Piezoelectric Belts as a Method for Measuring Chest and Abdominal Movement for Obstructive Sleep Apnea Diagnosis

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ABSTRACT. Distinguishing obstructive sleep apnea from central apnea depends upon accurate measure of chest and abdominal movement. American Academy of Sleep Medicine (AASM) polysomnography guidelines recommend the use of respiratory inductive plethysmography (RIP) belts but not piezoelectrode (PE) belts for measuring chest and abdominal movements. To compare these two sensors, we measured the signal amplitude for 10 RIP belts and 10 PE belts stretched by mechanical distraction across six distances (2.5 to 15.0 centimeters) and replicated 10 times for each belt. Amplitudes were measured using the Stellate Harmonie (Stellate Systems, Inc., Natus Medical, Inc., San Carlos, California, USA) recording system. A Pearson Product Moment Correlation coefficient was calculated. All RIP belts performed well at all distraction lengths and demonstrated linear performance. Eight of 10 PE belts performed well through all measures whereas, two showed nonlinear increase in signal on stretch of greater than 12.5 centimeters. Signals from PE belts highly correlated with the distance of distraction ($r=0.96$ to $0.99$) and the RIP belts ($r=0.98$ to $0.99$). These results suggest that PE belts perform similarly to RIP belts at distraction distances up to 10.0 centimeters. Further testing on biological models is needed to determine if PE belts are a suitable alternative for RIP belts in polysomnography.

KEY WORDS. Obstructive sleep apnea, piezoelectric, polysomnography, respiratory effort, respiratory inductive plethysmography.

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INTRODUCTION

Obstructive sleep apnea (OSA) is a disorder that affects at least six percent of American adults (White 2006). This sleep disorder is characterized by the closure of the airway with continued ventilatory effort. Left untreated, OSA increases the risk for cardiovascular disease and early death as well as decreases quality of life (White 2006). Determination of the chest and abdominal movements are important for differentiating obstructive verses central apnea. Obstructive apneas are identified by the absence of air flow for ten seconds or greater despite continued chest and abdominal movement. Central apneas are similar absences of air flow but associated with no chest or abdominal movement. In 2007, the American Academy of Sleep Medicine (AASM) guidelines recommended the use of respiratory inductive plethysmography (RIP) belts (calibrated or uncalibrated) for the measurement of chest and abdominal movements. While RIP belts measure stretch based on the inductive field produced by a coil, chest and abdominal movement can be measured by several mechanisms including strain gauges, intercostals electrodes, intrathoracic pressure monitors, and belts (Epstein et al. 2009).

Piezoelectric (PE) belts are frequently used and measure movement by the change in impedance of crystals that are sensitive to pressure changes. These belts were not formally tested, therefore, were not included in the recommendations. Although they can sense very minimal changes in pressure, some authors felt these belts could only provide a qualitative measure (Ishida et al. 2004). The following research compares the linear stretch potential of RIP and PE as a first step to examine equivalency.

METHODS

We tested 10 RIP belts and 10 PE belts for signal amplitude compared to six distances of stretch (2.5 to 15.0 cm). These distances were determined from a preliminary measurement of four adults and found the average adult’s chest increases in circumference from 3.0 to 12.0 cm with minimum and maximum inspiration. The PE belts were all older than one year in use in the laboratory and the RIP belts were all under eight months of use in the laboratory. Each distance was measured ten times for each belt on a mechanical stretch machine. Amplitudes were measured peak to peak without any filtering using the Stellate Harmonie (Stellate Systems, Inc., Natus Medical, Inc., San Carlos, California, USA) recording system. The average amplitude was calculated for each distance for each belt and graphed independently. The correlation was determined using a Pearson Product Momentum Correlation coefficient ($P < 0.05$).

RESULTS

All ten RIP belts performed well at all lengths of distraction and demonstrated linear performance across each distance. Eight out of the ten PE belts performed well
through all measures. Two PE belts had dramatic increase in signal amplitude on a stretch of greater than 10.0 centimeters. The remaining eight of the PE belts showed minor diminishing signal differentiation at higher stretch distances. Correlating the signal to distraction length showed PE belts performed with high correlations ranging from $r=0.96$ to $r=0.99$ with an average of $r=0.98$. Similarly, the RIP belts performed with $r$ values ranging from 0.98 to 0.99 with an average of $r=0.99$.

**DISCUSSION**

We found that the PE belts produced linear signal output with linear distraction and highly correlated with the RIP belt performance especially in the 2.5 to 10.2 cm distraction range. PE belts were not as reliable at distances typically beyond normal inspiration (>10.0 cm). These data would suggest that PE belts should perform similarly to the RIP belts in the typical change in circumference with normal inspiration.

We found that the 10 PE belts had a high correlation with RIP belts in the 2.5 to 10.0 cm stretch and 8 of the 10 for distances up to 15.0 cm. This range of stretch is typical for normal adult inspiration, and would support the use of these belts for the detection of respiration. We did not investigate stretch distance less than 2.5 cm and thus minimal distance change may not correlate between the two sensor types. Chest circumference may increase beyond 10.0 cm, but these distances are more commonly associated with deep inspiratory events such as yawns or sighs. At higher degrees of linear distraction (12.5 to 15.0 cm), some PE belts experienced signal degradation. The lack of uniform results in this range may be more related to the fabric characteristics than the PE sensor itself. The differences in the PE belts performances may be due to the different types of PE belt fabric, age of sensors, or sensor malfunction. The bands were different ages and this may have influenced the findings. However, this finding may point to the need for a quality assurance measure in the sleep laboratory setting. They also suggest that manual testing of belts with linear distraction may provide a method for identification of belts that are not suitable for use in a clinical laboratory.

Identification of ventilatory effort is important in distinguishing obstructive from central sleep apnea. For this identification, the current AASM guidelines do not indicate a need for quantification of effort. Relative quantification of effort can be important in determining respiratory event related arousals (RERAs) especially in children. Fiamma et al. (2007) have shown that RIP belts have a good correlation with airflow measured by mouth piece, and Kaplan et al. (2000) demonstrated the ability of RIP belts to detect flow limitation through increasing ventilatory effort. Our study suggests that PE belts should be further considered in the measurement of ventilator effort. These belts performed similarly to the RIP belts on linear distraction but had some limitation at higher distances of distraction. This may be related to the underlying principle of the belts. RIP belts are measuring distance of distraction
A. Respiratory inductive plethysmography (RIP) belts.

B. Piezoelectrode (PE) belts.

**FIG. 1.** Amplitude of signal produced by various distances of distraction of: A. respiratory inductive plethysmography (RIP) belts; B. piezoelectrode (PE) belts.
through the stretch of an inductive coil, whereas the PE belts are measuring pressure related to the stretch of the belt. The latter may have limitation due to the elastic properties of the belt. Both of these measures give us similar parameters but each with a slightly different view. Our experiment measured linear distraction, and thus may have favored the RIP belts. Our work supports the results found by Pennock (1990). Pennock (1990) compared PE belts with other methods, specifically RIP belts using paradigms of flow and volume change in 3-liter anesthesia bags and test subjects. The peak flow measured by PE belts on the anesthesia bags had a high correlation of 0.993 to the actual peak flow. PE belts also produce a linear signal that is proportional to flow (Pennock 1990).

PE belts are sensitive to stretch via changes in pressure. Our study ignored pressure on the belts and focused on distance of distraction regardless of pressure. The results may have favored PE belts if our experiment used pressure as the measure of displacement. Redesigning the study to evaluate distraction based on pressure may show greater linear relationship in PE belts, than RIP belts. This difference raises an interesting dilemma to the underlying information needed in polysomnography. Frequently the distinction of obstructive apnea from central apnea is the demonstration of "respiratory effort" which could be interpreted as the ability to move air to and from the lungs. One could argue that this transfer of air requires pressure changes which results in the change of chest and abdominal circumference. Therefore respiratory effort would be more closely associated with pressure than movement. Primary measures of intrathoracic pressure are the gold standard for characterizing respiratory effort, but we have yet to distinguish extra-thoracic pressure from change in circumference. This may be an important issue for individuals who have chest wall abnormalities that may have variable pressure changes to create chest movement, such as skeletal deformities.

PE belts have other attractive features. In their article introducing PE belts, Ishida et al. (2004) state that PE belts are comfortable and easy to use. PE belts cost less than their RIP belt counterparts and thus reduce operational costs for a sleep study.

CONCLUSION

Similar to Pennock’s (1990) findings, our research demonstrates that PE belts can perform similarly to RIP belts on linear distraction. We suggest PE belts are a viable method for monitoring chest and abdominal movement for patients with normal inspiration. Further work comparing these methods in subjects with sleep apnea will help in identifying PE belts as an option for sleep laboratories.

REFERENCES


