Identification of Sleep Bruxism with an Ambulatory Wireless Recording System

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Purpose*:** To examine whether an ambulatory bruxism recording system, including a biologic monitor, that measures sleep variables and sympatho-vagal balance can specifically identify sleep bruxism (SB) at home. ***Materials and Methods: Twenty-six volunteers, including 16 SB subjects, were recruited. Each participant recorded his or her electromyogram (EMG), sympatho-vagal balance, and sound level for 3 consecutive nights using an audio-video recorder to identify SB. Data of sleep variables were compared among the 3 experimental nights. The episodes were classified into SB episodes with and without grinding and non-SB episodes. EMG patterns, amplitude, sympatho-vagal balance, and sound level of all episodes were analyzed so as to determine the appropriate thresholds to detect SB episodes and grinding sound. Then, all episodes without video-recording data were classified into SB and non-SB episodes by using the appropriate thresholds, and the sensitivity and specificity to detect SB episodes were calculated. ***Results*:** With regard to sleep variables, there were no significant differences except for sleep latency between the first and second nights. The appropriate EMG pattern and thresholds of amplitude, sympatho-vagal balance, and sound level were phasic or mixed EMG pattern, 20% of maximum voluntary contraction, mean + 1 SD, and mean + 2 SDs, respectively. The sensitivity and specificity to detect SB episodes were 88.4% and 74.2%, respectively. ***Conclusion*:** The results suggest that this system enables the detection of SB episodes at home with considerably high accuracy and little interference with sleep. *Int J Prosthodont 2013;26:527–535. doi: 10.11607/ijp.3331*

Sleep bruxism (SB) is defined as a stereotyped oromandibular activity during sleep characterized by teeth grinding and clenching. Since SB is known to cause various problems involving the teeth, masticatory muscles, and temporomandibular joints,[2–10] it is important to establish a valid and practical diagnostic method for identifying SB. Although the prevalence of SB is reported to be 5% to 8% of the adult population,[11] this was determined by self-reporting or by a sleep partner's report of tooth grinding. The diagnosis of SB is difficult because many patients are not aware of their own bruxism. Therefore, the reported prevalence is likely underestimated.

Polysomnography (PSG) at a sleep laboratory is considered the most reliable technique for diagnosing SB. PSG can record not only electromyograms (EMGs), but also electroencephalograms (EEGs), electrooculograms (EOGs), nasal air oximetry, and heart rate.[12–15] In addition, an audio-video monitor can differentiate SB from other orofacial activities, such as swallowing, coughing, or body movements.[16] However, PSG requires facilities to accommodate a subject, and repetitive recordings are difficult due to economic and time constraints. In addition, the influence of foreign environments on sleep during PSG recordings has been discussed extensively.[17] Therefore, in most clinical cases, self-reporting and sleep partner's reports or clinical findings, such as tooth wear, hypertrophy of the masseter muscle, pain in the temporomandibular joint, headaches, or fatigue in the masticatory muscles in the morning, have often been used to diagnose SB, although these methods are scientifically unreliable for diagnosis.[18–21]

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Fig 1 Ambulatory wireless bruxism recording system. Center: biologic monitor, right: sound level meter, circle: transmitter.

This clinical situation provides a valid reason for developing a compact but reliable ambulatory recording system of SB. The development of a system that allows subjects to sleep in a natural home environment is valuable, even though the diagnostic power for SB is inferior to PSG. Yamaguchi et al[22–24] have already developed a wireless EMG system and reported that the data obtained using it are highly correlated with PSG data. However, since the subjects of these previous studies were limited to subjects without SB, it is necessary to verify the diagnostic power of these types of ambulatory recording systems for use with SB patients.

Temporal relationships between SB and changes in EEGs and autonomic nervous system activity have been reported. An increase in sympathetic tone was found to be present approximately 4 minutes before the onset of SB. Subsequently, the mean heart rate starts to increase approximately 10 seconds before the onset of SB. An increase in sympathetic activity occurs 4 seconds before the onset of SB, and an increase in heart rate occurs one cardiac cycle before the onset of SB.[14,15,25,26] In the present study, based on these recent findings on physiologic phenomena in regard to SB, the authors focused on the relationship between SB and the change in sympatho-vagal balance before the onset of SB. The sympatho-vagal balance was usually calculated from heart rate fluctuations recorded by ECG. However, it is necessary to tightly affix ECG electrodes to the skin, which may restrict body movement or interfere with sleep. Suzuki et al[27,28] developed a wristwatch-type biologic monitor that could analyze sympatho-vagal balance based on the pulse wave of blood flow in the finger. This monitor is so compact that it can record sympatho-vagal balance at home without interfering with sleep.

A grinding sound is one of the major findings of SB and one of the criteria used to diagnose it, although few studies have been performed to quantify this grinding sound in a natural environment.[29]

Recently, the authors developed an ambulatory bruxism recording system that can simultaneously analyze EMG, sympatho-vagal balance, and the sounds associated with bruxism in a natural home environment. The purpose of the present study was to examine three hypotheses. First, the use of this recording system does not disturb sleep. Second, this recording system can specifically identify SB. Third, this recording system has a high diagnostic power with respect to SB.

Materials and Methods

Subjects

Twenty-six volunteers (12 men, 14 women, aged 24.5 ± 3.3 years) from the Department of Fixed Prosthodontics, Osaka University Graduate School of Dentistry, Osaka, Japan, were recruited. Sixteen subjects (10 men, 6 women, aged 24.7 ± 3.0 years) met the clinical inclusion criteria of SB, which included self-awareness of SB in combination with at least one of the following conditions: *(1)* sounds associated with bruxism reported by a bed partner or family member, *(2)* jaw muscle discomfort upon waking in the morning, and *(3)* abnormal tooth wear.[1] None of the subjects had any medical or psychologic disorders, nor were they undergoing any medical treatment.

The study was approved by the Ethics Committee of Osaka University Graduate School of Dentistry. All subjects signed a consent form.

EMG Measurement System

A newly developed ambulatory wireless recording system (BMS-6012, Harada Electronic Industry) (Fig 1) was used to identify SB. The system includes a receiver unit and a transmitter that records unilateral masseter muscle activity. The transmitter unit with built-in electrodes contains an A/D converter with a sampling frequency of 1 kHz and a frequency passband of 10 to 500 Hz. The telemetric frequencies were 315.00 and 433.92 MHz. The transmitter unit was attached to the center of the cheek skin surface on the unilateral masseter muscle belly by adhesive gel pads and adhesive tape (Elastpore, Nichiban) for stronger fixation.

The antenna of the transmitter unit was fixed to the hair by a clip, and the receiver unit was placed under the pillow. Amplified EMG digital data were transmitted to the receiver unit and stored in a memory card (Compact Flash, 256 MB). The data were later

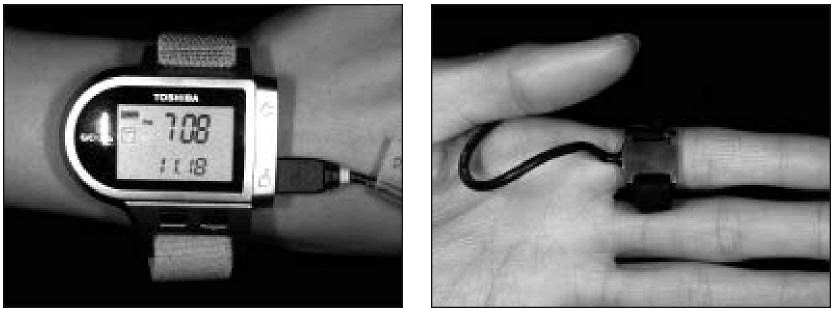

Fig 2 Motion sensor.

transferred to a personal computer and analyzed using a software program equipped with BMS-6012 (EMG Data Receiver, Harada Electronic Industry), an EMG analysis program (Unique Acquisition, Unique Medical), and custom software that was developed by the authors.[30]

Biologic Monitor

A wristwatch-type motion sensor (Toshiba Motion Sensor, NEM-T1, Toshiba) (Fig 2) was used for biologic monitoring. The dimensions of the sensor were 55 × 57 × 14 mm, and the sensor weight was only 35 g. A rechargeable battery was used as an electrical power source. Physiologic data could be measured for over 40 hours on a full electric charge. The pulse wave intervals of blood flow (pulse-to-pulse intervals or PPIs)[31] were recorded and stored by the sensor, which was attached to the tip of the index finger, and the amount of body activities was recorded by a triaxial accelerometer contained in the sensor. The sampling rate of the pulse wave and triaxial accelerometer was 64 Hz. The amount of body activity was calculated as the number by which the scalar of the three-axis acceleration is larger than 0.05 g, which is the same as actigraph.[32] The data were transferred to a personal computer, and the frequency spectrum was calculated from the PPIs using sleep analysis software (NEM-SS1, Toshiba). The integral value of the power from 0.04 to 0.15 Hz was categorized as the low-frequency (LF) signal and that from 0.15 to 0.4 Hz as the high-frequency (HF) signal. The LF/HF ratio was used as an index of the sympatho-vagal balance.

Sound Level Meter

A sound level meter (CENTRE322) (Fig 1) was used to record the level of grinding noise beside a pillow. The measurement range was 30 to 130 dB and the resolution was 0.1 dB. The sampling rate was 1 Hz.

Video Recorder

A digital video recorder (HDR-CX550V, Sony) equipped with an infrared camera was used to record facial and body movements and sound for a definitive diagnosis of SB. Each subject personally set up the recorder beside the bed to record upper body movement. In this study, the data obtained from the video recorder were regarded as the gold standard for identifying SB.

Recording Procedure

Subjects were told to use the recording system at home following the instructions provided on an explanatory leaflet that described in detail the procedure and how to set up the system and record data for 3 consecutive nights.

On the first night, subjects wore only the motion sensor to record the baseline data of sleep variables: sleep efficiency, sleep latency, number of awakenings, and number of body movements. On the second and third nights, in addition to wearing the motion sensor, the masseter muscle EMG activity and the sound level were recorded. Video recording was also performed, and the subjects wore eye masks while sleeping to protect their privacy. Only the EMG data recorded on the third night were used for analysis.

The subjects were also required to fill out a five-point scale questionnaire after each recording. The questionnaire asked: *(1)* How well did you sleep?, *(2)* How difficult is it to set up the system?, and *(3)* Did you mind wearing the system while you slept? The questionnaire responses were evaluated as follows. For question no. 1, “very well” was assigned five points and “terrible” was assigned one point. For question no. 2, “very easy” was assigned five points and “very difficult” was assigned one point. For question no. 3, “never” was assigned five points and “very much” was assigned one point.

Subjects refrained from consuming alcohol or caffeine during the 3 nights of the evaluation.

Synchronization of Devices

To synchronize signals between devices correctly, each subject was instructed to strictly follow the recording procedure and had to practice synchronizing the devices before starting the actual recordings by research staff.

The motion sensor and sound level meter have built-in clocks, which had been accurately adjusted prior to the experiment. Therefore, data obtained from the two recording devices were synchronized completely according to the built-in clocks. Since the EMG device had no built-in clock, each subject was instructed to clench his/her teeth as strongly and quickly as possible at a certain time setting (eg, 12 o'clock midnight) by the radio or television time signal after he/she set up the recording system and started all devices for data recording. The onset of EMG burst recorded by clenching was used to synchronize EMG data obtained from other devices.

Analysis

Influence on sleep. For 26 subjects, sleep variables and the questionnaire data were evaluated, and the mean score for each question was calculated. The data were statistically compared among the 3 experimental nights.

EMG patterns. For 16 subjects who were clinically diagnosed as bruxism subjects, EMG activity with 10% or more of maximum voluntary contraction (MVC) sustained for 0.25 seconds or more were manually selected as EMG bursts. These bursts were further classified into SB episodes with or without grinding sound and non-SB episodes based on the audio-video recording data. All episodes were further classified into three EMG patterns: *(1)* phasic type (three or more EMG bursts, each lasting 0.25 to 2.0 seconds), *(2)* tonic type (one EMG burst lasting longer than 2.0 seconds), and *(3)* mixed type (both types of bursts).[12,13] The rate of SB and non-SB episodes in each EMG pattern was calculated. Episodes including artifacts were excluded from the analysis.

EMG amplitudes. All EMG bursts in episodes with phasic or mixed type were classified into 10% to 15%, 15% to 20%, 20% to 25%, 25% to 30%, 30% to 35%, 35% to 40%, 40% to 45%, 45% to 50%, and over 50% of MVC. The rate of bursts in SB episodes in each category and the sensitivity and specificity to detect bursts in SB episodes in each category were calculated.

Sympatho-vagal balance. Episodes with 20% or more of MVC were analyzed. First, the mean LF/HF ratio for 5 minutes before the onset of SB and non-SB episodes was calculated every minute and compared with the mean LF/HF ratio at the onset of episodes individually. Second, the mean LF/HF ratios 5 minutes before and after episodes were calculated and compared not only with the mean LF/HF ratio at the onset of episodes, but also between SB and non-SB episodes.

In addition, the LH/HF ratios were calculated at 1, 2, 3, 4, and 5 minutes before the onset of SB episodes. Next, the mean, the mean with 1 SD, the mean with 2 SDs, and the mean with 3 SDs of these LF/HF ratios were further calculated to draw a receiver operating characteristic (ROC) curve. The ROC curve was used to determine the most appropriate LH/HF ratio for detecting SB episodes.

Sound level. Sound levels from 11 subjects who had SB with grinding were analyzed. The mean sound levels during episodes of SB with grinding, SB without grinding, and non-SB, in addition to the overall mean level, were compared.

Accuracy for detecting SB episodes. The accuracy for detecting SB episodes using the recording system was calculated as follows. First, episodes with both phasic or mixed EMG patterns and an EMG amplitude of at least 20% MVC were regarded as SB episodes. The sensitivity and specificity when detecting SB episodes with only EMG data were first calculated when the audio-video recording data were regarded as the gold standard.

Second, to improve the accuracy for detecting SB, the sensitivity and specificity when detecting SB episodes with both thresholds of EMG stated above and sympatho-vagal balance (mean + 1 SD LF/HF ratio 5 minutes before the SB onset) were then calculated.

SB episodes with a mean sound level of at least the overall mean + 2 SD among true positive SB episodes were regarded as SB with grinding, and the sensitivity and specificity for detecting SB with grinding noise using this threshold were calculated.

Finally, the accuracy using these thresholds to detect SB was validated using an ROC curve.

Statistical Analysis

Sleep efficiency, sleep latency, the number of awakenings during sleep, and the responses to the questionnaire were compared among 3 experimental nights using the Dunnett test. The sensitivity and specificity for detecting SB were calculated, and an ROC curve[33] was used to confirm the appropriate threshold to detect SB. The mean LF/HF ratios were compared using

Table 1 Comparison of Sleep Variables Among 3 Experimental Nights*

	First night	Second night	Third night	*P*
Sleep efficiency (%)	98.96 ± 1.54	98.88 ± 1.58	98.57 ± 3.06	.797
Sleep latency (min/night)	4.64 ± 2.87	7.15 ± 2.66	5.65 ± 2.52	.003
No. of awakenings during sleep (times/night)	4.80 ± 7.50	3.65 ± 5.25	5.04 ± 11.11	.714

*Dunnett test, n = 26.

Table 2 Comparison of Scores in Questionnaires Among 3 Experimental Nights*

Question no.	First night	Second night	Third night	*P*
1	3.03 ± 0.94	3.14 ± 0.92	3.17 ± 1.00	.85
2	4.62 ± 0.49	4.38 ± 0.56	4.48 ± 0.51	.22
3	4.28 ± 0.59	4.07 ± 0.65	4.17 ± 0.66	.47

*Dunnett test, n = 26.

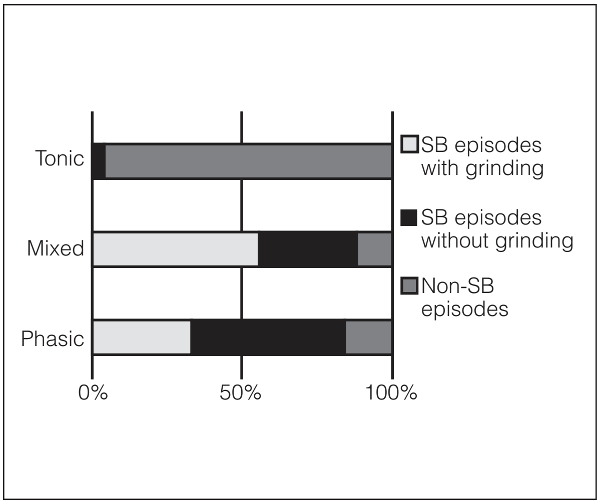

Fig 3 Proportion of SB episodes with grinding, SB episodes without grinding, and non-SB episodes for three EMG patterns.

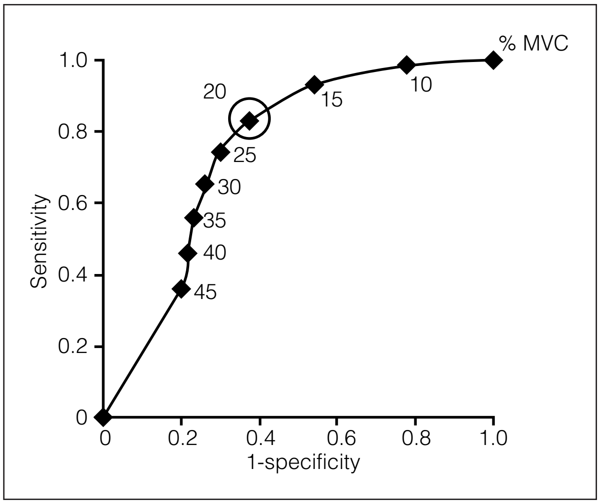

Fig 4 ROC curve for the EMG threshold to detect bursts in SB episodes. The ROC curve revealed that the appropriate threshold for detecting bursts in SB episodes was 20% of MVC (*circle*).

a Friedman test and a post hoc Wilcoxon test. Sound levels among SB episodes were compared using the Tukey test. A *P* value of less than .05 was deemed statistically significant using SPSS statistics version 17 (IBM).

Results

Influence on Sleep

With regard to sleep efficiency, sleep latency, and the number of awakenings during sleep, there were no significant differences between the first night and the second or third nights, except for the sleep latency between the first and second nights (Table 1). There were no significant differences in the questionnaire responses among the three experimental nights (Table 2).

EMG Patterns

In the tonic EMG pattern, the percentage of SB episodes without grinding was less than 5%, and the percentage of non-SB episodes was more than 95%. SB episodes with grinding were not found in tonic EMG patterns. In mixed EMG patterns, the percentage of SB episodes with and without grinding was more than 85%. The vast majority of phasic EMG patterns were also SB episodes with and without grinding (more than 80%) (Fig 3).

EMG Amplitudes

The sensitivity and specificity to detect bursts in SB episodes, when 20% of MVC was used as the EMG threshold, was 83.0% and 64.2%, respectively. The

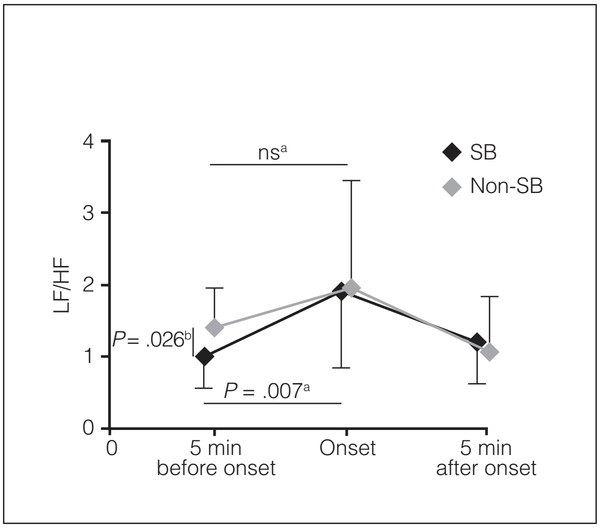

Fig 5 Sympatho-vagal balances (LF/HF ratio) 5 minutes before onset, at onset, and 5 minutes after onset of SB and non-SB episodes. **(a)** Friedman test, Wilcoxon test, **(b)** Wilcoxon test, α = .05, n = 16.

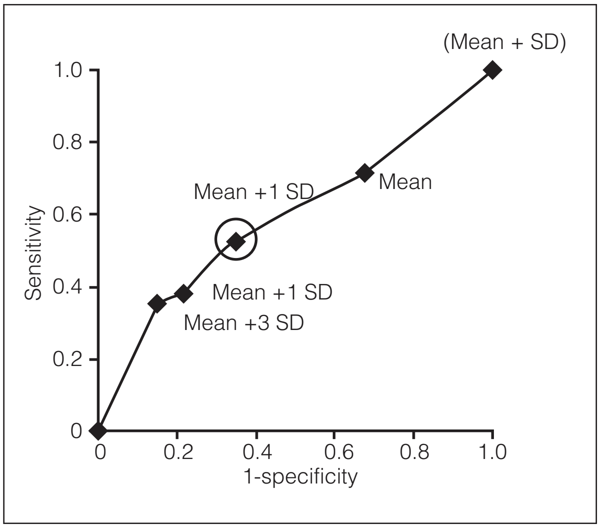

Fig 6 ROC curve for the threshold of sympatho-vagal balance (LF/HF ratio) to detect SB episodes. The mean + 1 SD LF/HF ratio 5 minutes before the onset of SB was the most appropriate for detecting SB episodes (*circle*).

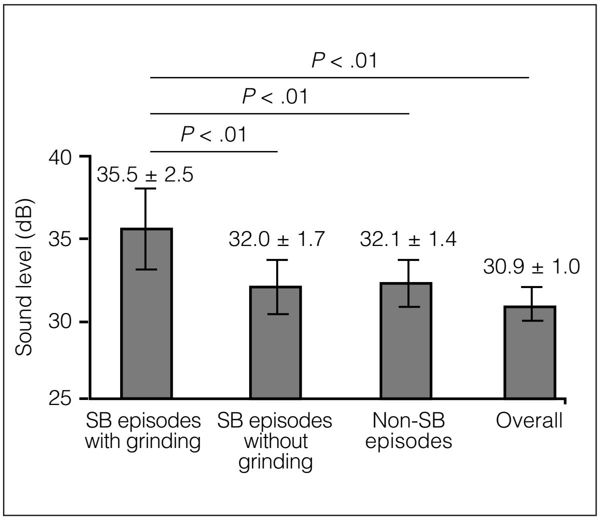

Fig 7 Mean sound levels of SB episodes with and without grinding, non-SB episodes, and overall.

ROC curve revealed that the appropriate threshold EMG amplitude for detecting bursts in SB episodes was 20% of MVC (Fig 4).

Sympatho-vagal Balance

The mean LF/HF ratios for 4 to 5, 3 to 4, 2 to 3, and 1 to 2 minutes before the onset of SB episodes were significantly lower than the ratio at SB onset ($P \leq .003$), whereas the mean LF/HF ratios for 4 to 5, 3 to 4, 2 to 3, and 1 to 2 minutes before the onset of non-SB episodes were not significantly different from the ratio at SB onset.

The mean LF/HF ratio for 5 minutes before the onset of SB episodes was significantly lower than that at SB onset ($P = .007$) (Fig 5). There were no significant differences in the mean LF/HF ratios for 5 minutes before SB onset, at onset, and 5 minutes after onset in non-SB episodes (Fig 5). The mean LF/HF ratio for 5 minutes before the onset of SB episodes was significantly lower than that for 5 minutes before the onset of non-SB episodes ($P = .026$) (Fig 5).

The ROC curve indicated that the mean + 1 SD LF/HF ratio for 5 minutes before the onset of SB episodes was the most appropriate for detecting SB episodes (Fig 6).

Sound Level

The mean ± SD sound levels during SB episodes with grinding, SB episodes without grinding, non-SB episodes, and overall were 35.5 ± 2.5 dB, 32.0 ± 1.7 dB, 32.1 ± 1.7 dB, and 30.9 ± 1.0 dB, respectively. The sound level was significantly higher in SB episodes with grinding than in the other episodes ($P < .01$) (Fig 7). The sound was detected even in SB episodes without grinding because SB was often accompanied with body movements such as turning over or sleep talking and a sound level meter picked up the noise derived from bedclothes and voice during the duration of SB episode analysis.

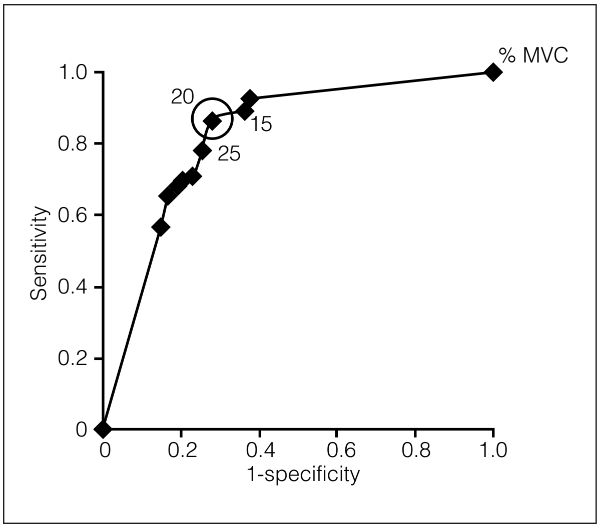

Fig 8 ROC curve to confirm the appropriate EMG threshold for detecting SB episodes. Here, 20% of MVC was confirmed to be most appropriate for detecting SB episodes with phasic or mixed patterns of EMG when the mean + 1 SD LF/HF ratio 5 minutes before the onset of SB episodes was used as a threshold of sympatho-vagal balance (*circle*).

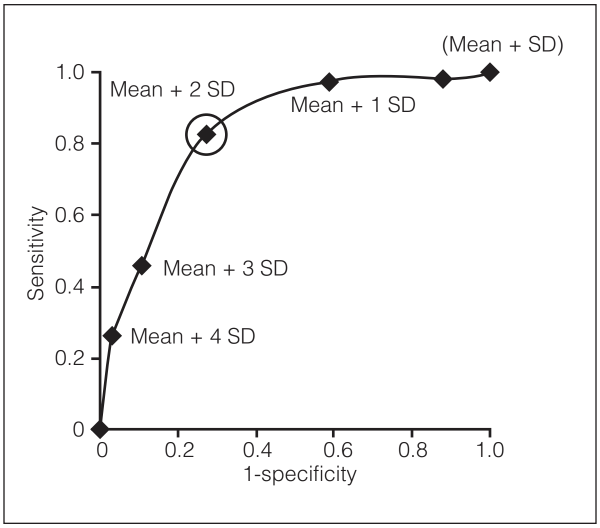

Fig 9 ROC curve to confirm the appropriate threshold of sound level for detecting SB episodes with grinding. The mean + 2 SDs of sound level was the most appropriate threshold for detecting SB episodes with grinding (*circle*).

Accuracy for Detecting SB Episodes

The sensitivity and specificity for detecting SB episodes with phasic and mixed EMG bursts only, when 20% MVC was used as the threshold EMG amplitude, were 90.8% and 67.4%, respectively.

The sensitivity and specificity for detecting SB episodes with thresholds of both EMG and sympatho-vagal balance, when the mean + 1 SD LF/HF ratio 5 minutes before the onset of SB episodes was used as a threshold of sympatho-vagal balance, were 88.4% and 74.2%, respectively.

The sensitivity and specificity for detecting SB episodes with grinding, when the overall mean + 2 SD was used as a threshold sound level, were 82.2% and 71.9%, respectively.

The ROC curve showed that both threshold EMG amplitude and sound level were appropriate for detecting SB episodes or SB episodes with grinding (Figs 8 and 9).

Discussion

Recent reports[22–24] have shown that the wireless EMG device used in the present study had sufficient faculties to detect rhythmic masseter muscle activity (RMMA) only in normal subjects. Ikeda et al[34] reported an algorithm to specifically detect SB episodes using EMG and heart rate variability from ECG. However, since the device developed in their study requires electrical cords to connect it to the body, the device may extract artifacts caused by body movement or may interfere with natural sleep.

In the present study, the detecting power of SB episodes at home was verified using a wireless EMG device, a wristwatch-type biologic monitor, and a sound level meter, together with an audio-video recorder, which is considered to be a gold standard device for detecting SB episodes. Since the masseter muscle EMG activities include activities derived from not only SB episodes but also non-SB episodes, such as clenching, sleep talking, or RMMA without teeth contact, the biologic data obtained from a biologic monitor and a sound level meter were used to effectively remove EMG activities of those non-SB episodes from all EMG data collected.

The results shown in Tables 1 and 2 suggest that the ambulatory wireless bruxism recording system enables the system to be set up by the subject in a natural home environment and records data with little interference with sleep.

The data regarding sleep quality were calculated based on Cole's algorithm for wake/sleep identification from the amount of body activity.[32] It was reported that the accuracy of wake/sleep identification was dependent upon age.[35] Therefore, it was difficult to identify the precise wake/sleep cycle using only a biologic monitor. In the present study, the effect of age on wake/sleep identification was slight because the ages of the subjects were similar (24.5 ± 3.3 years). It has been suggested that sleep quality is affected when the sleeping environment is changed with electrodes and other recording devices on the first night of recording, called the first night effect. It appeared from the first night effect that the sleep latency at the second night was significantly longer than others.

The vast majority of SB episodes were found to be phasic or mixed EMG patterns. When the EMG amplitude of 20% MVC was adopted as a threshold for detecting SB episodes from these two EMG patterns, the sensitivity was high (90.8%), but the specificity was not as high (67.4%). For clinical use, a higher specificity appears to be necessary. The results of the biologic monitor indicated that the mean LF/HF ratio was significantly higher for 5 minutes before the onset of SB episodes than at SB onset, whereas there were no significant differences in non-SB episodes. Previous reports revealed a change in sympatho-vagal balance 4 minutes before the onset of SB episodes,[15] but the sympatho-vagal balance around the onset of non-SB episodes has not been verified.

The sensitivity for detecting SB episodes using thresholds of both EMG and sympatho-vagal balance decreased slightly from 90.8% to 88.4%, while the specificity increased considerably from 67.4% to 74.2%. These results suggest that the sympatho-vagal balance could be a valuable parameter for detecting SB episodes, even though approximately one-fourth of all non-SB episodes were still regarded as SB episodes.

Sound level is also valuable for detecting SB with grinding. In the present study, the sensitivity and specificity for detecting SB with grinding using the episodes with a sound level of at least an overall mean + 2 SDs as the threshold level were 82.2% and 71.9%, respectively, suggesting that quantitative evaluation of the sound level enabled the detection of SB with grinding without audio-video recording, even though the sound level varied depending on, for example, sleep habits, sleep coverings, weather, season, and location.

Audio-visual recording of jaw movement and oromandibular activities with a video recorder are likely to be the most definitive method of diagnosing SB, but many subjects are adverse to having their sleeping appearance recorded on video. Therefore, the authors do not wish to include a video recorder in their system. Moreover, the labor for examining hours of video recording is costly. So, a simpler and more economical procedure of patients recording SB by themselves for a long time was desirable, especially for a large group of subjects, since SB has day-to-day variation.

The present study was not a randomized controlled trial. The analyzing procedure was complicated, and only young subjects participated. Although it is necessary to overcome these limitations in further studies, it can be expected that the system introduced in the present study would be a convenient device for detecting SB episodes with high accuracy in the natural home environment.

Conclusion

The results of the present study suggest that an ambulatory wireless bruxism recording system including a biologic monitor enables the detection of SB and SB with grinding from EMG, sympatho-vagal balance, and sound data during sleep at home with considerably high accuracy and little interference with sleep.

Acknowledgment

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