Tracheal sounds and motion

A new approach in estimating respiratory airflow

Introduction/Problem Statement

Sleep apnea is a breathing disorder characterized by repetitive complete or partial cessations of breathing (apneas and hypopneas, respectively) during sleep for at least 10 seconds.

Sleep apnea increases the risk of hypertension, stroke and cardiovascular diseases. Based on underlying pathophysiology, these respiratory events are classified as obstructive or central (e.g. with or without increased respiratory efforts). Accurate and reliable detection and classification of apneas and hypopneas is critical for the diagnosis and quantification of disease severity, as well as for appropriate therapy selection.

SLEEP APNEA AFFECTS:

9% OF MEN

4% OF WOMEN

Since both heart failure and stroke are major causes of death and disability that consume a large proportion of health care resources, and because sleep apnea is a very common disorder affecting approximately 9% of men and 4% of women, it is recognized as a major public health problem.

Presently, the standard method of diagnosing sleep apnea is by technician-attended polysomnography (PSG). This requires the patient to spend a night in a sleep laboratory[2-7]. Polysomnographic diagnosis and assessment of severity of OSA depends upon the 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[8].

Current techniques of airflow measurement:

1. **Pneumotachography** has traditionally been considered the gold standard for flow measurement and detection of apneas[8] as illustrated in Figure 1. However, this technique is not suitable for routine sleep studies with a PSG. The major limitations are related to patient tolerance due to discomfort rather than validity of the data recorded. Also, there could be leakages through the face mask, leading to underestimation of ventilatory volume. This technique is of limited use in sleep studies because the face mask leads to sleep disturbance[10]. Other techniques to measure airflow include oronasal thermal airflow sensors (thermistors or thermocouples), nasal cannulas and respiratory inductance plethysmography (RIP).

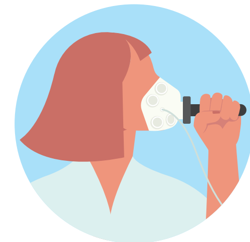

Figure 1: Pneumotograph face mask

2. **Thermal airflow sensors** are sensors that use the temperature difference between the exhaled and ambient air for airflow estimation and detection of mouth breathing. The use of temperature as a surrogate for airflow measurement can detect apnea as it has the advantage to detect both nasal and oral airflow. Thermistors do not provide an accurate measure assessment of changes in airflow and are insensitive to detecting hypopneas[1].

3. **Nasal cannulas** are pressure sensors that can detect pressure changes during inspiration and expiration. Most sleep laboratories use signals from a thermistor and nasal pressure (NP) to assure an oronasal flow measurement. This sensor combination improves identifying apneas that are missed by thermistors or overestimated by NP in the case of mouth breathing, for example.

   However, these two sensors typically cause much discomfort to patients having a negative impact on their sleep[10]. Therefore, they are usually displaced or even removed by the patients during recording at night.

   In the absence of oesophageal pressure,

4. **RIP** is recommended for evaluating respiratory efforts during sleep studies. However, reliable results with these sensors depend on the accurate placement and stability of the belts, which is challenging in certain patients, particularly obese patients. In addition, body movements during the night can cause belt displacement which will diminish the accuracy of measurements.

Thus, alternative methods for detecting oral airflow and evaluating respiratory effort during sleep are required.

Proposed Solution

Fortunately, an alternative method which improves patient's comfort is through analyzing tracheal breath sounds and motion. This will result in more reliable and accurate results as well as provide the patient with a better experience.

Tracheal sounds have been the focus of many research studies. Tracheal sounds, heard at the suprasternal notch, are a measure of the body surface vibrations. Turbulent airflow in the airways transmit these pressure variations through the inner surface of the trachea[11]. The surface sensor detects tracheal wall vibrations and can therefore detect tracheal breathing sounds[12, 13].

> **Tracheal sound sensors are a simple and non-invasive method of measurement and are more reliable than other breathing sensors.**

Developments in acoustic processing techniques and enhancements in tracheal sound signals over the past decade have led to improvements in the accuracy and clinical relevance of diagnoses based on this technology. Past and current research suggests that they may have a major role in the diagnosis of obstructive sleep apnea.

Respiratory Flow Measurement and Detection of Events

Tracheal sounds correlate well with respiratory flow and could be used in the same way as any other flow signal for the analysis of respiratory events during sleep.

The detection of tracheal sounds for the measurement of sleep-related respiratory disorders has therefore widely been investigated in many studies.

FOR EXAMPLE:

In 1980, Krumpe et al.[14] were the first to show that laryngeal sound monitoring could be useful in sleep studies. They found that apnea could be identified by the cessation of laryngeal sounds during continuous monitoring.

In 1982, Cummiskey et al.[15] used a tracheal sound sensor associated with a thermistor, a nasal pressure cannula and pulse oximetry for the detection of apneas and hypopneas. They showed that there was no significant difference in the number of events detected with the tracheal sounds or the reference sensors.

BresoDX1 and Airflow Measurement

BresoDX1 is a prescription-use device that is intended for healthcare professionals to use as an aid in the diagnostic evaluation of moderate to severe sleep apnea for adults.

It consists of:

1. Microphone
2. 3-dimensional accelerometer
3. FDA-cleared oximetry module

The device records a patient's physiological signals such as tracheal breath sounds, body positions and movements, arterial oxy-hemoglobin saturation, and pulse rate during sleep (illustrated in the figure below).

Figure 2: BresoDX1 System

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Efficacy of BresoDX1

A study was conducted to test the efficacy of BresoDX1 in measuring airflow and respiratory motion using tracheal sounds and movement in comparison to the PSG (gold standard) airflow measurement, as explained below.

Study Population

A total of 252 adults (≥18 years) were recruited for this study.

Subjects ≥ 18 years of age referred for PSG because of a suspicion of a sleep disorder were included in this study at University Health Network.

Exclusion criteria: In-hospital patients, those who self-reported neuromuscular disorders, obesity hypoventilation, severe lung diseases such as chronic obstructive pulmonary disease, or allergic to adhesive tape.

Study Set-up and Measurements

Simultaneous to PSG, a tracheal module (BresoSensor SN) with an embedded microphone and 3-D accelerometer was attached over the suprasternal notch to record tracheal sounds and motion, respectively.

Measurements

1. In-laboratory overnight PSG,
2. BresoDX1 (Bresotec Inc., Toronto, Canada), including: a microphone, affixed over the suprasternal notch using adhesive tape and a 3-dimensional accelerometer to measure body movement.

Results

The agreement between the estimated airflow from BresoDX1 and the reference airflow measured by the nasal pressure was quantified by determining the differences between both signals. Mean squared error (MSE) is a common metric to quantify these differences. Also, in order to evaluate the physiological interpretation of the estimated airflow, the average signal amplitude was determined during respiratory events and normal breathing.

Figure 1 presents a Nasal pressure signal overlayed with a BresoDX1 estimation of airflow during a regular breathing during sleep.

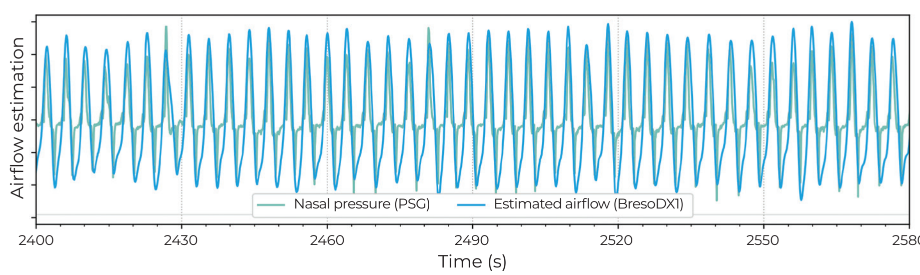

Figure 1: Nasal pressure (PSG) vs. estimated airflow from BresoDX1 during a data segment that represents normal breathing

In Figure 2, we can see the interruption of BresoDX1 airflow estimation during respiratory events.

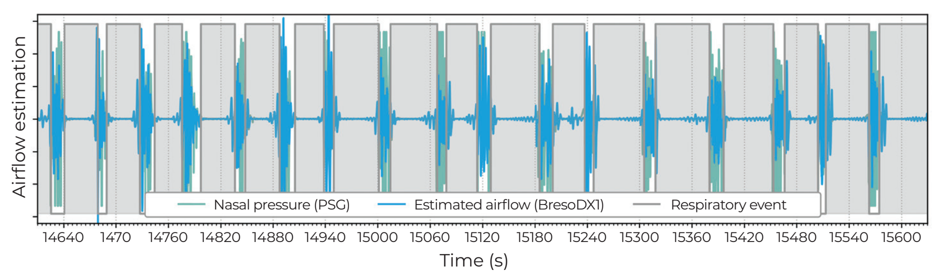

Figure 2: Nasal pressure (PSG) vs. estimated airflow from BresoDX1 during several respiratory events

Figure 3: BresoDX1 conveniently attached over the neck to collect tracheal motion and sounds

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In order to compare BresoDX1 and PSG nasal pressure, the mean squared error is presented in Figure 3.

It's noticeable that for apneas, the error is as low as 0.9% in average for all subjects of the trial.

This represents a very accurate measure of airflow changes during the patient's sleep. It's also possible to notice that during events, the signal amplitude drops considerably, as we can see in Figure 4.

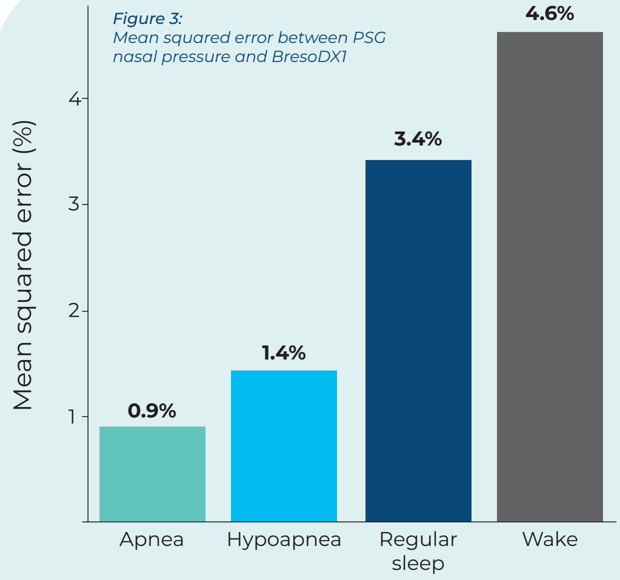

Figure 3:
Mean squared error between PSG nasal pressure and BresoDX1

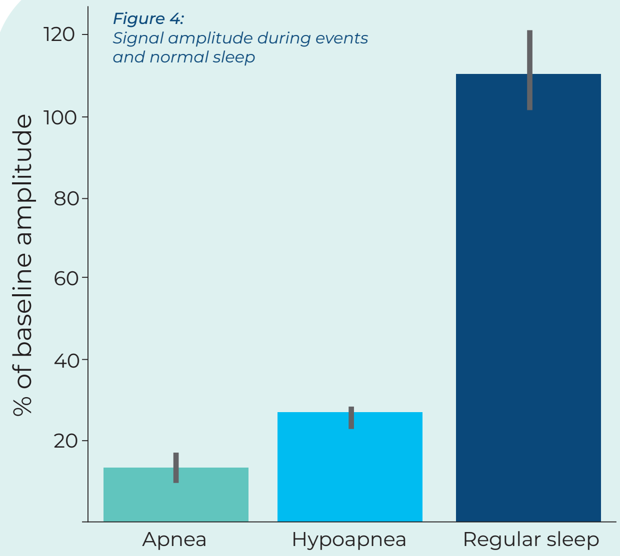

Figure 4:
Signal amplitude during events and normal sleep

Conclusion

These findings provide evidence that tracheal sound and motion signals can provide an accurate estimate of respiratory airflow that can be used to detect apneas and hypopneas. Such a simple and convenient method could be used for portable monitoring to detect sleep apnea. Further studies using this device in the home setting will be required to test this possibility.

REFERENCES:

1. R. Farre et al., Accuracy of thermistors and thermocouples as flow measuring devices for detecting hypopneas European Respiratory Journal. 1998;11:179-182.
2. Leung, R.S. and T. Douglas Bradley, *Sleep apnea and cardiovascular disease*. American Journal of Respiratory and Critical Care Medicine, 2001. **164**(12): p. 2147-2165.
3. Nieto, F.J., et al., *Association of sleep-disordered breathing, sleep apnea, and hypertension in a large community-based study*. Jama, 2000. **283**(14): p. 1829-1836.
4. Shahar, E., et al., *Sleep-disordered breathing and cardiovascular disease: cross-sectional results of the Sleep Heart Health Study*. American journal of respiratory and critical care medicine, 2001. **163**(1): p. 19-25.
5. Bradley, T.D. and J.S. Floras, *Sleep apnea and heart failure part I: obstructive sleep apnea*. Circulation, 2003. **107**(12): p. 1671-1678.
6. Arzt, M., et al., *Association of sleep-disordered breathing and the occurrence of stroke*. American journal of respiratory and critical care medicine, 2005. **172**(11): p. 1447-1451.
7. Young, T., et al., *Estimation of the clinically diagnosed proportion of sleep apnea syndrome in middle-aged men and women*. Sleep, 1997. **20**(9): p. 705-6.
8. Berry RB, Budhiraja R, Gottlieb DJ, et al. *Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events*. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. J Clin Sleep Med. 2012; **8**(5): 597–619.
9. Guilleminault C, Stoohs R, Duncan S. *Snoring: daytime sleep- iness in regular heavy snorers*. Chest 1991; **99**: 40-8.
10. Goodwin JL, Enright PL, Kaemingk KL, et al. *Feasibility of using unattended polysomnography in children for research – report of the Tucson Children's Assessment of Sleep Apnea study (TuCASA)*. Sleep. 2001; **24**(8): 937–944.
11. Gavriely N. *Breath Sounds Methodology*. Boca Raton, CRC Press, 1995; pp. 31–33.
12. Meslier M, Simon I, Kouatchet I, et al. *Validation of a suprasternal pressure transducer for apnea classification during sleep*. Sleep 2002; **25**: 753–757.
13. Amaddeo A, Fernandez-Bolanos M, Olmo Arroyo J, et al. *Validation of a suprasternal pressure sensor for sleep apnea classification in children*. J Clin Sleep Med 2016; **12**: 1641–1647
14. Krumpe PE, Cummiskey JM. *Use of laryngeal sound recordings to monitor apnea*. Am Rev Respir Dis 1980; **122**: 797–801.
15. Cummiskey J, Williams TC, Krumpe PE, et al. *The detection and quantification of sleep apnea by tracheal sound recordings*. Am Rev Respir Dis 1982; **126**: 221–224

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