# Criteria for the Detection of Sleep-Associated Bruxism in Humans

**Takashi Ikeda, DDS, PhD**
Assistant Professor
Department of Fixed Prosthodontics

**Keisuke Nishigawa, DDS, PhD**
Assistant Professor
Department of Fixed Prosthodontics

Tokushima University
School of Dentistry
Tokushima, Japan

**Kazuo Kondo, DDS, PhD**
Private Practice
Ehime, Japan
and Visiting Scholar (1989–1991)
University of California, Los Angeles
Los Angeles, California

**Hisahiro Takeuchi, DDS, PhD**
Assistant Professor
Department of Fixed Prosthodontics
Tokushima University
School of Dentistry
Tokushima, Japan

**Glenn T. Clark, DDS, MS**
Associate Dean of Research,
Professor, and Chair
University of California, Los Angeles
School of Dentistry, Diagnostic
Sciences and Orofacial Pain
Los Angeles, California

**Correspondence to:**
Dr Glenn T. Clark
43–009A Center for Health Science
10833 Le Conte Avenue
Los Angeles, California 90095–1668

*Surface electromyography of the masseter and electrocardiogram recordings of heart activity during sleep were performed on nine subjects who suffer from an oral motor dysfunction (bruxism) during sleep. Signals were monitored in the subject's home sleeping environment over 4 consecutive nights. A total of 36 nights of data were analyzed to perform the following:* (1) *describe the nature and magnitude of total masseter muscle electromyographic activity above a minimum threshold of 3% of each subject's individually established maximum voluntary contraction level; and* (2) *describe electrocardiograph rate changes (using the R-R interval) that occurred in relation to these electromyographic elevations. From these data, criteria for detection of bruxism events were established and combined into a fully automated event detection algorithm. The mean number and duration of the detected bruxism events are reported. The underlying logic for the criteria selected, and what effect other possible criteria would have on the separation of abnormal from normal motor events, is also presented and discussed.*

J OROFACIAL PAIN 1996;10:270–282.

**key words:** bruxism, detection criteria, sleep, masseter muscle, electromyography

In the past, sleep-associated bruxism was studied with polysomnographic methods (including surface electromyography tracing from the jaw elevator muscles). The presence or absence of bruxism and its frequency were determined from these recordings using a combination of the amplitude and pattern of the electromyographic (EMG) tracing recorded from the masseter or temporalis muscle. Over the years, such polysomnographic recordings have adequately described the general characteristics and nature of bruxism. Unfortunately, however, these visual assessment methods do not lend themselves to reliable quantification of the behavior.

What is known about bruxism currently is that the jaw elevator muscles commonly exhibit two basic patterns of activity: rhythmic, chewinglike movements; and prolonged, strong isotonic contractions.[1] The total duration of bruxism per night is approximately 10 minutes in patients with clinically obvious signs of bruxism (eg, attrition).[2,3] It has also been reported that most bruxism episodes appear during stage 1 and stage 2 sleep.[1,4] In addition, bruxism occurs frequently during partial sleep arousal (when sleep moves from a deeper to a lighter stage).[5] Some bruxism episodes have been reported to be accompanied with increased heart and respiratory rates.[3,5,6]

Bruxism has been described in the literature since the turn of the century. Until the arrival of multichannel sleep laboratory studies in the 1950s, however, the actual behavior of bruxism had not been measured. In the 1970s, portable EMG recording devices were developed by Rugh and colleagues[7,9] to record masseter muscle activity in the subject's home environment. Rugh's device provided cumulative totals of nightly electrical activity above 20 μV and allowed new and important data about the levels of masseter muscle activity to be gathered in the patient's usual sleeping environment. Most of the studies using Rugh's portable EMG device used a 20-μV threshold to prevent recording of minor masseter contractions presumed to be not significant in clenching and grinding. Clark and colleagues[10–13] utilized Rugh's portable EMG recorder in various studies that recorded the bruxism levels in patients and evaluated the effect of an audio alarm method for suppression of the bruxism response. In general, these single-channel EMG-based home measurement systems have helped achieve a greater understanding of bruxism. The disadvantages of this method are that second-by-second levels of bruxism are not available for study, and correlation between motor activity and sleep stage level is not possible. In 1981, Wagner[14] developed another single-channel EMG home-based recording system. Wagner's system involved an EMG amplifier, filter, and integrator; unlike Rugh's portable cumulative EMG recording system, it defined bruxism as activity greater than 5 μV (integral average). Wagner also determined that 3 seconds of quiescent EMG recording was required to tally separate bruxing episodes. Summary scores of bruxism levels per night were available from Wagner's data.

In 1982, Piccione and colleagues[15] defined bruxing events using masseter EMG amplitude, rhythmicity, and duration criteria from a polygraphic recording. They proposed that a bruxism event was present only if the EMG amplitude exceeded 20 μV. Further, the EMG had to rise above this level for no less than 0.5 seconds and no longer than 1.5 seconds to be a bruxism event. They also required that bruxism events occur in a series of two or more rhythmic contractions separated by no more than 2.5 seconds. Piccione and colleagues did not score any prolonged EMG elevations (> 1.5 seconds) nor were solitary elevations scored as bruxism. In 1983, Stock and Clarke'[6] described a bruxism detection system that consisted of a battery-operated analog EMG device, an optoisolater, an analog-to-digital (A/D) converter, a microprocessor, and a cassette tape recorder. Bruxism events were selected automatically by the device if they satisfied three criteria: *(1)* EMG elevations had to be more than the fourth least significant bit of an 8-bit amplifier whose gain was adjusted to not trigger with ordinary orofacial movements; *(2)* duration of EMG elevations should be greater than or equal to 2 seconds; and *(3)* gaps of 1 second or less between the elevations were joined and considered a single event.

In 1988, using yet another set of criteria, Ware and Rugh[2] compared the amount and topography of bruxing events in various sleep stages during 1 night of sleep across three groups of patients. An episode was scored as bruxism if it met the following four criteria: *(1)* the EMG signal was seen as an artifact on the electroencephalogram (EEG) tracing; *(2)* it was greater than 75 μV or it was twice the background activity; *(3)* the phasic events were repetitive with two or more discrete bursts; and *(4)* the phasic events lasted more than 0.25 seconds. During the scoring, bruxism duration was measured, and the number of discrete (phasic) bursts were counted. In 1990, Okeson et al[17] defined and detected a bruxing event if activity of the masseter muscle exceeded 40% of its maximum clench and lasted 2 or more seconds. In 1992, Velly Miguel et al[18] adopted these same criteria.

Although these previous studies have allowed the development of better ideas about the nature of bruxism, it is clear that quite different criteria are used to measure the level of bruxism (Table 1). If research about the nature of bruxism is to continue, a standard set of criteria for what constitutes a bruxism event needs to be established. In addition, regardless of whether these recordings are performed in a sleep laboratory or in the subject's home environment, most researchers suggest that the recording technique involve the collection of several consecutive nights of data because of its variable nature. Because the technology is now within reach, the recorded data should be scored using a semiautomated or fully automated computer method to reduce measurement error and speed up the analysis. In the past, the polygraphic records of bruxism have been scored by an expert using visual analysis methodology. Although it is somewhat tedious to score a typical 7-hour sleep tracing by hand, it requires no sophisticated equipment, and artifacts are easy to detect. The disadvantage is that such an interpretation requires a substantial amount of expertise and is often not repeatable between different individuals scoring the same record.

The advantages of using a semiautomated or fully automated computer scoring routine are in-

**Table 1** Review of Bruxism Event Detection Criteria (1975–1992)

| | Amplitude | Duration | Linkage | Other criteria | Analyzing method |
|---|---|---|---|---|---|
| Rugh and Solberg[8] (1975) | > 20 mV (integral average) | None | None | None stated | Analog device |
| Wagner[14] (1981) | > 5 mV (integral average) | None | < 3 s | None stated | Analog device and manual |
| Piccione et al[15] (1982) | > 20 mV (integral average) | ≥ 0.5 s < 1.5 s | < 2.5 s | None stated | Manual |
| Stock and Clarke[16] (1983) | A level greater than that produced by ordinary orofacial movement | ≥ 2 s | ≤ 1 s | None stated | Analog device and computer algorithm |
| Kydd and Daly[3] (1985) | None | None | None | Movement artifacts and electrical noise were deleted | Manual |
| Ware and Rugh[2] (1988) | Twice the background or > 75 mV (raw) | > 0.25 s | None | None stated | Manual |
| Okeson et al[17] (1990) | > 40% MVC peak (raw) | ≥ 2 s | None | None stated | Manual |
| Velly Miguel et al[18] (1992) | > 40% MVC peak (raw) | > 0.25 s | None | None stated | Manual |

MVC = maximum voluntary contraction.

creased reliability and reproducibility. In addition, if the computer algorithm is powerful enough to incorporate one or more channels of data besides the masseter EMG channel, it is possible to better define the bruxism event or assess its correlation with other physiologic events (eg, the extent that a bruxism event is associated with a sleep state change).

The present study had three purposes: *(1)* describe the EMG and electrocardiographic (ECG) data that were recorded from a group of bruxism subjects; *(2)* using this data, select the most logical criteria to be used in a computer algorithm to detect bruxism events; and *(3)* describe in detail this algorithm and present detailed descriptive data on the level of bruxism observed in the subjects.

## Materials and Methods

### Subjects

Individuals with self-acknowledged facial pain and clinically confirmed dental attrition, who responded to an advertisement in the campus newspaper and satisfied the inclusion and exclusion criteria (see below), were selected as subjects. Potential subjects had to meet the following inclusion criteria: *(1)* be between 18 and 65 years of age; *(2)* exhibit evidence of tooth attrition such that at least one tooth (usually canine) had dentine exposure on the occlusal or incisal surface; *(3)* be in good health; *(4)* have tried in the past, but not presently be actively using, an occlusal coverage acrylic resin appliance; and *(5)* have stated they have frequent jaw or tooth pain in the morning and have demonstrated moderate to severe tenderness in two or more sites in their jaw closing muscles (masseter and temporalis). The tenderness rating was elicited via the application of 1.8 kg of pressure to the muscle for 2 seconds with a hand-held pressure algometer device (Pain Diagnostics and Thermography, White Plains, NY). After experiencing the pressure, the subjects selected a number from 0 to 3 that represented their pain level (0 = none, 1 = mild, 2 = moderate, 3 = severe). Exclusion criteria for the subjects were the following: *(1)* the daily use of any medications or alcohol; *(2)* the inability to sleep with a recording apparatus attached; and *(3)* the need for any urgent dental treatment.

### Study Design

The data collection setup used in this descriptive study is shown in Fig 1. Masseter muscle EMG activity was measured using miniature bipolar surface electrodes. Electrocardiographic activity was recorded by placing electrodes over the subject's left clavicle, sternum, and left lateral chest wall. The signals from the various electrodes were amplified and recorded onto a portable multichan-

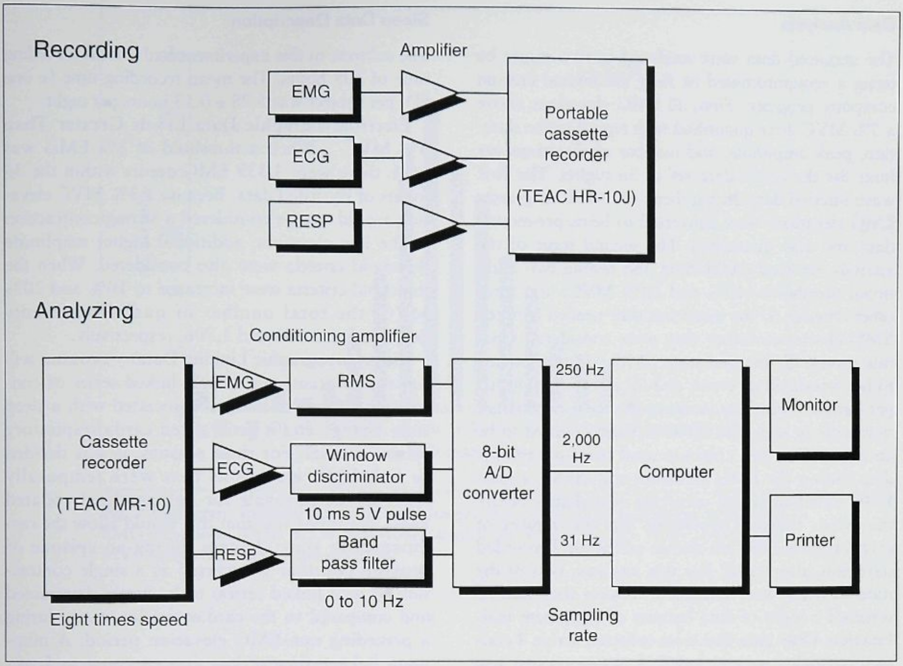


Fig 1 Respiration (RESP), ECG, and EMG data were collected by a portable cassette recorder (TEAC HR-10J) in the patients' homes. These data were then reproduced by a cassette recorder (TEAC MR-10) at a speed eight times faster than the original; then they were transformed, acquired to 8-bit digital data, and stored in a computer.

nel analog tape recorder (TEAC HR-10J, cassette data recorder). All recordings were performed in the subject's home for 4 consecutive nights, unless a technical problem occurred (eg, electrode detachment). In the latter case, an additional recording night was performed as soon as the problem was discovered.

### Data Reduction and Acquisition to Computer

The analog-tape–recorded data were first conditioned and then acquired to computer in a digital format. This process involved playing back the data on a second device (TEAC, MR-10) at a tape speed that was eight times faster than the original recording speed. Next, using a signal conditioning device (SA-414 Analog Processor, SA Instrumentation Service Associates, Encinitas, CA), the raw EMG signal was amplified and converted to a smooth EMG signal using a root mean square (RMS) conversion. The electrocardiographic (ECG) signal was conditioned by first detecting the R wave of the ECG tracing using a window discriminator. Each detected R wave then triggered a 10-ms 5-V square wave pulse. These pulse and smooth EMG data were then transferred by an 8-bit A/D converter and data acquisition system to the computer. The signal sampling rate of the RMS-converted EMG signal was 250 Hz, and the R wave triggered pulse signal was sampled at 2,000 Hz. Respiration data was filtered with a band pass filter between 0 to 10 Hz and sampled at 31 Hz. For final analysis and display of the data, the amplitude of the EMG signal was quantified in terms of the subjects' 100% maximum voluntary contraction (MVC) level. The 100% MVC for each subject was recorded at the beginning of each night using three brief (2-second) MVC efforts.

### Data Analysis

The acquired data were analyzed in two stages by using a semiautomated or fully automated custom computer program. First, all EMG elevations above a 3% MVC were quantified with regard to the duration, peak amplitude, and number of elevations per hour for the entire data set of 36 nights. The R-R wave interval data during these 3% MVC or greater EMG elevations were converted to beats-per-minute data and also quantified. The second stage of the analysis involved establishing and testing two additional thresholds (10% and 20% MVC) and three other criteria: *(1)* the minimum time needed between EMG elevations before they were considered separate events; *(2)* the minimum EMG duration needed to be considered an event; and *(3)* a minimum beats-per-minute (bpm) rate increase occurring in conjunction with an identified EMG elevation needed to be an event. This last criterion used beats-per-minute data during the EMG elevation and during a non-EMG elevation period occurring immediately before the event. The null hypothesis that the number of events per hour did not change across the 4 recorded days was also tested. For this analysis, two of the nine subjects were excluded because they had to rerecord a night of data because of equipment malfunction. Only data that were collected across 4 consecutive nights were included. A regression line was then fit to each subject's nightly data (events per hour). The weighted mean slope of these lines were established for each of the three different threshold criteria (3%, 10%, 20% MVC). Weighting of the subjects' data was performed because some subjects had better fitting linear trends for their data than others. To incorporate this feature, an inverse regression coefficient variance estimate was used to weight the linear trends. The weighted mean slope lines were then tested using a one-sample two-trial $t$ test to see if they were significantly different from zero. Finally, the resulting bruxism event data were both described and displayed using two- and three-axis plots. The underlying logic for the above criteria and the results of the above analysis are presented in the next section. A brief abstract of these results has appeared previously.[19]

## Results

### Subject Demographics

Nine subjects (five men and four women) completed the protocol. Their mean age (± one standard deviation [SD]) was 26.2 ± 4.18 years.

### Sleep Data Description

The subjects in this experiment had a total recording time of 208 hours. The mean recording time (± one SD) per subject was 5.78 ± 0.53 hours per night.

**Electromyographic Data Levels Greater Than 3% MVC.** When a threshold of 3% EMG was used, there were 3,339 EMG events within the 36 nights of recorded data. Because a 3% MVC elevation would not be considered a strong contraction of the jaw elevators, additional higher amplitude threshold criteria were also considered. When the threshold criteria were increased to 10% and 20% MVC, the total number of qualifying events decreased to 2,601 and 1,706, respectively.

**Electromyographic Linking Data.** Bruxism will sometimes occur as a closely linked series of contractions. Bruxism is often associated with a sleep state change and a generalized cardiorespiratory system arousal. For these reasons, it was decided to link EMG elevations that were temporally related. The rationale for linking closely related EMG elevations was that this would allow the cardiovascular state changes during an episode of bruxism (whether it occurred as a single contraction or as a linked series) to be better determined and compared to the cardiovascular status during a preceding non-EMG elevation period. A minimum linkage time of less than or equal to 5 seconds between EMG offset and next onset was selected, and all qualifying EMG elevations that satisfied these threshold and linkage criteria were now considered as a single potential bruxism event. As a result of adding this criterion, there were now determined to be 2,078 potential bruxism events (using 3% MVC) within the 36 nights of recorded data. When the threshold criteria were increased to 10% and 20% MVC, the total number of qualifying potential bruxism events after linkage decreased to 1,570 and 1,057, respectively.

**Electromyographic Duration Data.** There are high amplitude EMG elevations of short duration that occur as myoclonic twitches or as a result of EMG signal or line artifacts. Therefore, all EMG elevations that were above threshold for less than 3 seconds from onset to offset were eliminated. When a minimum EMG duration of 3 seconds was used in combination with the 3% MVC and the 5-second linking criteria, there were 1,538 potential bruxism events within the 36 nights of recorded data. When the threshold criteria were increased to 10% and 20% MVC, the 3-second minimum duration criteria reduced the total number of potential bruxism events after linkage decreased to 920 and 526, respectively.

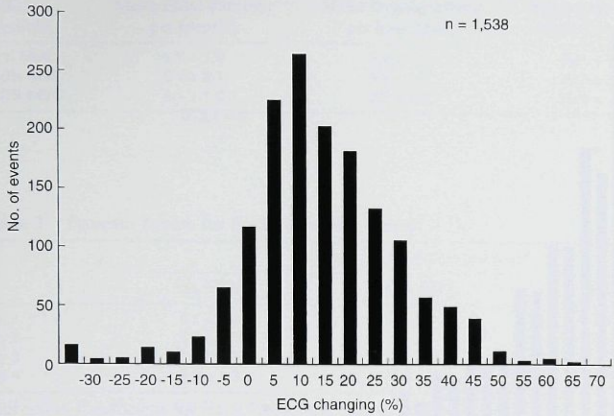


**Fig 2** Histogram showing the heart rate changes that occurred in association with 1,538 EMG elevations. These 1,538 elevations satisfied all three minimum EMG criteria (3% MVC threshold, linkage, and duration).

**Electrocardiographic Rate Change Data.** As mentioned above, bruxism is a phenomenon that typically occurs in association with a generalized cardiorespiratory system arousal. For this reason, the final event detection criterion was a minimum beats-per-minute rate change of greater than 5%. This magnitude of change would equate to an increase from 60 bpm to 63 bpm within a 5-second period. The comparison period for this assessment was the 5-second time period immediately preceding the detected potential bruxism event. When a greater than 5% bpm rate change increase criterion was added to the previously discussed EMG criteria (linkage and duration), there were determined to be 1,270 bruxism events within the 36 nights of recorded data for the 3% MVC threshold. When the EMG threshold criteria were increased to 10% and 20% MVC, the total number of bruxism events decreased to 756 and 414, respectively.

Figure 2 shows a histogram of the number of times a heart rate change within the specified range occurred in association with the detected bruxism events (n = 1,538) that satisfied all three minimum EMG criteria (3% MVC threshold, linkage, and duration). The most common heart rate change was a 10% to 14.9% increase. In this figure, 82.6% of the potential bruxism events also had a greater than or equal to 5% increase in bpm. The change in EMG amplitude threshold to 10% and 20% MVC did not substantially alter this pattern. For a 10% MVC EMG threshold, 82.2% of the potential bruxism events were above the 5% bpm increase; for the 20% EMG amplitude threshold, this figure was 78.8%.

**Peak EMG Elevations and Duration of Bruxism Events.** A histogram of the 1,270 bruxism events that were above the 3% MVC threshold and that satisfied the other described criteria (linkage, duration, and ECG change) is presented in Fig 3. Each bar in this figure represents the number of bruxism events that had a peak amplitude in the specified range. From this figure, it can be seen that the most common bruxism events had a peak EMG elevation between 10% and 14.9% of MVC.

A histogram of the 1,270 bruxism events with a specified duration are presented in Fig 4. As in Fig 3, these bruxism events were those that were above the 3% MVC threshold level and satisfied the described minimum linkage, duration, and ECG change criteria. Each bar in the figure represents the number of bruxism events that had a duration in the specified time range. From this figure, it can be seen that the most common duration

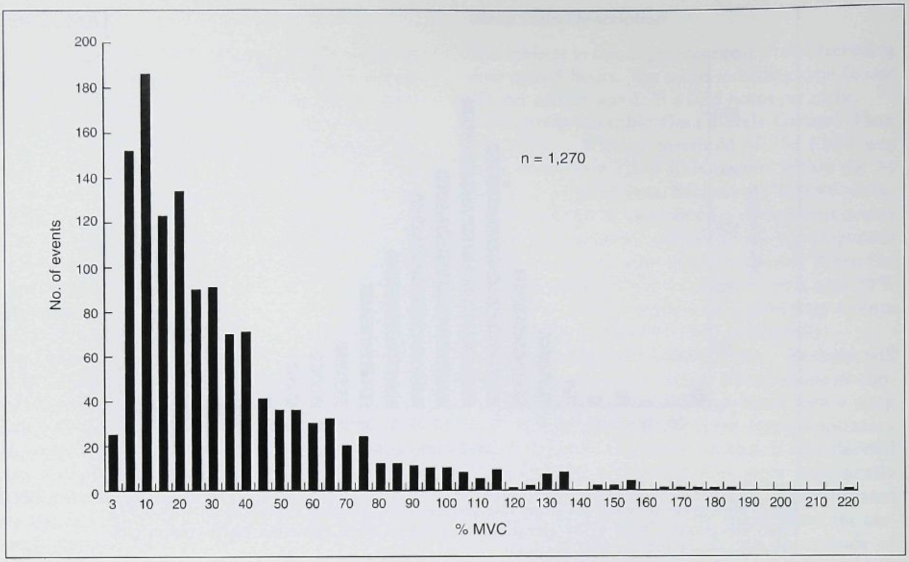


Fig 3 Histogram showing the 1,270 EMG elevations that were above the 3% MVC threshold. These 1,270 EMG elevations also satisfied all three criteria (linkage, duration, and ECG rate change).

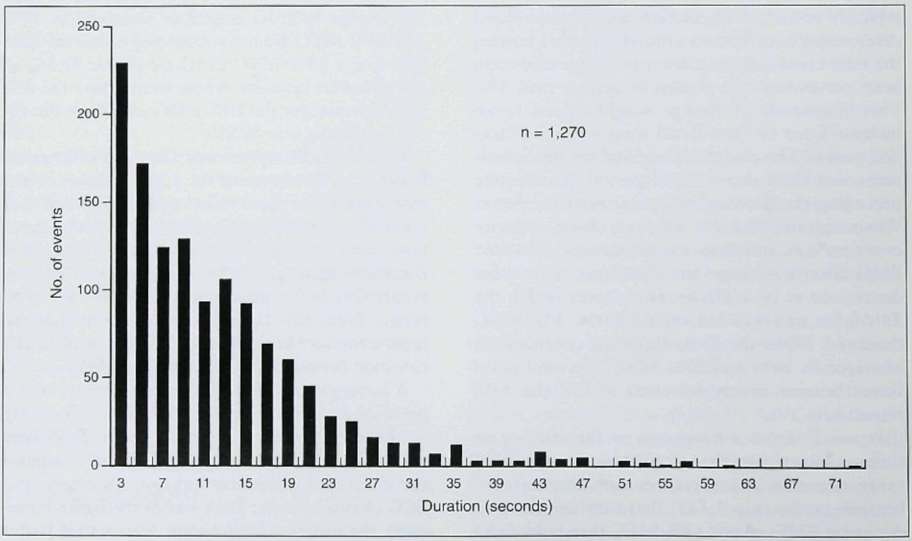


Fig 4 Histogram showing the duration of 1,270 EMG elevations that were above the 3% MVC threshold. The EMG elevations also satisfied all three criteria (linkage, duration, and ECG rate change).

**Table 2** Bruxism Events at Three Different EMG Thresholds

| EMG threshold | Mean EMG duration per event(s) | Mean bruxism events per hour (No.) | Mean peak EMG level (% MVC) |
|---|---|---|---|
| > 3% MVC | 12.9 ± 1.9 | 6.2 ± 1.6 | 36.1 ± 10.6 |
| > 10% MVC | 10.1 ± 2.1 | 3.6 ± 1.2 | 46.3 ± 10.3 |
| > 20% MVC | 8.1 ± 1.6 | 2.0 ± 1.0 | 56.5 ± 9.7 |

**Table 3** Bruxism Events for Each Recording Day (n = 7)

| | Mean (± SD) events per hour | | |
|---|---|---|---|
| | 3% MVC | 10% MVC | 20% MVC |
| Day 1 | 5.7 ± 2.0 | 3.0 ± 1.4 | 1.5 ± 0.7 |
| Day 2 | 5.7 ± 1.7 | 3.7 ± 1.3 | 2.1 ± 0.9 |
| Day 3 | 6.1 ± 2.5 | 4.5 ± 2.1 | 2.6 ± 1.5 |
| Day 4 | 6.0 ± 1.3 | 3.6 ± 1.3 | 2.3 ± 1.3 |

Regression Coefficient for Each Recording Day (n = 7)

| | Regression coefficient weight | *P* values |
|---|---|---|
| 3% MVC | −0.08 + 0.42 | .594 |
| 10% MVC | −0.40 + 0.46 | .043 |
| 20% MVC | −0.45 + 0.41 | .017 |

was between 3.0 and 4.9 seconds. The maximum value in these data was 72.8 seconds.

The mean (± one SD) duration per bruxism event, number of bruxism events per hour, and peak EMG level per event that satisfied the three different qualifying thresholds are presented in Table 2.

**Order Effect Data.** To see whether the number of events across each recording day varied in a systematic fashion, the total number of bruxism events (using the 3%, 10%, and 20% MVC amplitude criteria) per day was determined and compared for significant differences. The mean number (± one SD) of bruxism events per hour, the weighted mean regression coefficients fit to these data, and the *P* values from the *t* test are presented in Table 3. The data revealed no statistically significant differences for the 3% MVC criteria, but the 10% and 20% MVC criteria events did show a statistically significant difference across the 4 days of recording.

**Final Bruxism Criteria Data.** Figure 5 shows two bruxism events from a single subject who met the four described criteria (EMG threshold = 10% MVC). The area below the elevated EMG signal that defines the event is marked with a solid double line. In Fig 6, a single subject's entire night of EMG data is displayed using a three-axis plot.

**Final Bruxism Event Detection Algorithm.** The logic by which the above algorithm works is demonstrated in Fig 7. Each EMG potential elevation needed to satisfy four criteria (EMG threshold, linkage, duration, and ECG change) in a sequential fashion to qualify as a bruxism event. Detection of the event was automatically performed by customizing a software program.

## Discussion

Until an accurate and reasonable cost effective method of measuring the occurrence of bruxism is available, no substantial progress will be made in its understanding and subsequent treatment. The methodology proposed to analyze and quantify bruxism events could also be applied to study any episodic motor behavior (eg, periodic leg movement disorder). Of course, instrumented sleep studies performed in a hospital-based sleep disorders clinic can be used for the diagnosis of bruxism.[20,21] Unfortunately, most patients are unable to record multiple nights without considerable

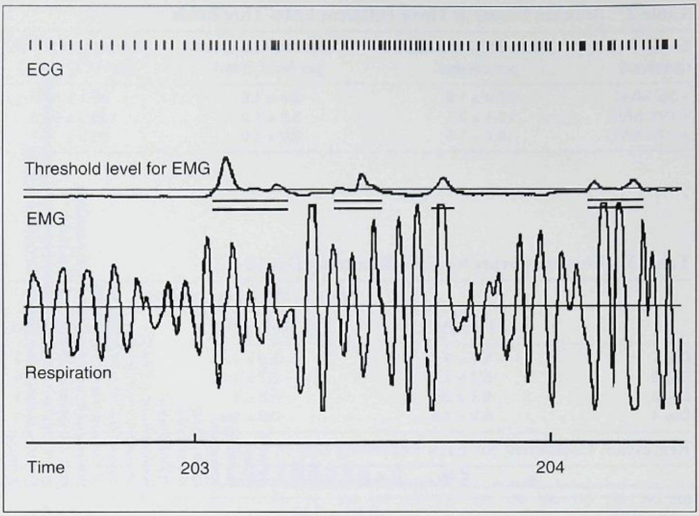


**Fig 5** Two bruxism events (2 minutes of actual recording). The small vertical lines at the top of tracing represent a heart beat. In the middle upper portion of the tracing, the continuous horizontal line represents the RMS-smoothed EMG data. The horizontal straight line superimposed on the EMG data line is the 10% MVC level. When the EMG line is above this 10% level and satisfies the previously described linkage and duration criteria, a single horizontal line appears beneath the EMG elevation. For this EMG elevation to be qualified as a bruxism event, it must also satisfy ECG rate change criterion. All qualified bruxism events have a second horizontal line beneath the EMG elevation. The other continuous horizontal line with variable amplitude represents the respiration changes. These data were not used for any analytic purpose in this study.

expense. Furthermore, the variable nature of bruxism often results in an unproductive recording during the first 1 or 2 nights during a sleep laboratory recording session. Our data reconfirmed this finding by showing a small but consistent increase in the level of bruxism across the 4 nights. The magnitude of this change might actually be smaller in our study than in prior reports because recordings were performed in the subject's own sleeping environment. We speculate that a more dramatic change in the sleep environment, as would occur in a hospital-based sleep laboratory, might have a stronger influence on bruxism levels during the first night. For this reason, we recommend that a minimum of 4 nights of recording be utilized in bruxism studies.

In designing the event detection algorithm for bruxism, it was decided that using a combination of EMG and heart rate changes might be helpful. This decision was based on reports that bruxism events are consistently accompanied by an increase in heart rate and respiration.[3,5,6] The observations of these prior authors were clearly confirmed by our data.

In selecting the EMG amplitude to use as a minimum threshold, prior research[17,18] suggested bruxism event detection thresholds as high as 40% of MVC. These authors made this determination based on raw peak EMG and not smoothed integral average EMG (as used in our study). They did not provide any data showing that this was a logical threshold to utilize, nor did they establish how many of the recorded elevations in the population were above 40% versus below 40%. Based on the distribution of RMS-converted peak EMG activity in our data, we elected to use 10% as the minimum threshold. A 20%, and most certainly a 40%, MVC level would be too high to use as a minimum event detection threshold when using smoothed integral averaged EMG. It is certainly

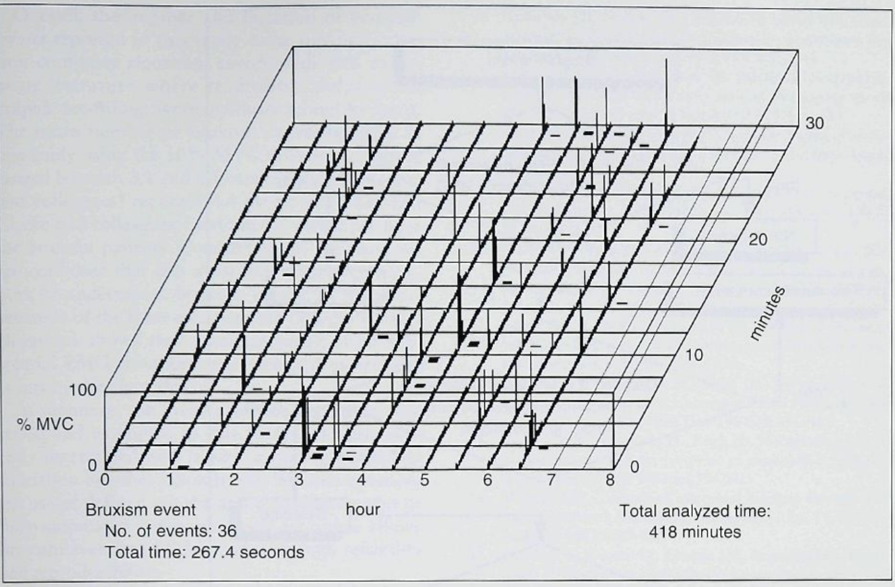


Fig 6 Example of a whole night's EMG data from a single patient. The oblique axis lines represent the actual recorded data. Each oblique line, beginning at the bottom left of the horizontal line, is 30 minutes of recording. The vertical axis is the level of EMG quantified in a percent of subject's maximum voluntary contraction level. Each short horizontal line represents turn markers repeating every 2 minutes. Along the bottom horizontal axis, each 30-minute epoch of EMG begins and then follows the oblique lines. A small horizontal dash can be seen next to oblique line; this dash indicates that the EMG elevation satisfied the algorithm and was classified as a bruxism event.

debatable regarding how harmful an isolated 10% MVC elevation would be; however, because the stated goal of the research is to record all substantial bruxism elevations, we believe the 10% criterion appears appropriate. By changing the threshold criteria from 3% to 10% MVC, 22.1% of the potential bruxism events were eliminated. If 20% MVC threshold criterion was used, 48.9% of the potential bruxism events would have been eliminated.

Approximately 38% of the potential bruxism events were affected by the linkage criterion. This means that 62% of all EMG elevation were farther apart than 5 seconds. A strong reason for selection of a minimum linkage duration of 5 seconds was that to calculate any heart rate change, a minimum preceding period of at least 5 seconds without an EMG elevation was needed to allow the ECG rate to return to a nonaroused level.

With regard to the 3-second duration criterion for a bruxism event, only 25.9% of the 3% MVC events were eliminated; however, 41.4% and 50.2% of 10% and 20% MVC events were eliminated, respectively. The selection of 3 seconds as the minimum duration criterion was so that at least two and hopefully three heart beats per minute were available to calculate the ECG rate. It should also be noted that selecting a high EMG threshold decreases the duration of a bruxism event if the time-above-threshold is used to measure the length of the event. The mean duration of EMG events above 10% MVC (after linking) was 10.1 seconds. This value was only slightly longer than those reported by other researchers. Reding and colleagues[4] reported 9 seconds as the typical duration of what they described as bruxism rhythmic contractions. Clarke et al[22] reported bruxism events to be 7.8 seconds. Unfortunately, prior reports on duration of bruxism events do not clearly specify how the duration was calculated. We believe the selection of a 3-second minimum duration appears appropriate for our algorithm

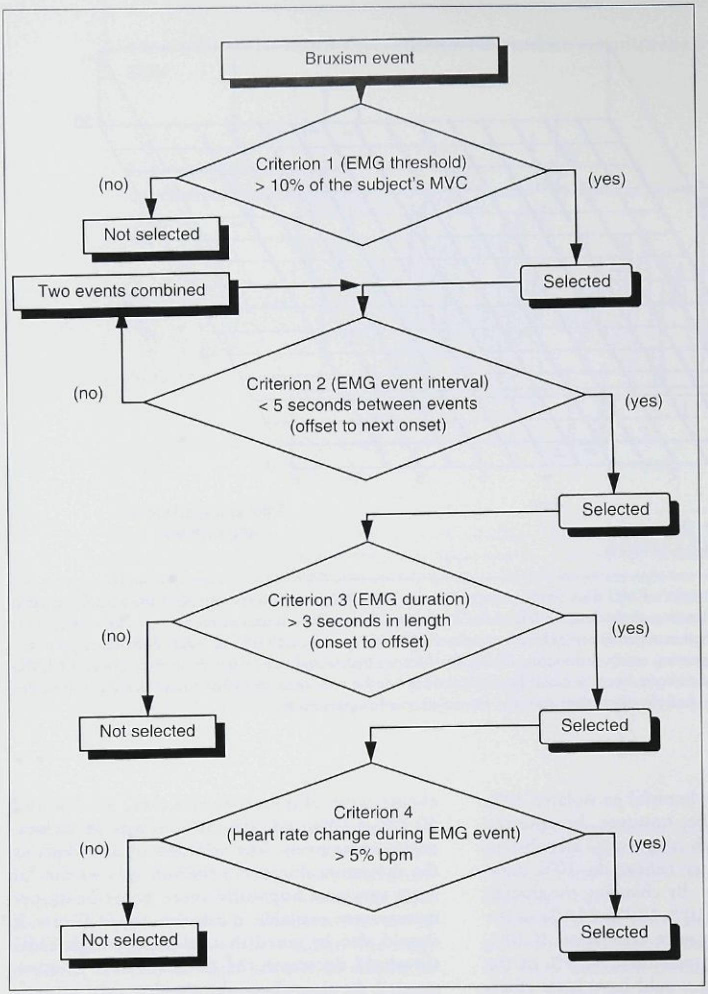


Fig 7 Bruxism event detection algorithm.

because most events will be detected and most artifacts (eg, myoclonic twitches and EMG artifacts) will be rejected.

Okeson and colleagues[20] reported that heart rate during bruxing events increased on average by 16.6% with a range from 6.1% to 40.2%, but they did not suggest a minimum ECG rate change that should serve as a criterion for detection. In our data, we also report an average ECG rate change to be between 10% and 20%, and the vast majority of these ECG rate changes associated with EMG elevations were clearly more than 5%. For this reason, the 5% ECG criterion was reasonable to include. The addition of this criterion caused an additional 18% of the EMG elevation to be eliminated.

Overall, the number and duration of bruxism events reported in this study using our four-criterion computer algorithm corresponds well to the prior literature where traditional polysomnographic recordings were tediously scored by hand. The mean number of bruxism events reported in this study using the 10% MVC threshold criterion ranged between 3.1 and 4.8 events per hour. Reding and colleagues[4] reported 4.4 events per hour, and Clarke and colleagues[22] indicated 5 events per hour for bruxism patients. Considering all the data, we are confident that this algorithm does not overreport or underreport bruxism events. A visual assessment of the three-axis diagram of nightly EMG elevations shows that a vast majority of all substantial EMG elevations were detected as bruxism events by the algorithm.

In summary, the event detection algorithm proposed and examined in this study has been logically determined and is now awaiting additional validation by other laboratories. Without question, the use of defined criteria and a semiautomated or fully automated computer-based algorithm allows bruxism events to be detected with high reliability and reproducibility.

## References


1. Rugh JD, Harlan J. Nocturnal bruxism and temporomandibular disorders. In: Jankovic J, Tolosa E (eds). Advances in Neurology, vol 49. New York: Raven Press, 1988:329–341.
2. Ware JC, Rugh JD. Destructive bruxism: Sleep stage relationship. Sleep 1988;11:172–181.
3. Kydd WL, Daly C. Duration of nocturnal tooth contacts during bruxing. J Prosthet Dent 1985;53:717–721.
4. Reding GR, Zepelin H, Robinson JE Jr, Zimmerman SO, Smith VH. Nocturnal teeth-grinding: All-night psychophysiologic studies. J Dent Res 1968;47:786–797.
5. Satoh T, Harada Y. Electrophysiological study on toothgrinding during sleep. Electroencephalogr Clin Neurophysiol 1973;35:267–275.
6. Robinson JE, Reding GR, Zepelin H, Smith VH, Zimmerman SO. Nocturnal teeth-grinding: A reassessment for dentistry. J Am Dent Assoc 1969;78:1308–1311.
7. Solberg WK, Clark GT, Rugh JD. Nocturnal electromyographic evaluation of bruxism patients undergoing short term splint therapy. J Oral Rehabil 1975;2:215–223.
8. Rugh JD, Solberg WK. Electromyographic studies of bruxist behavior before and after treatment. J Cal Dent Assoc 1975;3:56–59.
9. Rugh JD, Johnson RW. Temporal analysis of nocturnal bruxism during EMG feedback. J Periodontol 1981; 52:263–265.
10. Clark GT, Beemsterboer PL, Solberg WK, Rugh JD. Nocturnal electromyographic evaluation of myofacial pain dysfunction in patients undergoing occlusal splint therapy. J Am Dent Assoc 1979;99:607–611.
11. Clark GT, Rugh JD, Handelman SL. Nocturnal masseter muscle activity and urinary catecholamine levels in bruxers. J Dent Res 1980;59:1571–1576.
12. Clark GT, Beemsterboer PL, Rugh JD. The treatment of nocturnal bruxism using contingent EMG feedback with an arousal task. Behav Res Ther 1981;19:451–455.
13. Clark GT, Beemsterboer PL, Rugh JD. Nocturnal masseter muscle activity and the symptom of masticatory dysfunction. J Oral Rehabil 1981;8:279–286.
14. Wagner MT. Controlling nocturnal bruxism through the use of aversive conditioning during sleep. Am J Clin Biofeedback 1981;4:87–92.
15. Piccione A, Coates TJ, George JM, Rosenthal D, Karzmark P. Nocturnal biofeedback for nocturnal bruxism. Biofeedback Self-Regulation 1982;7:405–419.
16. Stock P, Clarke NG. Monitoring bruxism. Med Biol Eng Comput 1983;21:295–300.
17. Okeson JP, Phillips BA, Berry DTR, Cook Y, Paesani D, Galante J. Nocturnal bruxing events in healthy geriatric subjects. J Oral Rehabil 1990;17:411–418.
18. Velly Miguel AM, Montplaisir J, Rompré PH, Lund JP, Lavigne GJ. Bruxism and other orofacial movements during sleep. J Craniomandib Disord Facial Oral Pain 1992; 6:71–81.
19. Kondo K, Clark GT. A method for detecting a bruxism event [abstract 1969]. J Dent Res 1991;70:512.
20. Okeson JP, Phillips BA, Berry DTR, Baldwin RM. Nocturnal bruxing events: A report of normative data and cardiovascular response. J Oral Rehabil 1994;21:623–630.
21. Vilmann A, Møller E, Wildschiødtz G. A system for analysis of sleep and nocturnal activity in craniomandibular muscles. J Orofacial Pain 1994;8:266–277.
22. Clarke NG, Townsend GC, Carey SE. Bruxing patterns in man during sleep. J Oral Rehabil 1984;11:123–127.

## Resumen

Criterio Para La Deteccion Del Bruxismo En Humanos Asociado Con El Sueño

Durante el periodo del sueño, la electromiografía de superficie en el músculo masetero y la lectura del electrocardiograma de la actividad del corazón fue llevada a cabo en nueve individuos que padecen de disfuncion oral motora (bruxismo). En el propio ambiente del hogar de esos individuos, las señales fueron monitoreadas durante cuatro noches consecutivas. Una información total de 36 noches fue analizada pare llevar a cabo lo siguiente: *(1)* Describir la naturaleza y magnitud de la actividad electromiográfica total del músculo masetero por encima de un umbral mínimo de 3% para cada nivel de contracción maximo establecido para cada individuo; *(2)* Describir los cambios de valor del electrocardiograma (usando el intervalo r-r) que ocurrieron en relación a esos cambios electromiográficos. A partir de los datos obtenidos se estableció un criterio para la detección de los eventos bruxistas, combinados en un evento de detección algorítmico completamente automático. El número promedio y la detección de los eventos bruxistas fueron reportados. Se presenta y se discute la lógica bajo el criterio seleccionado y el efecto, que otro posible criterio podria tener de la separación de los eventos motores normales de lo anormal.



## Zusammenfassung

Kriterien für die Entdeckung von Bruxismus während des Schlafes bei Menschen

Oberflächen-Elektromyographie des Masseters und Elektrocardiographieaufnahmen wurden während des Schlafes von neun an Oral-Motorstörungen (Bruxismus) während des Schlafes leidenen Personen aufgenommen. Die Daten wurden in ihrer normalen Schlafumgebung zu Hause in vier aufeinanderfolgenden Nächten regestriert. Insgesamt wurden Daten von 36 Nächten analysiert, um das Folgende wahrzunehemen: *(1)* Die Beschreibung der Eigenschaften und des Umfangs der gesamten Wirksamkeit der Masseterelektrographie, die eine Minimalschwelle von 3% der vorher gemessenen maximalvoluntaristischen Höhe der Muskelverkürzung bei jedem Individuum überschritten hat, und *(2)* Die Beschreibung der Änderungen im Grad der Electrocardiographie (im Gebrauch des R-R Interval), die im Vergleich zu diesen electromyographischen Erhöhungen vorkamen. Kriterien für die Entdeckung der einzelnen Bruxismusergebnisse wurden aus diesen Daten formuliert und in einen völlig automatisierten Algorythmus kombiniert, der das Ergebnis identifizieren kann. Die durchschnittliche Zahl und Dauer des Bruxismusergebnisses werden hier beschrieben. Die zugrundeliegende Logik für die gewählten Kriterien und die Wirkung, die die anderen möglichen Kriterien der Diskriminierung von normalen und unnormalen Motorergebnissen haben würden, werden ebenfalls dargestellt und diskutiert.