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Evaluation of the different sleep-disordered breathing patterns of the compressed tracheal sound

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HIGHLIGHTS

- Even if sustained partial obstruction is found to be common among sleep-disordered breathing (SDB) patients, it is not easily observed in conventional polysomnography recordings.
- Oesophageal pressure decreased and the tracheal sound presented most high frequency components in the 1001–2000 Hz frequency band during the sustained partial obstruction.
- The presented compressed tracheal sound analysis seems to provide an easy and reliable method for screening not only apneas or hypopneas but also sustained partial obstruction.

ABSTRACT

Objective: Suitability of the compressed tracheal sound signal for screening different sleep-disordered breathing patterns was evaluated. The previous results suggest that the plain pattern in the compressed sound signal represents mostly normal, unobstructed breathing, the thick pattern consists of periodic apneas/hypopneas and during the thin pattern, flow limitation in the nasal cannula signal is abundant.
Methods: Twenty-seven patients underwent a polysomnography with a tracheal sound and oesophageal pressure monitoring. The tracheal sound data was compressed and scored visually into three different breathing patterns. The percentage of oesophageal pressure values under −8 cm H_2O, the minimum pressure value and the average duration of the breathing cycles were extracted from 10-min episodes of those plain, thick and thin patterns. In addition, the spectral contents of the tracheal sound during the different breathing patterns were evaluated.
Results: The percentage of time when the oesophageal pressure negativity increased was highest during the thin pattern and lowest during the plain pattern. In addition, the thin pattern presented most high frequency components in the 1001–2000 Hz frequency band of the tracheal sound.
Conclusions: The results confirmed our previous findings that both the thick and thin patterns seem to consist of obstructed breathing, whereas during the plain pattern the breathing is normal, unobstructed.
Significance: Most screening methods for sleep-disordered breathing reveal only periodic apneas/hypopneas, but with the compressed sound signal the sustained partial obstruction can be estimated as well.

1. Introduction

Obstructive sleep apnea (OSA) is common; its prevalence is estimated to be 2–4% (Young et al., 1993). However, in addition to apneas and hypopneas revealing OSA, sleep recordings consist of other sleep-disordered breathing patterns, as well. These patterns include short flow limitation events associated with an increase in negative oesophageal pressure as well as an arousal, as in the upper airway resistance syndrome (UARS), or sustained low limitation periods, lasting from several minutes up to tens of minutes (Hernandez et al., 2001; Tenhunen et al., 2009). The sustained partial obstruction detected by a sleep mattress sensor has been found to be common especially among postmenopausal

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women (Polo-Kantola et al., 2003). According to our recent work, sustained partial obstruction seems to be associated with somnolence and presumably also with depressed mood (Tenhunen et al., 2013).

The need for sleep studies is vast, and various systems either with visual, automated or semi-automated methods has been developed to simplify and speed up the recording procedure. One of the methods used to study respiratory events during sleep is the analysis of tracheal sound. It has been developed to detect sleep apnea and other respiratory events among both in adults and children (Krumpe and Cummiskey, 1980; Beckerman et al., 1982; Cummiskey et al., 1982; Sanna et al., 1991; Nakano et al., 2004; Kulkas et al., 2009). Also developmental works for a diagnostic assessment and portable screening devices have been done (Lugaresi et al., 1983; East and East, 1985; Hida et al., 1988). However, collecting only the events resembling apneas/hypopneas ignores periods with sustained partial obstruction. We have previously presented a visual analysis method to evaluate nocturnal tracheal sound (Rauhala et al., 2008). The method utilises heavy data compression. The resulting visual representation of the compressed tracheal sound signal reveals three distinct sound patterns. The plain sound pattern seems to represent mostly normal breathing with low sound amplitude levels, the thick sound pattern consists of intermittent alternation of sound amplitude levels associated with apneas and hypopneas, and the thin sound pattern, in which the sound amplitude level is continuously high and flow limitation in the nasal pressure transducer is abundant.

In the present work, we continue the evaluation of compressed tracheal sound patterns. We study the changes in the oesophageal pressure values associated with different compressed sound patterns. In addition, we evaluate the spectral content of the raw tracheal sound signal during these compressed patterns. Our hypothesis is that during the plain sound pattern the oesophageal pressure (pESO) values remain normal and that during the thick and the thin patterns, the pESO negativity increases indicating upper airway obstruction. As along with increasing obstruction, the spectrum of the tracheal sound signal consists more of higher frequencies (Rao et al., 1990; Yonemaru et al., 1993; Pasterkamp et al., 1996; Kaniusas et al., 2005; Herzog et al., 2008; Michael et al., 2008), we hope to find out that during the plain sound pattern, the spectrum of the tracheal sound consists mostly of lower frequencies. During the thick and the thin patterns higher frequencies would be more common.

2. Methods

2.1. Subjects and recordings

Twenty-seven consecutive patients (22 male, 5 female) referred to the Sleep Unit of Pirkanmaa Hospital District volunteered to participate in this study. The patients were studied due to the suspicion of sleep-disordered breathing. All of the subjects gave their written consent. The study was approved by the Ethical Committee of Pirkanmaa Hospital District.

The sleep recording montage consisted of six EEG derivations (F3-A2, F4-A1, C3-A2, C4-A1, O1-A2, O2-A1), two EOG channels, submental and anterior tibialis muscle EMG, body position, pulse oximetry, Emfit sleep mattress and electrocardiogram. Thoracic and abdominal respiratory movements were recorded with inductive belts. Airflow was measured by nasal pressure transducer and thermistor. Recordings were performed with the Embla N7000 (Embla®, Natus Medical Inc., USA) and the Somnologica Studio 3 software (Medcare®, Iceland) simultaneously with the oesophageal pressure (pESO) measurement (Reggie, Camtech AS, Norway) and tracheal sound recording. These external device data were converted into Embla data format and their temporal synchronization was confirmed before the analysis (Kulkas et al., 2008; Tenhunen et al., 2009). A sampling rate of 11,025 Hz was used for tracheal sound, 2 Hz for pulse oximetry, 10 Hz for respiratory movements and 20 Hz for oesophageal pressure, 500 Hz for ECG, and 200 Hz for all other signals. The pESO measurement is invasive but the signal has some advantages, for example, it shows breathing efforts both during normal and obstructed breathing (including obstructive apneas) (Reda et al., 2001).

The tracheal sound recordings were performed with an electret microphone (Panasonic WM-60A, Matsushita Electric Industrial Co, Ltd, Kadoma Osaka, Japan). The microphone's conical air cavity is 25 mm in diameter and 3 mm in depth. The sensitivity of the microphone is 10 mV/Pa and the frequency range in the free field is 20 Hz–20 kHz, ±2 dB (Sovijarvi et al., 1998). The microphone was attached to the skin in the suprasternal notch as in our previous studies (Rauhala et al., 2008; Tenhunen et al., 2009; Kulkas et al., 2010). The tracheal sound signal was amplified and high-pass filtered with a cut-off frequency of 50 Hz and fed into a Sound Blaster Audigy 2 NX sound card (Creative Labs, Singapore) for a 24 bit A/D conversion followed by an USI-01 isolator (MESO, Mittweida, Germany) providing galvanic isolation between the patient and the recording equipment. The obtained tracheal sound signal provides the raw data from the sounds recorded over the trachea.

2.2. Visual scoring

Nocturnal polysomnography recordings were scored into the sleep stages according to the standard criteria, and the apnea-hypopnea index (AHI) was calculated according to the hypopnea rule 4B (Iber et al., 2007). Microarousals were scored according to the criteria of the American Sleep Disorders Association (American Sleep Disorders Association (ASDA), 1992).

For the visual analysis of the different sound signal patterns the tracheal sound signal data were reduced as in our previous work (Rauhala et al., 2008). In the reduction procedure only the maximum and minimum sound signal values of each consecutive 15-s epoch was taken. This compressed sound information (four maximum and minimum samples per minute) was used for the visual analysis. The compressed tracheal sound signal was scored into four different categories: a plain signal curve close to zero, a thin signal curve deviating clearly from zero and a thick, highly varying signal curve. The fourth category consisted of the periods of signal periods of low quality (not-scored periods). After that, one 10-min representative episode of plain, thin and thick tracheal sound pattern was selected for present analysis from each subject, whenever present. This selection was performed by two researchers working together to assure the validity of the selected episodes. An example of each type of compressed sound pattern is shown in Fig. 1a, and examples of the raw signals (tracheal sound, pESO, and nasal flow) for 3-min, part of each 10-min pattern, are presented in Fig. 1b–d.

2.3. pESO analysis

A special software was developed to import the pESO signal to the Somnologica software. The oesophageal pressure value of -8 cm H_2O is considered the threshold between obstructive and non-obstructive events when using the Reggie device (Oeverland et al., 2005). This threshold was used to differentiate increased respiratory effort and normal breathing. As the first quantity, the percentage of time with pESO values of -8 cm H_2O or less was calculated during each 10-min compressed sound pattern. This quantity also was used in our previous work validating Emfit sleep mattress performance (Tenhunen et al., 2011). In addition, the most negative oesophageal pressure value (pESOmin) for each 10-min sound pattern was collected automatically.