using the RIPsum signal is not reliable and may underestimate the AI. Thus, the RIPsum signal may have an impact on the clinical diagnosis of the OSA and undermines the severity of the disease.

Apneas are defined as events where the respiratory flow is absent or reduced by more than 90% of the reference value for at least 10 seconds. They are easily detected on TS with the same definitions (Figure 2). Furthermore, using TS, apnea could be identified by the cessation of tracheal sounds and/or the absence of definite respiratory cycles during monitoring. A first generation PneaVoX® has been already validated against a pneumotachygraph for apnea detection and there were no differences in apnea number and duration recorded by the tracheal sound method and the PNT. Our data showed that the TS signal detects less apneas than the NP signal and more apneas the RIPsum, placing the TS as the closest signal to the Therm in term of apnea detection in comparison to the performance of the NP and the RIPsum. Our data also showed that the TS signal detected more apneas than the Therm signal. TS may indeed overestimate the number of detected apneas in comparison to the Therm signal detection; however, some of these extra apneas detected by the TS may simply be events that were missed by the Therm signal. TS may record the presence of apneas while the thermistor shows air movement (Figure 4b) during periods of thermistor drift or when airflow is so slow that upper airway aerodynamic sounds are not produced. This difference could also be due to the high sensitivity of thermistors which may cause false positive events.

Tracheal sounds are well correlated with respiratory flow and can be used as an additional flow indicator for the analysis of respiratory events during sleep. The recording of TS eliminates the need for oral respiration sensors (Figure 4c). Because they are recorded directly on the sternal notch, TS reflect total ventilation, whether oral or nasal. Detection of oral respiration is important during sleep and AASM recommends its detection with thermistors. During exclusive oral breathing, the nasal pressure signal is zero while the thermistor signal
detects respiratory variations. TS sensors could also be used as auxiliary airflow sensors to reliably detect oral breathing (Figure 4c). The TS signal is recognized in the French clinical practice recommendations as a valid signal, associated with nasal pressure, to detect oronasal respiration.²³

The Bland Altman plots show important patient to patient variability. This is mainly due to the patient to patient variability presence of central apneas. The more central apneas present in the recording, the higher is the number of apneas in common and the better is the correlation between the sensors. The quality of the recording may also partially have contributed to this variability. In fact, for 4 patients with only obstructive apneas, no apneas were detected on the RIPsum signal. However, these results show that the mean difference value of the number of detected apneas between the Therm and the TS was smaller than between the Therm and the NP and between the Therm and the RIPsum. These results suggest that with respect to the Therm as a reference signal for apnea detection, the TS signal has a better performance than the recommended NP and the RIPsum signals. Further statistical analysis supports the higher performance of the TS signal comparing to the NP and the RIPsum. The Kappa score for the TS was the highest at 0.72 which falls within the range of good agreement (>0.60). The sensitivity of the TS (96.06%) for apnea detection was as good as that of the NP (99.23%) with a slightly better specificity (76.07 for TS and 69.27% for the NP). However, while the RIPsum has a lower Kappa (0.57) and a lower sensitivity (64.07), its specificity was excellent (93.06) compared to the TS and the NP.

A Pearson's correlation was run to determine the relationship between each pair of signals. Using the thermistor signal as a reference for apnea detection, there was a very strong positive correlation between Therm and TS (r = .972, N=35, p < .001), between Therm and NP (r = .968, N=35, p < .001) and between Therm and RIPsum (r = .879, N=35, p < .001).
Finally, the NP had the longest average apnea duration in comparison to the TS and the Therm, but the difference was not clinically significant. The average duration of apneas detected with RIPsum was the lowest. This could be explained by the fact that for most mixed apneas, only the central part of the event was detected as an apnea with the RIPsum signal which reduced the length of the real apneas. Some mixed apneas were not detected by the RIPsum signal for the same reason. By limiting the length of the event to the central part only, the total duration of the event did not meet the minimum 10 second requirement for apnea detection. Finally, some obstructive apneas lasted close to the necessary 10 seconds duration when scored on the NP or TS but they were shorter when evaluated with the Therm or the RIPsum. Thus, some borderline apneas were detected using some sensors but not others and this may have contributed to the higher number of apneas detected by the NP and the TS. Pearson’s correlation was also performed for apnea duration with each sensor. There was a strong positive correlation between Therm and TS ($r = .907, N=35, p < .001$), between Therm and NP ($r = .931, N=35, p < .001$) and between Therm and RIPsum ($r = .827, N=35, p < .001$).

One limitation of our study is that the pneumotach, the gold standard sensor for respiratory flow measurement, was not used. However, this technique is not suitable for routine sleep studies with a PSG as it requires the use of a full-face mask which could influence the quality of sleep. Our data was collected during routine diagnosis recording at the sleep laboratory where procedures didn’t include the PNT to avoid altering the results of the diagnosis. We used the Thermistor signal as the reference which is the AASM recommended sensor for routine sleep recording. Another limitation is that the TS signal used in this study cannot be generated and recorded by generic PSG equipment and the sensor is limited to a particular PSG system. However, while the study evaluates only one TS device with certain specifications, it opens the door for other devices to be tested as well. The principle remains the same for all TS devices which is the use of an acoustic sensor placed just above the sternal
notch with the apnea defined as the absence of respiratory sound for at least 10 seconds. Finally, an overall visual quality validation for all signals was performed but this validation was not quantified. More studies are necessary to validate and assess the applicability of TS devices. Another limitation of this study is, that finally we cannot determine in how far this new sensor contributes to the clarification of the severity of the disease and adds to the clinical diagnosis of sleep apnea. Advantages in the application of the new sensor and follow up studies based on the new signals may ultimately show whether a significant contribution to clinical diagnosis and severity of the disease can be derived.
Conclusions

In conclusion, visual detection of apneas was performed in thirty-five PSG recordings using four different noninvasive methods. We found that apneas could be identified by the cessation of tracheal sounds during continuous monitoring. The tracheal sound device used in this study provides a sensitive, reliable, technically simple, and easily applied noninvasive means to monitor respiration during sleep. While NP tends to overestimate the number of apneas and cannot detect oral breathing, TS can detect apneas seen by a thermistor and/or a RIPsum, as well as additional events that could be missed by these two sensors. Lastly, combined with NP, TS allow the detection of oral breathing and can reclassify as hypopneas apneas that would be incorrectly detected by NP alone. TS can therefore be used as a substitute for oral thermistors to reliably detect apneas and associated with NP, TS meet the oronasal flow evaluation required by the AASM for apnea detection.

In our study the TS signal was of good quality for all the recordings, which indicates good applicability of the sensor. In addition, the TS sensor can easily be placed on patients, is well tolerated, does not disturb sleep and once installed properly, it is not susceptible to move or be displaced during sleep. We propose that the advantages of this kind of systems justify their routine use in nocturnal polysomnography as well as in home polygraphy. However, prospective evaluation in a larger group of patients with analysis of hypopneas as well as apneas is needed to establish a larger clinical utility of this approach.
Acknowledgements

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**Abbreviations**

AASM: American Academy of Sleep Medicine

AHI: Apnea Hypopnea Index

AI: Apnea Index

BMI: Body Mass Index

EDF: European Data Format

NP: Nasal Pressure

NPP: Negative Predictive Value

OSA: Obstructive Sleep Apnea

PPV: Positive Predictive Value

PSG: Polysomnography

RIP: Respiratory Inductance Plethysmography

SSP: Suprasternal Pressure

Therm: Thermistor

TST: Total Sleep Time
Figure legends

**Figure 1:** Presentation of a tracheal sound transducer. A) Diagram of the PneaVoX sensor that uses both an acoustic sensor and a pressure sensor. The sensors are inserted in a protective plastic housing to ensure an airtight acoustic chamber between the skin and the transducer. B) Placement of TS sensor right above the sternal notch using a double-faced tape. If necessary, an adhesive bandage could be used over the sensor to hold it in place.

**Figure 2:** Example of apneas (central (a), mixed (b) and obstructive (c)) detected separately on 4 different signals (Flow sound intensity, Nasal Pressure, Thermistor and RIPsum). The AASM definition of apnea in terms of signal amplitude decrease and duration was applied to all 4 signals. The esophageal pressure signal confirms the characterization of the illustrated apneas. Note how obstructive apneas could be mistaken for hypopneas when using the RIPsum signal. The duration of the detected apneas could also vary from one signal to the other.

Definition of abbreviations: RIPsum = Sum of the thoracic and abdominal signals measured using respiratory inductance plethysmography.

**Figure 3:** Results of the Bland-Altman analysis for apnea detection outcomes considering the Thermistor method as the reference. The mean difference value of the number of detected apneas between the thermistor and the tracheal sounds was smaller than between the thermistor and the nasal pressure and between the thermistor and the RIPsum.

Definition of abbreviations: Therm = Thermistor; NP = Nasal Pressure; TS = Tracheal sounds and RIPsum = Sum of the thoracic and abdominal signals measured using respiratory inductance plethysmography. SD = standard deviation.

**Figure 4:** Examples of apnea detection errors by different signals. a) Obstructive apnea missed by the RIPsum signal. Sometimes during obstructive apnea, the RIPsum signal is not reduced more than 90% as it should during apneas because the thoracic and abdominal signals are not necessary in paradoxical movements. Thus, the thorax and abdominal belt signals do not exactly sum up to zero. b) Central apnea missed by the Therm signal. Based on the Therm signal, there is flow and an apnea should not be scored. However, when examining the esophageal pressure, there was no respiratory effort which is interpreted as a presence of central apnea. Note that the event is clearly identified by the NP, TS and RIPsum signals. This discrepancy could be due
to high sensitivity of the thermal flow sensor. c) Oral breathing mistaken for apnea by the NP signal. In the absence of the thermistor and based solely on the nasal pressure, one could score an apnea given that the nasal flow amplitude is reduced more than 90%. Note that respiratory cycles persist on the Therm, TS and RIPsum signals.

Definition of abbreviations: RIPsum = Sum of the thoracic and abdominal signals measured using respiratory inductance plethysmography.
Table legends

Table 1: Results are derived from individual analysis of apnea detection for each sensor (NP, RIPsum and TS). The Cohen’s Kappa, sensitivity and specificity, as well as positive predictive and negative predictive values for apnea detection were calculated for all 35 patients using Therm as a reference signal.

Definition of abbreviations: Therm = Thermistor; NP = Nasal Pressure; TS = Tracheal sounds and RIP = Respiratory Inductance Plethysmography; PPV = Positive Predictive Value; NPV = Negative Predictive Value.

Table 2: Results of the Pearson correlation analysis (n=35 patients) of the apnea detection using the thermistor, the nasal pressure, the RIPsum and the Tracheal sound signals. Statistical analysis was performed using the IBM SPSS V22.

Definition of abbreviations: Therm = Thermistor; NP = Nasal Pressure; TS = Tracheal sounds and RIP = Respiratory Inductance Plethysmography.

Table 3: Results of the Pearson correlation analysis (n=35 patients) of the apnea duration using the thermistor, the nasal pressure, the RIPsum and the Tracheal sound signals. This statistical analysis was performed using the IBM SPSS V22.

Definition of abbreviations: Therm = Thermistor; NP = Nasal Pressure; TS = Tracheal sounds and RIP = Respiratory Inductance Plethysmography.
References


Table 1. Statistical results for apnea detection

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Table 2. Pearson correlation results for apnea detection

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<td>Pearson Correlation</td>
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<td>.982*</td>
<td>.869*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>n</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.01 level (2-tailed).
Table 3. Pearson correlation results for apnea duration

<table>
<thead>
<tr>
<th></th>
<th>Thermistor</th>
<th>NasalPressure</th>
<th>RIPsum</th>
<th>TrachealSound</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermistor</strong></td>
<td>Pearson correlation</td>
<td>1.000</td>
<td>.931*</td>
<td>.827*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>____</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>NasalPressure</strong></td>
<td>Pearson correlation</td>
<td>.931*</td>
<td>1.000</td>
<td>.770*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>____</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>RIPsum</strong></td>
<td>Pearson correlation</td>
<td>.827*</td>
<td>.770*</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
<td>____</td>
</tr>
<tr>
<td><strong>TrachealSound</strong></td>
<td>Pearson correlation</td>
<td>.907*</td>
<td>.908*</td>
<td>.847*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td></td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.01 level (2-tailed).
\( \frac{\text{T} \downarrow \text{NP}}{2} \) (number of apneas)

\( \text{Therm} + \text{NP} \)

Mean = -35.69

1.96*SD = 28.35

-1.96*SD = -99.72

\( \frac{\text{T} \downarrow \text{RIPsum}}{2} \) (number of apneas)

\( \text{Therm} + \text{RIPsum} \)

Mean = 34.51

1.96*SD = 145.01

-1.96*SD = -75.98

\( \frac{\text{T} \downarrow \text{TS}}{2} \) (number of apneas)

\( \text{Therm} + \text{TS} \)

Mean = -24.34

1.96*SD = 32.13

-1.96*SD = -80.82
Flow sound intensity
Nasal flow
Thermistor
RIPsum
Esophageal pressure

a) Apnea missed by RIPsum signal
b) Apnea missed by Therm signal
c) Oral breathing mistaken for apnea by NP signal