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SCIENTIFIC INVESTIGATIONS

Use of Chest Wall Electromyography to Detect Respiratory Effort during Polysomnography

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Study Objectives: To evaluate the ability of chest wall EMG (CW-EMG) using surface electrodes to classify apneas as obstructive, mixed, or central compared to classification using dual channel uncalibrated respiratory inductance plethysmography (RIP).

Methods: CW-EMG was recorded from electrodes in the eighth intercostal space at the right mid-axillary line. Consecutive adult clinical sleep studies were retrospectively reviewed, and the first 60 studies with at least 10 obstructive and 10 mixed or central apneas and technically adequate tracings were selected. Four obstructive and six central or mixed apneas (as classified by previous clinical scoring) were randomly selected. A blinded experienced scorer classified the apneas on the basis of tracings showing either RIP channels or the CW-EMG channel. The agreement using the two classification methods was determined by kappa analysis and intraclass correlation.

Results: The percentage agreement was 89.5%, the kappa statistic was 0.83 (95% confidence interval 0.79 to 0.87), and the intraclass correlation was 0.83, showing good agreement. Of the 249 apneas classified as central by RIP, 26 were classified as obstructive (10.4%) and 7 as mixed (2.8%) by CW-EMG. Of the 229 events classified as central by CW-EMG, 7 (3.1%) were classified as obstructive and 6 (2.6%) as mixed by RIP.

Conclusions: Monitoring CW-EMG may provide a clinically useful method of detection of respiratory effort when used with RIP and can prevent false classification of apneas as central. RIP can rarely detect respiratory effort not easily discernible by CW-EMG and the combination of the two methods is more likely to avoid apnea misclassification.

Keywords: apnea, diaphragmatic EMG, polysomnography, respiratory effort

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INTRODUCTION

Detection of respiratory effort during clinical polysomnography (PSG) is usually based on signals acquired from respiratory inductance plethysmography (RIP) effort belts around the chest and abdomen.[1–4] Central apneas are identified by absence of deflections in these signals during the apnea. However, in some individuals, deflections in the RIP signals during obstructive apneas are small and can result in misclassification of an obstructive apnea as a central apnea or of a mixed apnea as a central apnea.[5,6] The gold standard for detection of respiratory effort is esophageal manometry.[1–4] Deflections in esophageal pressure not only detect respiratory effort, but unlike effort belt signals, reflect the level of inspiratory effort. However, esophageal manometry is rarely used in the clinical setting because it is more invasive and requires special training and equipment.

Monitoring of surface EMG signals has been used to detect respiratory effort in research sleep studies.[7–12] If placed in the parasternal area in an intercostal space, the EMG is sometimes referred to as intercostal EMG. When placed near the insertion of the diaphragm on the chest wall, the measurement is often referred to as diaphragmatic EMG. However, if electrodes are placed appropriately they can detect both diaphragmatic and chest wall muscle (including intercostal) EMG bursts during inspiration.[13] The initial American Academy of Sleep Medicine scoring manual published in 2007 listed monitoring of intercostal/diaphragmatic EMG as an alternative sensor for monitoring respiratory effort.[2] However, more recently the method has not been listed as an alternative sensor due to a paucity of clinical studies evaluating the accuracy compared to RIP or esophageal manometry.[1,3]

We hypothesized that detection of inspiratory bursts of EMG activity with surface electrodes on the chest wall would provide a useful alternative method of detection of respiratory effort for classification of apneas compared to RIP belts. As chest wall EMG (CW-EMG) has been used routinely used in our sleep center to complement RIP (primary sensor for respiratory effort detection), we undertook a study to compare the

BRIEF SUMMARY

Current Knowledge/Study Rationale: Recording of surface electromyography (EMG) activity of the chest wall has been used in research studies, but the utility of the technique for detection of respiratory effort during routine clinical polysomnography has not been well documented. This study compared apnea classification using uncalibrated respiratory inductance plethysmography and chest wall EMG.

Study Impact: The study suggests that chest wall EMG using routine clinical techniques can provide useful complementary information to respiratory inductance plethysmography concerning the presence of respiratory effort during apnea.

Table 1—Subject demographics.

	Mean	SD
Age (y)	56.6	15.4
Sex M/F	44/16	
BMI (kg/m^2)	31.4	5.6
AHI (events/h)	36.2	23.1
Obstructive apneas* (% total events)	27.6	17.1
Mixed apneas* (% total events)	7.6	14.9
Central apneas* (% total events)	24.9	23.2
Hypopneas* (% total events)	39.9	20.7

*Apnea classification based on clinical technologist scoring. AHI, apnea-hypopnea index; BMI, body mass index; SD, standard deviation.

classification of apneas (obstructive, mixed, central) by CW-EMG and RIP.

METHODS

Consecutive adult sleep studies recorded over a 3-month period at the UF Health Sleep Center were retrospectively analyzed. The retrospective analysis was approved by the institutional review board of the University of Florida. The first 60 studies meeting the following criteria based on clinical technologist scoring of the entire study (split studies were included) were analyzed:

(a) Age older than 18 y
(b) At least 10 central or mixed apneas
(c) At least 10 obstructive apneas
(d) Chest and abdominal RIP belt signals were of adequate technical quality.
(e) CW-EMG tracing was of adequate technical quality for at least half of the study. A technically adequate tracing was defined as the ability to see inspiratory bursts during unobstructed breathing and absence of a large amount of 60 Hz or electrocardiogram (ECG) artifact obscuring the signal of interest.

A total of 647 consecutive adult sleep studies (diagnostic, positive airway pressure [PAP] titration, and split night) were reviewed to select the required number for analysis. Of these studies 79 (12.2%) fulfilled criteria (a) to (d). However, 19 studies did not have technically adequate CW-EMG activity.

Standard polysomnographic techniques were utilized with recording of frontal, central, and occipital electroencephalogram and right and left eye movement derivations (E1-M2, E2-M2), and chin derivations as recommended by the Scoring Manual of the American Academy of Sleep Medicine.[1] Airflow was detected using an oronasal thermal sensor and nasal pressure (diagnostic study) or positive airway pressure device flow signal (PAP titration study). Uncalibrated chest and abdominal respiratory inductance plethysmography signals were used to detect respiratory effort. Pulse oximetry and right and left anterior tibial EMG were also recorded. The Grass Comet Digital PSG system (Natus Neurology, Warwick, RI) was utilized. Signals were acquired with a 200-Hz sampling rate and viewed using Twin software (Natus Neurology, Warwick, RI).

Chest Wall EMG

The CW-EMG signal was recorded using a bipolar AC amplifier (Comet amplifier) with two adhesive patch electrodes placed 2 cm apart in the eighth intercostal space at the right mid-axillary line. An electrode impedance of less than 10 Kohm was considered acceptable. Contractions of both the intercostal muscles and diaphragm are believed to contribute to the signal. The CW-EMG signal was displayed using the following filter settings. A low filter setting of 25 Hz was used to reduce ECG artifact. A high filter setting of 100 Hz and notch 60 Hz filter were also used. Although the recommended low filter setting for EMG is usually 10 Hz, using 25 Hz significantly reduced ECG artifact in the signal. Chest and abdominal RIP belt signals were displayed with a low filter setting of 0.1 Hz and high filter setting of 15 Hz. The sensitivity of both RIP and CW-EMG signals was adjusted for optimal event classification.

Event Selection

In each study, six central or mixed apneas and four obstructive apneas were randomly chosen. The random number function in Excel (Microsoft, Redmond WA) was used to select an epoch number. The next event with technically adequate tracings was selected until the required number of events were identified. If the random epoch number selected an epoch after the last respiratory event, another random number was generated.

Screen shots showing EEG, electrooculogram, chin EMG, and ECG, derivations along with arterial oxygen saturation, nasal pressure, thermal airflow, or PAP flow were obtained with either chest and abdominal RIP channels or the CW-EMG channel displayed. The screen shot was de-identified and copied into Power Point (Microsoft, Redmond, WA) for viewing. These screen shots showing either chest/abdominal RIP or CW-EMG for each event were presented to a single blinded observer for classification as obstructive apnea, mixed apnea, or central apnea. Only one individual was responsible for blinded review of all data. For each apnea event the screen shots of the two methods were presented with many intervening tracings so that the scorer could not compare the appearance of the two methods for a given apnea.

Analyzing Agreement

The agreement between methods was determined by both kappa analysis and intraclass correlation using statistical software (Med Calc, Med Calc Software Bvba, Ostend, Belgium). The percentage agreement was computed as the number of pairs with agreement ×100/total number of pairs.

RESULTS

The demographic information for the study population is shown in **Table 1**. The patients were middle aged or older with an increased body mass index. The apnea-hypopnea index was in the moderate to severe range. For split as well as diagnostic and PAP titration sleep studies the respiratory event types as

a percent of the total events and apnea-hypopnea index for the entire night are displayed. By design, a significant percentage of the apneas were central and mixed apneas (clinical technologist scoring).

Event Agreement

The event classification with the two methods is shown in **Table 2**. The diagonal represents event agreement. The percentage of agreement was 89.5%. The kappa statistic was 0.83 (95% confidence interval 0.79 to 0.87), consistent with excellent agreement. The intraclass correlation (for absolute agreement) was also computed and was 0.83 (95% confidence interval 0.80 to 0.86).

Events with Disagreement between the Methods

The most important potential utility of use of CW-EMG is to identify events falsely labeled as central by RIP bands. If unambiguous inspiratory bursts are identified in the CW-EMG signal, this is strong evidence for the presence of respiratory effort.

Of the 249 events classified as central by RIP, 26 were classified as obstructive by CW-EMG (10.4%) and 7 as mixed (2.8%). An example of such an event is shown in **Figure 1**. However, of the 229 events classified as central by CW-EMG, 7 (3.1%) were classified as obstructive by RIP and 6 (2.6%) as mixed. In these events close examination of the CW-EMG signal often revealed subtle inspiratory bursts that were not detected by the blinded observer. An example of an apnea classified as central by CW-EMG but obstructive by RIP is shown in **Figure 2**. There are very small inspiratory bursts in the CW-EMG but not prominent enough to be noted by the blinded scorer. In this apnea, ECG artifact in the CW-EMG signal is more prominent than in **Figure 1** and made recognition of inspiratory bursts more difficult.

DISCUSSION

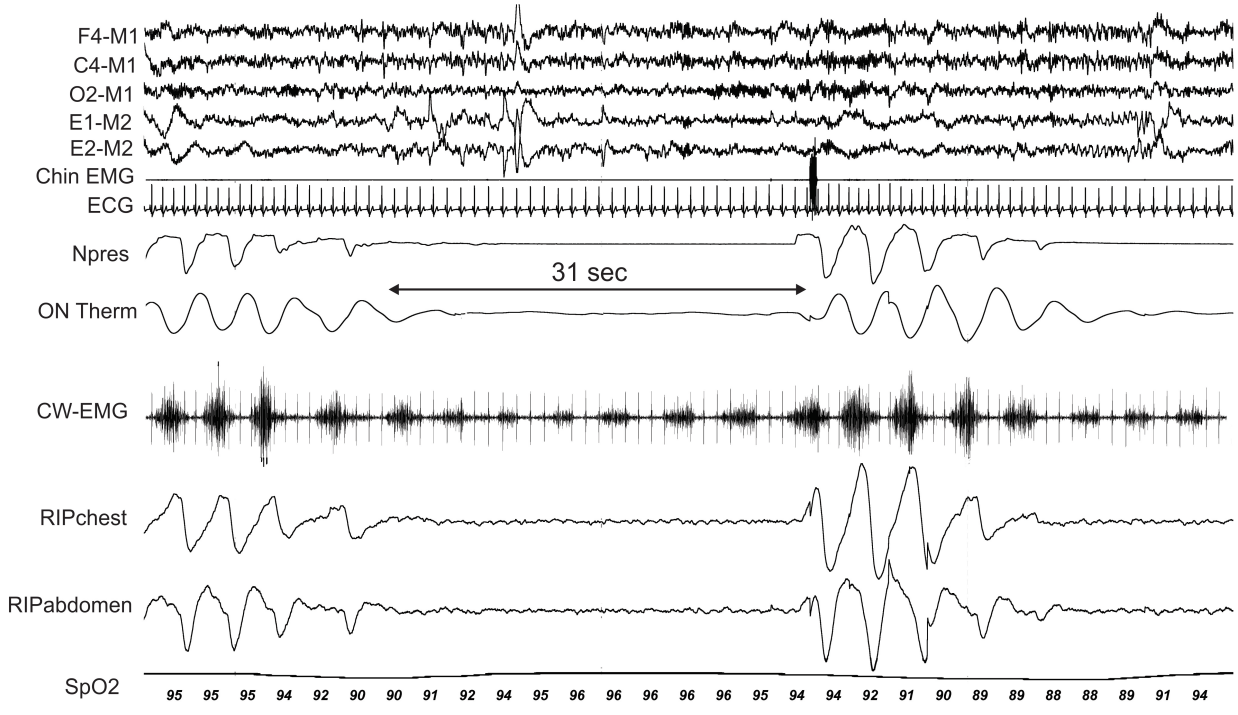
The main findings of this study are (1) that there is a high degree of agreement when apneas are classified by RIP and CW-EMG and (2) a significant number of events classified as central apneas by RIP were classified as obstructive by CW-EMG. Thus, use of the relatively simple CW-EMG technique can avoid false classification of apneas as central. However, CW-EMG also classified some events as central apneas that were classified as obstructive based on RIP. It appears that a

Table 2—Agreement table for apnea classification.

		CW-EMG			
		OA	MA	CA	
RIP	OA	225	8	7	240
	MA	9	96	6	111
	CA	26	7	216	249
		260	111	229	600

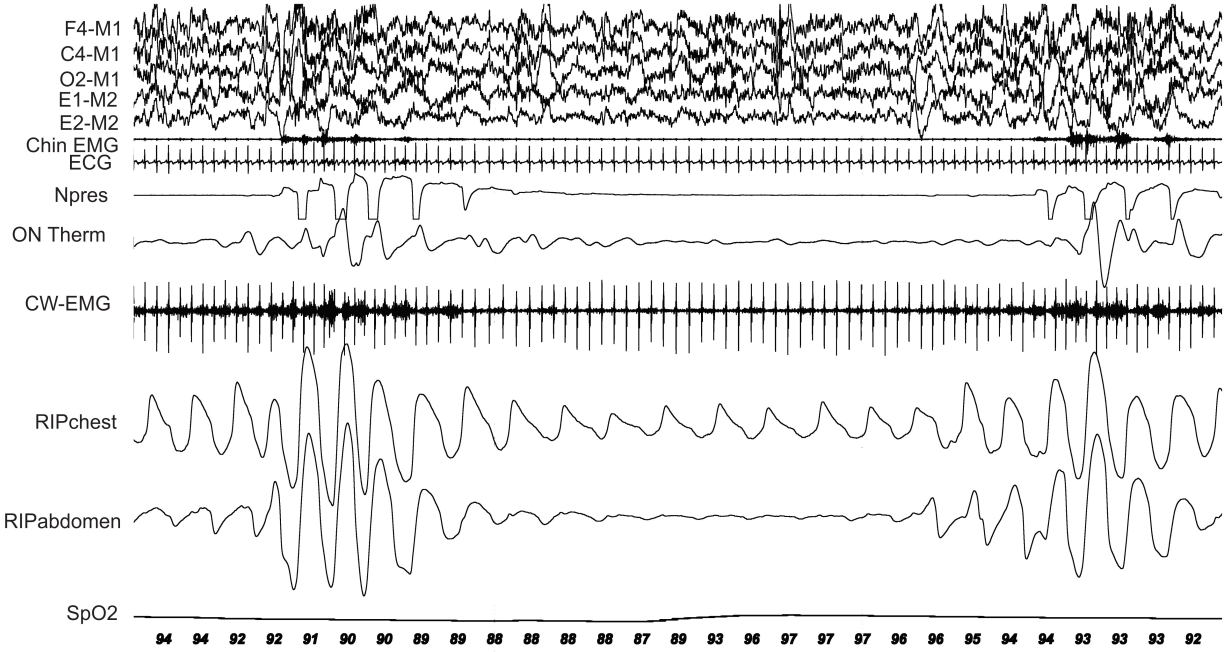
CA, central apnea; CW-EMG, chest wall electromyography (surface EMG signal); MA, mixed; OA, obstructive; RIP, respiratory inductance plethysmography.

Figure 1—The depicted apnea would appear to be central based on the RIP signals but is in fact obstructive.



Note the inspiratory bursts in the chest wall EMG (CW-EMG) tracing. Here ON Them is oronasal thermal sensor flow and Npres is the nasal pressure flow signal. This is a tracing of REM sleep showing that CW-EMG activity is noted during REM sleep using the electrode placement used in this study.

Figure 2—The apnea shown is clearly obstructive based on RIP tracings.



The event was scored as central by the blinded scorer based on the CW-EMG signal. There are very small EMG bursts that were missed by the scorer. The prominent ECG artifact (compare with Figure 1) likely contributed to the difficulty in recognizing the bursts.

combination of the two methods will result in the most accurate classification of respiratory events. That is, the methods are complementary.

Our study has a number of limitations. First, we did not compare CW-EMG with a gold standard (esophageal manometry). We were able to evaluate a large number of patients in whom CW-EMG was placed as part of routine clinical care using a method that would be practical during clinical PSG. It could be argued that the presence of unequivocal inspiratory EMG bursts is strong evidence for the obstructive nature of events. However, we cannot eliminate the possibility that apneas classified as central by both CW-EMG and RIP methods were in fact obstructive.

Luo et al.[6] used both esophageal pressure and diaphragmatic EMG recorded using a multipair esophageal electrode to detect the absence of respiratory effort during apnea. About one-third of the central events as assessed by RIP were not central using esophageal pressure deflections and diaphragmatic EMG. There was no difference in the number of central events diagnosed by esophageal pressure and diaphragmatic EMG. In our study we used surface EMG monitoring because use of an esophageal electrode would not be practical for routine clinical monitoring. Stoohs and coworkers[8] compared esophageal manometry and surface diaphragmatic EMG in patients with obstructive sleep apnea. The ECG artifact in the EMG signal was minimized by a gating technique, the signal was rectified, and a moving time average was determined. During obstructive events, changes in the EMG signal closely tracked the esophageal pressure signal in most patients. Over the course of the obstructive events the increase in esophageal pressure deflections and the EMG signal were similar as a percentage of baseline. This suggests that the surface EMG signal is an acceptable surrogate for esophageal pressure deflections to detect respiratory effort. However, it is possible that use of esophageal manometry in our study would have detected respiratory effort in some apneas classified as central by both RIP and CW-EMG signals.

Another limitation of our study was the retrospective nature. Although we identified consecutive patients meeting our study selection criteria, the retrospective nature may have affected our results. In addition, we eliminated studies in which the RIP and/or CW-EMG signals were not adequate. There was no special protocol for changing electrode placement if the CW-EMG signal did not show inspiratory bursts with normal breathing. In addition, because these were routine clinical studies, the CW-EMG electrodes were not replaced if all other signals were satisfactory and the patient was asleep. It should be noted that 19 of the first 79 studies otherwise meeting selection criteria for analysis did not have technically adequate CW-EMG signals. Inability to record an adequate signal is a limitation of the CW-EMG method. A prospective study with a systematic approach to verifying proper electrode placement and replacement of electrodes as needed during the study is needed to determine the frequency of this issue.

We analyzed apnea classification but did not analyze the usefulness of the CW-EMG signal in the identification of hypopneas or the classification of hypopneas as obstructive or central.[1,3] In many of our subjects there was an augmentation of the inspiratory EMG burst during apnea. As noted previously, in a study by Stoohs and coworkers,[8] processing the surface EMG by a gating technique to eliminate ECG artifact followed by rectification and integration produced a signal

that correlated with esophageal pressure deflections. Such a transformed CW-EMG signal would be useful for estimating the magnitude of respiratory effort during periods of reduced airflow. However, classification of hypopneas as obstructive or central would also require some measure of the relationship between flow and the magnitude of respiratory effort.[14] In research studies, airflow is usually measured with a pneumotachograph in a mask covering the nose and mouth. In clinical studies, the nasal pressure signal (often with square root transformation) provides a useful semiquantitative measurement of airflow. However, the accuracy of the nasal cannula to estimate airflow can vary during the night (nasal cannula displacement) and periods of mouth breathing further reduce the ability to accurately estimate flow.[15] Optimal evaluation of the ability of the CW-EMG signal to definitively classify hypopneas as obstructive or central requires different methods than used in routine clinical studies. Given the aforementioned issues we chose to analyze the ability of CW-EMG to classify apneas but not hypopneas using routine clinical methodology.

We concede that because many patients have predominantly hypopneas, this limits the relevance of the findings of the current study for routine clinical practice. However, in patients with a significant number of putative apneas, monitoring the CW-EMG is potentially useful. For example, in the 11 patients in whom apneas were classified as central by RIP and obstructive by CW-EMG, with analysis of all events by a scorer blinded to either RIP or CW-EMG signals, the average number of central apneas decreased from 18.8 ± 14.1 to 4.4 ± 8.8 events ($p < 0.01$) using CW-EMG.

A significant limitation of the surface CW-EMG method is the problem of ECG artifact. In some of the sleep studies we evaluated, significant ECG artifact made detection of inspiratory bursts challenging. We placed electrodes on the right side in an attempt to reduce this problem. We also noted that the magnitude of the artifact can be reduced by use of a low filter (high-pass filter) of 25 Hz. Some PSG systems have the ability to remove ECG artifact from EMG signals. Our system did not have this ability but we found that use of a 25-Hz low filter did reduce the artifact to an acceptable level in most patients. However, this filter option is not present on all PSG systems. Using the 25-Hz filter also tends to reduce the magnitude of inspiratory bursts. A better approach would be reduction of the artifact by computational or blanking techniques.[16,17]

In summary, recording of CW-EMG using methods similar to those routinely used to record chin and anterior tibial EMG was clinically useful for classification of apnea in our patients. There was a high degree of agreement with RIP effort belt signals. The CW-EMG signal also prevented the false classification of a significant number of apneas as central (based on RIP belts). However, esophageal manometry is the gold standard and both methods may potentially misclassify apneas as central. We propose that monitoring of CW-EMG signal may provide a useful complement to RIP signals for classification of apneas during clinical PSG. Prospective evaluation in a larger group of patients with analysis of hypopneas as well as apneas is needed to establish the clinical utility of this approach.

ABBREVIATIONS

AHI, apnea-hypopnea index
BMI, body mass index
CW-EMG, chest wall EMG
ECG, electrocardiographic
OSA, obstructive sleep apnea
PAP, positive airway pressure
RIP, respiratory inductance plethysmography

REFERENCES

1. Berry RB, Brooks R, Gamaldo CE, et al.; for the American Academy of Sleep Medicine. The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, Version 2.2. www.aasmnet.org. Darien, IL: American Academy of Sleep Medicine, 2015.
2. Iber C, Ancoli-Israel S, Chesson AL Jr, Quan SF; for the American Academy of Sleep Medicine. The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, 1st ed. Westchester, IL: American Academy of Sleep Medicine, 2007.
3. Berry RB, Budhiraja R, Gottlieb DJ, Gozal D, 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;8:597–619.
4. Vandenbussche NL, Overeem S, van Dijk JP, Simons PJ, Pevernagie DA. Assessment of respiratory effort during sleep: esophageal pressure versus noninvasive monitoring techniques. Sleep Med Rev 2015;24:28–36.
5. Staats BA, Bonekat HW, Harris CD, Offord KP. Chest wall motion in sleep apnea. Am Rev Respir Dis 1984;130:59–63.
6. Luo YM, Tang J, Jolley C, et al. Distinguishing obstructive from central sleep apnea events: diaphragm electromyogram and esophageal pressure compared. Chest 2009;135:1133–41.
7. White JE, Drinnan MJ, Smithson AJ, Griffiths CJ, Gibson GJ. Respiratory muscle activity during rapid eye movement (REM) sleep in patients with chronic obstructive pulmonary disease. Thorax 1995;50:376–82.
8. Stoohs RA, Blum HC, Knaack L, Butsch-von-der-Heydt B, Guilleminault C. Comparison of pleural pressure and transcutaneous diaphragmatic electromyogram in obstructive sleep apnea syndrome. Sleep 2005;28:321–9.
9. Gauda EB, Miller MJ, Carlo WA, DiFiore JM, Martin RJ. Genioglossus and diaphragm activity during obstructive apnea and airway occlusion in infants. Pediatr Res 1989;26:583–7.
10. Praud JP, D'Allest AM, Delaperche MF, Bobin S, Gaultier C. Diaphragmatic and genioglossus electromyographic activity at the onset and at the end of obstructive apnea in children with obstructive sleep apnea syndrome. Pediatr Res 1988;23:1–4.
11. Worsnop C, Kay A, Pierce R, Kim Y, Trinder J. Activity of respiratory pump and upper airway muscles during sleep onset. J Appl Physiol 1998;85:908–20.
12. Reilly CC, Jolley CJ, Elston C, Moxham J, Rafferty GF. Measurement of parasternal intercostal electromyogram during an infective exacerbation in patients with cystic fibrosis Eur Respir J 2012;40:977–81.
13. Verin E, Straus C, Demoule A, et al. Validation of improved recording site to measure phrenic conduction from surface electrodes in humans. J Appl Physiol 2002;92:967–74.
14. Mooney AM, Abounasr KK, Rapoport DM, Ayappa I. Relative prolongation of inspiratory time predicts high versus low resistance categorization of hypopneas. J Clin Sleep Med 2012;8:177–85.
15. Thurnheer R, Xie X, Block KE. Accuracy of nasal cannula pressure recordings for assessment of ventilation during sleep. Am J Respir Crit Care Med 2001;164:1914–9.
16. Abbaspour S, Fallah A. Removing ECG Artifact from the surface EMG signal using adaptive subtraction technique. J Biomed Phys Eng 2014;4:33–8.
17. Willigenburg NW, Daffertshofer A, Kingma I, van Dieën JH. Removing ECG contamination from EMG recordings: a comparison of ICA-based and other filtering procedures. J Electromyogr Kinesiol 2012;22:485–93.

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