

Review Article

Assessment of bruxism in the clinic*

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SUMMARY Bruxism is a much-discussed clinical issue in dentistry. Although bruxism is not a life-threatening disorder, it can influence the quality of human life, especially through dental problems, such as tooth wear, frequent fractures of dental restorations and pain in the oro-facial region. Therefore, various clinical methods have been devised to assess bruxism over the last 70 years. This paper reviews the assessment of bruxism, provides information on various assessment methods which are available in clinical situations and discusses their effectiveness and usefulness. Currently, there is no definitive method for assessing bruxism clinically that has reasonable diagnostic and technical validity, affects therapeutic decisions and is cost effective. One future direction is to

refine questionnaire items and clinical examination because they are the easiest to apply in everyday practice. Another possible direction is to establish a method that can measure actual bruxism activity directly using a device that can be applied to patients routinely. More clinical studies should examine the clinical impact of bruxism on oral structures, treatment success and the factors influencing the decision-making process in dental treatment.

KEYWORDS: bruxism, diagnostic criteria, clinical assessment, assessment, questionnaire, clinical observation, tooth wear, monitoring, intra-oral appliance, review

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Introduction

Bruxism is generally recognized as non-functional jaw movement and is thought to be an important aetiological factor, which could cause and/or accelerate abnormal tooth wear, periodontal disease and temporomandibular disorders (TMD). Although there is a lot of research on the prevalence, aetiology, effect and management of bruxism, there are no established guidelines or consensus, which can be applied to dental practice to date. It is evident that bruxism can affect oral structures and the masticatory system destructively, but it is difficult to grasp the actual condition/activity clinically. Hence, most dentists have difficulty in evaluating whether his/her patient actually has active bruxism or not. Even though some patterns of tooth

wear are often considered to be signs of bruxism, objective and reliable assessments of such patterns are necessary for its clinical diagnosis.

This article summarizes methods for assessing bruxism in the clinic to date. A search of the English literature with Medline/PubMed through February 2008 with terms 'bruxism' and 'assessment', 'bruxism' and 'measurement', and 'bruxism' and 'evaluation' was undertaken and yielded 119, 85 and 161 papers, respectively. After excluding the overlap among these search results, literatures related to the methods for assessing bruxism were selected and a hand search was then added to include relevant articles for this review.

Definition of bruxism

'Bruxism', defined as forcible clenching or grinding of the teeth, or a combination of both, has long been regarded as a disorder requiring treatment (1, 2).

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Bruxism has also been defined as: (i) the parafunctional grinding of teeth and (ii) an oral habit consisting of involuntary rhythmic or spasmodic non-functional gnashing, grinding or clenching of the teeth, in other than chewing movements of the mandible, which may lead to occlusal trauma – also called as *tooth grinding*, *occlusal neurosis*, according to the Glossary of Prosthodontic Terms, 8th edition (3).

Bruxism, according to the American Academy of Orofacial Pain, is a diurnal or nocturnal parafunctional activity which includes clenching, bracing, gnashing and grinding of the teeth. Bruxism is considered to be the most detrimental thing among the parafunctional activities of the stomatognathic system, being responsible for tooth wear, periodontal tissue lesions, and articular and/or muscular damage (4).

For a more operational definition, the American Academy of Sleep Medicine (AASM) defined sleep bruxism as a sleep-related movement disorder characterized by grinding or clenching of the teeth during sleep, usually associated with sleep arousal (5).

The view of this behaviour as a parafunctional disorder is likely because of the fact that it can cause tooth structure breakdown (1, 6, 7). Moreover, it is widely believed that bruxism plays an important role in the development of craniofacial pain, including TMD (8, 9).

Mechanism

The aetiology and neurological mechanism that generate sleep bruxism are not well understood. During the past decade, however, in connection with the methodological improvement of clinical investigations, research has been predominantly focused on the analysis of central factors (10, 11). A number of studies have proven the major role played by central factors in the development of sleep bruxism (12–15) and a growing body of evidence suggests that it appears to be induced within the central nervous system and, in part, is associated with the phenomenon of arousal reactions during sleep (12, 16). Several studies showed that changes in the input feedback of peripheral oral receptors, e.g. alternation in the occlusal contact relationship and an increased vertical dimension, temporarily diminish but do not stop bruxism (13, 17, 18).

The three major hypothesized causes of sleep bruxism are neurological factors, peripheral stimulus and psychogenic elements. It has been suggested that

several medicines (e.g. L-dopa, SSRI, propranolol) are connected with bruxism (19, 20), however, the influence of these medicines on bruxism has not been fully understood. These medicines are suggested to be related to the generation, acceleration and control of bruxism (21).

Bruxism occurring during waking hours should be differentiated from sleep bruxism because the two conditions occur under different circumstances. Day-time bruxism, which mainly consists of clenching, is acquisitive behaviour.

Prevalence

According to review papers, in which data were collected from various pieces of original research, the prevalence of bruxism was reported to be 6–95% (2, 22). This wide-spread occurrence is because of differences in methods including the criteria for evaluating bruxism, sample populations and other factors. In general, the prevalence based on the evaluation of self-reporting of clenching of the teeth during waking hours is about 20%, whereas the prevalence of clenching during the sleeping hours is about 10%, and that of grinding of the teeth during the sleeping hours ranges from 8 to 16% (23–28).

Clinical impact

Parafunction and factors such as restorative materials, restoration design, implant design and location, the occlusal vertical dimension and periodontically compromised dentition are thought to be important in prosthodontic treatment (29). Unfortunately, few data are available on these topics. Some studies reported that bruxism might not be a primary factor, but it contributed to the wear of restorative materials (30), tooth survival in periodontitis (31), cracks in posterior teeth (32), implant failure (33) and complications with fixed partial dentures on implants (34). Most of the studies in this field defined a bruxer based on the subject's own reports or tooth wear. However, such definitions are unreliable.

It has also been suggested that bruxism causes an excessive load on dental implants and their superstructures, ultimately resulting in bone loss around the implants or even in implant failure. Not surprisingly, bruxism is, therefore, often considered as one of the risk factors for implant treatment, as stated in textbooks and

conference proceedings on oral implantology and prosthetic dentistry (35, 36). Although scientific reviews on this topic state that there is insufficient evidence to support or refute the possible causal relationship between bruxism and implant failure (37), a careful approach should be recommended (38).

In this respect, it is evident that bruxism has an impact on dental problems, so it is necessary to assess bruxism 'clinically'. Also, the purposes for accessing bruxism may vary according to the kinds of problems that the patient faces.

Methods for assessing bruxism

There are various ways to assess bruxism activity (Table 1), questionnaires being the most commonly used method. Clinical examination and observations of tooth wear are also widely used in both clinical and research settings. There are also studies which tried to detect bruxism activity using oral devices. These studies include the evaluation of the wear on occlusal splints (39), the detection of force applied to the device and interarch contacts (40). Portable electromyographic (EMG) recording of the masticatory muscles during sleep (41) is a more objective and direct method to assess bruxism. Recently, handier devices for measuring bruxism activity, e.g. BiteStrip^{®†} and Grindcare^{®‡}, were introduced (42, 43). Finally, polysomnography in a sleep laboratory (44–47) is currently considered as the most specific and accurate method for evaluating bruxism activity.

Table 1. Methods for assessing bruxism

Questionnaires
Clinical findings
Clinical examination
Diagnostic criteria of sleep bruxism, AASM
Use of validated clinical diagnostic criteria
Tooth wear
Intra-oral appliance
Wear of intra-oral appliance
Detection of bite force
Masticatory muscle electromyographic recording
Portable EMG recording device
Miniature self-contained EMG detector–analyser
Polysomnography

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The following sections provide an overview on the methods for the assessment of bruxism in the clinic.

Questionnaires

Questionnaires are generally used in both research and clinical situations. The principal advantage of this method is that it can be applied to a large population, although the information on bruxism is subjective in nature. A simple yes/no question on the awareness of bruxism was frequently used in epidemiological studies, in which the association between bruxism and tooth wear was investigated (48–50). Several researchers proposed questionnaires for detecting bruxers (51–53) and one of the typical questionnaires is presented in Table 2. Pintado *et al.* (53) reported that subjects who were classified as bruxers based on a history and clinical examination gave a positive response to at least two of the six items presented in Table 2. Unfortunately, this paper did not provide the information whether clinically determined bruxers were confirmed by other objective assessment methods. Even in a clinical situation, in general, questionnaires which consist of subjective questions only are not frequently used as those combined with observations on objective signs are considered to be more reliable.

It is evident that the use of self-reports to assess the presence or absence of bruxism is convenient for both clinicians and researchers, especially in epidemiological studies. Accuracy can be improved if time aspects or temporal profiles, e.g. period, frequency, duration and fluctuation within a day, are considered. However, about 80% of bruxism episodes such as clenching are not accompanied by noise (52); consequently, a large percentage of adults and children are considered to be unaware of their bruxism activity and thus will be unable to identify themselves as bruxers. Moreover, self-reports of bruxism-related signs/symptoms and awareness of bruxism have been found to show

Table 2. Questionnaire for detecting bruxer (53)

Has anyone heard you grinding your teeth at night?
Is your jaw ever fatigued or sore on awakening in the morning?
Are your teeth or gums ever sore on awakening in the morning?
Do you ever experience temporal headaches on awakening in the morning?
Are you ever aware of grinding your teeth during the day?
Are you ever aware of clenching your teeth during the day?

substantial fluctuation over time (54–56) and under- or overestimation of the prevalence of sleep bruxism has been reported (57, 58). Marbach *et al.* (59) suggested that dentists' belief that their patients are bruxers can increase the positive response in the self-reports of patients if they have been told to be bruxers by their dentists. Hence, it is safe to say that the use of self-reports alone to assess the presence or absence of bruxism is scientifically unreliable. Furthermore, variation in the prevalence among epidemiological studies is considered to be caused by these issues, because most of the prevalence data is based on individuals' self-reports. Thus, the actual prevalence of bruxism in various populations is not precisely known to date.

Clinical findings

The initial diagnosis of sleep bruxism is generally based on a report of tooth grinding sounds by a sleep partner, the presence of tooth wear or frequent fracture of dental restorations. Other objective signs such as hypertrophy of the masseter muscle or other subjective symptoms such as pain in the temporomandibular joint, headache, pain, fatigue or stiffness in the masticatory muscles on waking, could be indirect indications of sleep bruxism. Accordingly, in both research and clinical settings, the status of bruxism is typically evaluated based on the participant's self-report (27, 60–66), the clinical oral examination (67) or a combination of the two (68, 69). As the observation of tooth wear is considered to be a simple and clinically common method to investigate bruxism activity objectively, it is separately discussed in detail.

Clinical examination

The current clinical diagnosis of bruxism is principally dependent on history, tooth wear, tooth mobility and other clinical findings such as tongue/cheek indentation, masticatory muscle hypertrophy, pain in the temporomandibular joint, headache, pain or fatigue of the masticatory muscles. Examples of clinical and anamnestic indicators for detecting bruxism, taken from several published sources (2, 54, 70), are shown in Table 3. Tools similar to this were utilized in various studies (44, 68, 71) and considered to be more reliable than those consisting of subjective questions only. However, most items in Table 3 still contain vague factors. With regard to item 2, for instance, tooth wear

Table 3. Clinical and anamnestic indicators for bruxism (70)

Reports of tooth grinding or tapping sounds (usually reported by bed partner)
Presence of tooth wear seen within normal range of jaw movements or at eccentric position (bruxofacet)
Presence of masseter muscle hypertrophy on voluntary contraction
Complaint of masticatory muscle discomfort, fatigue or stiffness in the morning (occasionally, headache in temporal muscle region)
Tooth or teeth hypersensitive to cold air or liquid
Clicking or locking of temporomandibular joint
Tongue or cheek indentation

is a cumulative record of both functional and para-functional wear and is associated with multiple factors besides bruxism, although it is objective in nature. Item 3 is also objective in nature but considered as an indirect implication of bruxism. Item 4 is subjective in nature and considered as an indirect implication of bruxism. Items 5 and 6 can also be caused by other factors. The presence or absence of tongue or cheek indentations (item 7) itself does not prove the presence or absence of bruxism. It is also not easy to set definitive cut-offs regarding frequency or severity for these items. Moreover, the validity of these tools has not been confirmed.

Diagnostic criteria of sleep bruxism, AASM

Researchers who have been dedicated to the study of sleep typically consider that sleep bruxism is a stereotyped movement disorder in sleep disorders. Accordingly, the definition includes bruxism behaviour during daytime sleep but disregards other parafunctional activities during awake. However, because of its operational nature, the definition proposed by the American Sleep Disorder Association (72) and revised by the American Academy of Sleep Medicine (5) (Table 4) is considered to be one of the best descriptions for sleep bruxism for both clinical and research purposes (18, 73, 74).

Use of validated clinical diagnostic criteria

Romprè *et al.* (75) investigated the validity of the research diagnostic criteria in polysomnographic evaluation with clinical diagnostic criteria, which consisted of the four items presented in Table 5. When the cut-off point of four episodes per hour for the polysomno-

Table 4. Diagnostic criteria of sleep bruxism (5)

The patient reports or is aware of tooth-grinding sounds or tooth-clenching during sleep

One or more of the following is present:

- Abnormal wear of the teeth
- Jaw muscle discomfort, fatigue, or pain and jaw lock upon awakening
- Masseter muscle hypertrophy upon voluntary forceful clenching

Jaw muscle activity is not better explained by another current sleep disorder, medical or neurological disorder, medication use or substance use disorder

Table 5. Clinical diagnostic criteria for sleep bruxism (75)

A history of tooth grinding occurring at least 3 nights per week for the preceding 6 months, as confirmed by a sleep partner

Clinical presence of tooth wear

Masseter muscle hypertrophy

Report of jaw muscle fatigue or tenderness in the morning

graphic evaluation was applied, the sensitivity was 55% and the specificity was 84% because of the involvement of mild sleep bruxers and controls with high frequencies of sleep bruxism activities (75). In this respect, the criteria seem to include a broad spectrum of bruxers, i.e. from mild to severe. However, it could be difficult to detect clenching-type bruxers because the primary item in the criteria is based on the grinding sounds during sleep.

To date, there are various tools for assessing bruxism including the diagnostic criteria of the AASM. However, there are few studies in which the reliability of these criteria were scientifically examined (73, 75) and it still remains unclear whether the results of clinical observation truly reflect the status of bruxism or not. Overall, the recognition of bruxism based on clinical findings has its limitations.

Tooth wear

The most common observable effect of bruxism is excessive tooth wear, although bruxism may result in a variety of pathological conditions. Tooth wear is considered to be the result of three processes: attrition (wear through tooth-tooth contact), abrasion (wear produced by interaction between teeth and other materials) and erosion (dissolution of hard tissue by acidic substances) (76, 77). However, in general, tooth

wear is considered to be analogous to bruxism. Several studies have demonstrated a positive relationship between tooth wear and bruxism (49, 78) but others have not (79, 80). Although a number of systems for the classification and measurement of incisal and occlusal tooth wear have been introduced, only a few representative studies are presented in this section.

Schematic classification of tooth wear In a study using the Murphy classification of tooth wear (81, 82), this classification showed fair reliability if careful calibration was conducted (80): the intra-class correlation coefficient (ICC) between each examiner's score and the gold standard score was 0.86 and 0.93, respectively; the intra-examiner rate between the first and second score was 0.92 and the interexaminer rate was 0.86. Unfortunately, tooth-wear status was not predictive of an ongoing bruxism level as measured by the force-based bruxism detection system.

Individual (personal) tooth-wear index for epidemiological research An individual (personal) tooth-wear index to rank persons with regard to incisal and occlusal wear was developed to investigate the prevalence and severity of tooth wear (49). This index was introduced as a tool, which was applicable to epidemiological studies.

First, the extent of incisal or occlusal wear for a single tooth was evaluated by the following four-point scale:

- 0: no wear or negligible wear of enamel;
- 1: obvious wear of enamel or wear through the enamel to the dentine in single spots;
- 2: wear of the dentine up to one-third of the crown height;
- 3: wear of the dentine up to more than one-third of the crown height; excessive wear of tooth restorative material or dental material in the crown and bridge-work, more than one-third of the crown height.

Then, the individual (personal) tooth-wear index (I_A) was calculated from the scores of incisal or occlusal wear for each tooth of that individual.

$$I_A = \frac{10 \times G_1 + 30 \times G_2 + 100 \times G_3}{G_0 + G_1 + G_2 + G_3}$$

where G_0 , G_1 , G_2 and G_3 are the number of teeth with scores of 0, 1, 2 and 3, respectively.

This method makes it possible to calculate the degree of individual (personal) tooth wear without being influenced by the number of missing teeth. It is also

an advantage that this index could be applied to both natural and restored teeth. However, there are subjective criteria without quantitative evaluation for assessing the degree of tooth wear, such as 'negligible wear' in score 0 and 'obvious wear' in score 1. This situation is considered to influence the results of assessments and make this scale hard to use.

Eckfeldt *et al.* (49) verified the clinical validity of this index using 16 individuals, where the individual ranking of incisal and occlusal tooth wear was evaluated by two methods, i.e. the individual (personal) tooth-wear index and the consensus evaluation by three senior staff after calibration (gold standard). The correlation between the two measurements was 0.83, with 95% confidence limits of 0.57–0.94 (Spearman rank correlation coefficient).

An epidemiological study of 585 dentate individuals revealed that the individual (personal) tooth-wear index had a significant correlation with the occurrence of bruxism, the number of existing teeth, age, sex and the saliva buffer capacity, and that bruxism could only explain 3% of the wear (stepwise multiple linear regression analysis) (49). Unfortunately, the occurrence of bruxism was evaluated by a simple questionnaire (yes or no) and no careful assessment of bruxism was conducted.

Further, this index was utilized in an epidemiological study of 2529 dentate subjects (50), where the risk factors for high tooth wear were examined using a multivariate logistic regression model. Occlusal wear was recorded using the individual (personal) tooth-wear index and was age-adjusted by determining high occlusal wear for every 10-year age group as index values \geq 90th percentile. The results of the study revealed that high occlusal wear was correlated with frequent bruxism and an odds ratio of 2.5. However, other independent variables also exhibited a correlation with high occlusal wear: male gender, odds ratio 2.2; loss of molar occlusal contact, odds ratio from 1.5 to 3.1; edge-to-edge relation of incisors, odds ratio 1.7; unilateral bucco-lingual cusp-to-cusp relation, odds ratio 1.8; and unemployment, odds ratio 1.6. Bruxism is certainly not the only factor related to tooth wear, neither the most important one.

Tooth wear with reference to lateral excursions Quantitative and qualitative analyses of wear facets of dental casts were introduced to determine the severity and location of dental attrition (83). The study was first

conducted on 222 normal young adults (19–40 years of age, mean age 24.6; 120 males, 102 females), designed to investigate the possible relationships between dental attrition and early signs of TMD plus other factors, e.g. age, gender, orthodontic class and selected occlusal variables. Then this method was applied to a series of epidemiological studies on TMD (84) and the aetiology of attrition (48).

The severity of attrition facets was quantified by the following five-point scale:

- 0: no wear;
- 1: minimal wear of cusp or incisal tips;
- 2: facets parallel to the normal planes of contour;
- 3: noticeable flattening of cusps or incisal edges;
- 4: total loss of contour and dentinal exposure when identifiable.

Basically, this severity scoring was a brief form of the established criteria (85). The facets were graded in seven zones: incisor; right and left canine; right and left premolar and molar laterotrusion ('A' and 'C', Fig. 1); and right and left premolar and molar mediotrusion ('B', Fig. 1). The highest grade in each of the seven segments was recorded.

The maximum possible laterotrusion score for the posterior teeth was 2 premolar and 2 molar zones \times 2 facet locations \times a maximum severity score of 4 = 32. The maximum possible mediotrusion score for the posterior teeth was 2 premolar and 2 molar zones \times 1 facet location \times a maximum severity score of 4 = 16. The maximum possible score for the anterior teeth was 1 incisor and 2 canine zones \times 1 facet location \times a maximum severity score of 4 = 12.

The specific feature of this method is that the attrition facets for the posterior teeth are categorized with reference to lateral excursions (i.e. laterotrusion and mediotrusion). This method also makes it possible to

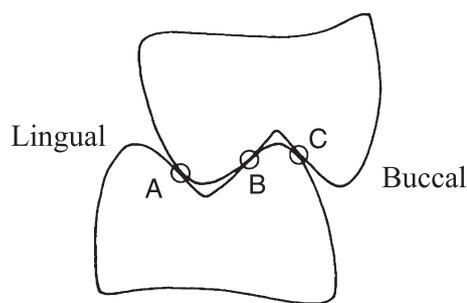


Fig. 1. Classification of locations of posterior tooth contact. Locations A and C correspond to contact in laterotrusion and location B to mediotrusion [after Seligman *et al.* (83)].

evaluate the degree of individual (personal) tooth wear. One of the benefits of this method includes the 'off-line' or 'delayed' evaluation of dental attrition along with various dental factors. However, taking impressions and the fabrication of dental casts are required, and it is obvious that errors during these procedures affect the results.

The epidemiological study of 222 normal young adults revealed that higher attrition scores were not associated with more awareness of bruxism (Mann-Whitney *U*-test) (83). Again, the occurrence of bruxism was evaluated by a simple questionnaire (yes or no) and no objective assessment of bruxism was conducted.

Severity and progression of tooth wear for each tooth The method for analyzing tooth wear using study casts was introduced to evaluate not only the severity but also the progression of incisal and occlusal tooth wear for each tooth (86). A longitudinal prospective study was conducted on 540 teeth in 20 individuals (10 males, 10 females; 16–56 years of age, mean age 32 years) for 18 months, revealing that occlusal wear scores in the incisor and canine regions were significantly higher than those in the posterior region and the overall progression in the observation period was minimal.

The severity of incisal and occlusal tooth wear for each tooth was quantified by the following five-point scale: 0: no visible facets in the enamel. Occlusal/incisal morphology intact;

1: marked wear facets in the enamel. Occlusal/incisal morphology altered;

2: wear into the dentine. The dentine exposed occlusally/incisally or adjacent tooth surface. Occlusal/incisal morphology changed in shape with height reduction of the crown;

3: extensive wear into the dentine. Larger dentine area (>2 mm²) exposed occlusally/incisally or adjacent tooth surface. Occlusal/incisal morphology totally lost locally or generally. Substantial loss of crown height;

4: wear into secondary dentine (verified by photographs).

The progression of tooth wear for each tooth was quantified by the following four-point scale:

0: no definite change in previously recorded area(s);

1: visible change, such as an increase of the facet area(s), without any measurable reduction of crown length; occlusal/incisal morphology changed in shape compared with the first examination;

2: measurable reduction of crown length, <1 mm;

3: marked reduction of crown length, >1 mm.

This method makes it possible to evaluate the severity and progression of tooth wear for each tooth. Here too, the criteria of the score seem to be relatively clear. However, it may be difficult to apply this method to individuals who exhibit fewer existing teeth. The interobserver concordance between two examiners in the initial evaluation (403 teeth) was 88% and their agreement in the follow-up evaluation (247 teeth) was 91% (86). Awareness of bruxism was reported by 17 of 20 individuals (85%) and only 2.4% of the 540 teeth examined exhibited a score of 0 for severity. No further analysis was performed on the relationship between bruxism and tooth wear.

Tooth wear is often used by the clinician as indicating the existence of bruxism because substantial tooth wear provides information about a history of forceful tooth-to-tooth contact. However, tooth wear is a cumulative record of both functional and parafunctional wear, and it neither prove ongoing bruxism activity nor it can indicate if the subject has static tooth clenching. It is also evident that multiple factors, e.g. age, gender, bruxism, occlusal condition, diet and drink are associated with tooth wear. Especially, it is suggested that erosion by acidic drink could be a major contributing factor to tooth wear (77). Both clinical and experimental observations show that each mechanism of tooth wear rarely acts alone but interacts with others. Although there are researches reporting significant association between bruxism and tooth wear, the evaluation of tooth wear for predicting actual bruxism activity and its severity is still controversial, and it is difficult to estimate the degree of the contribution of bruxism to tooth wear (77). Consequently, a universally applicable tooth-wear measuring system has not yet been established.

Intra-oral appliance

As described above, it is worthwhile to measure bruxism activity 'directly' because evaluation of existing tooth wear does not provide evidence of current bruxism. Several researchers have tried to measure sleep bruxism activity directly using an intra-oral appliance (40, 87–91).

The evaluation of sleep bruxism activity using the intra-oral appliance can be classified into two groups: (i) observation of wear facets of the intra-oral appliance

(87–90) and (ii) measurement of bite force loaded on the intra-oral appliance (40, 91).

Wear of intra-oral appliance

Wear facets on intra-oral appliance Holmgren *et al.* (87) reported a repetitive wear pattern on the occlusal splint. They observed wear facets on full-arch acrylic resin splints, which reappeared in the same location with a similar pattern and direction, even after adjustment of the splints. Also, Koriath *et al.* (89) reported that para-functional nocturnal dental activity on full-arch occlusal stabilization splints resulted in wear, which was both asymmetric and uneven. Unfortunately, no confirmation of the reliability of these methods has been reported.

Bruxcore plate The Bruxcore Bruxism-Monitoring Device (BBMD), an intra-oral appliance, was originally introduced as a device for measuring sleep bruxism activity objectively (92) and the Bruxcore plate* has been commercially available as a device to evaluate bruxism activity by counting the number of abraded microdots on its surface and by scoring the volumetric magnitude of abrasion. The BBMD is a 0.51-mm-thick polyvinyl chloride plate that consists of four layers with two alternating colours and a halftone dot screen on the topmost surface. The device is fabricated using a plate, which is heated and pressed over a maxillary dental cast and is put on the maxillary dental arch of the subject. The number of missing microdots is counted to assess the abraded area and the number of layers uncovered represents the depth parameter. Both parameters are combined to obtain an index for the amount of bruxism activity.

Unfortunately, one of the technical problems with BBMD is that the thickness of the device becomes uneven in the press-forming process and the adjustment of the surface, and this can influence the accuracy of assessment. Another disadvantage of this method is that it might be difficult to count a large number of missing dots with good precision. Isacson *et al.* (88) reported variability in the quantification of abrasion on the BBMD, where three different methods for measuring the abraded area were employed. Two raters determined the uncovered areas on the device by calculating the number of missing microdots viewed by a microscope with a reference scale, a microscope

without a reference scale and a computer-aided method. The results showed a small intra-observer variation of 5%, whereas the interobserver variation was statistically significant for all the three methods.

Recently, the reliability of a newly developed semi-automatic computer-based method using BBMD, in which the abraded area was counted in pixel, was evaluated (93). There was a very high inter-rater reliability of ICC = 0.99. The results also showed a sensitivity of 79.2% and a specificity of 95.2% with a selected cut-off point (abraded area of 2900 pixel) to distinguish bruxers from normal controls, and the clinical diagnosis based on the criteria of the American Sleep Disorders Association (72) was correctly predicted in 97.4% of the sleep bruxism individuals and 66.7% of the controls.

Finally, Pierce and Gale (39) conducted a 6-month clinical study in which both Bruxcore plates and portable EMG recordings were employed in 40 subjects for 14 nights. The event or duration of bruxism analysed with the EMG data did not correlate significantly with Bruxcore plate scores. In this respect, the bruxism activity assessed by Bruxcore plates may not be the same as that measured with a portable EMG device. Overall, the use of BBMD can record the wear of the appliance during sleep. However, the relationship between wear and bruxism activity is still questionable (21).

Detection of bite force

Takeuchi *et al.* (94) developed a recording device for sleep bruxism, an intra-splint force detector (ISFD), which uses an intra-oral appliance to measure the force being produced by tooth contact onto the appliance. The force is detected using a thin, deformation-sensitive piezoelectric film, which is embedded 1–2 mm below the occlusal surface of the appliance. It was confirmed that the duration of bruxism events during simulated bruxism, i.e. clenching, grinding, tapping and rhythmic clenching, evaluated with the ISFD was correlated with that of the masseter EMG. Even though the ISFD did not correctly capture force magnitudes during sustained clenching because of the characteristic of the piezoelectric film, i.e. this transducer is best at detecting rapid changes in force, not static forces, the measured durations established with the minimum threshold detection levels (5% for EMG and 10% for ISFD) significantly correlated ($r = 0.9985$). It was noted, however, the ISFD was not suitable for detecting the

*Bruxcore®, Boston, MA, USA.

magnitude of force during steady-state clenching behaviour.

Further, Baba *et al.* (91) also reported a good concordance between bruxism events during sleep recorded with the masseter muscle EMG and those with the ISFD. A nocturnal polysomnographic study performed on one subject revealed that the ISFD had a sensitivity of 0.89 when the masseter muscle EMG was used as the gold standard. The correlation coefficient between the duration of events detected by the ISFD and the EMG was also 0.89.

Overall, these results suggest that the ISFD is reasonably reliable for detecting bruxism events as reflected in forceful tooth-to-splint contacts during sleep.

The bite force during sleep-associated bruxism was measured with experimentally fabricated maxillary and mandibular acrylic intra-oral appliances (40). Two miniature strain-gauge transducers were placed at the right and left first molar regions of the maxillary intra-oral appliance and thin metal plates, which were in contact with the transducers were attached to the lower appliance. The recording was conducted in 10 subjects for three nights, revealing that the mean nocturnal bite force of detected bruxism events was 220.6 ± 127.5 N, and the mean duration was 7.1 ± 5.3 s. The highest amplitude of the nocturnal bite force in individual subjects was 414.8 N (range 153.0–796.3 N) and revealed that the bite force during sleep bruxism could exceed the amplitude of the maximum voluntary bite force during the daytime. Although bite force measurement provides objective assessment of bruxism, it remains at the experimental level resulting from problems in fabrication and usage, as well as cost.

The assessment of wear on the intra-oral device or bite force loaded on the intra-oral appliance seemed to be able to evaluate current sleep bruxism. The quantitative methods allow for the assessment of magnitude or duration of bruxism activity, although their reliability has not yet been evaluated in a clinical situation (39, 91). It is obvious, however, that the major problem of these methods is that subjects have to wear the intra-oral device and this may change the original bruxism activity. Well-designed comparative studies with the 'gold standard', e.g. polysomnographic recordings, are required to evaluate the possible influences of the intra-oral device on the original bruxism activity.

Masticatory muscle electromyographic recording

The measurement of bruxism activity using the intra-oral appliance has an advantage over previously mentioned clinical assessment modalities such as the use of a questionnaire, clinical examination or observation of tooth wear as it enables the assessment of actual bruxism activity. However, there is a high possibility that wearing the device affects natural bruxism activity. Among the various methods for the assessment of bruxism, the EMG recording has been commonly used to measure actual sleep bruxism activity directly. The principal advantage of this method is that the occurrence of bruxism can be assessed without intra-oral devices, which may change natural bruxism activity, even though the subject has to put on electrodes or other sensors.

Portable EMG recording device

A portable (ambulatory) EMG measurement system was originally developed from the device for recording brain waves to measure bruxism objectively in a daily life environment and is considered to be suitable for multiple-night recording of bruxism in the subject's home environment with minimal expense.

Starting in the 1970s, sleep bruxism episodes were measured over an extended period in patients' homes with the use of battery-operated EMG recording devices (95). In their earlier form, these instruments only provided cumulative data about the masseter activity levels above threshold and they did not give second-by-second bruxism information. After the introduction of these portable EMG recording devices, various studies on bruxism were conducted using them (46, 96, 97). Then the portable EMG recording system has become easy for subjects to operate and can measure masticatory muscle activity more minutely, i.e. the number, duration and magnitude of bruxism events can be evaluated with fair accuracy (18, 98–100). Criteria for the detection of sleep bruxism with the portable EMG recording system have been suggested (99) but their validity in a large population has not yet been confirmed.

The detection power of sleep bruxism is generally considered inferior to that in a sleep laboratory because other confounding oro-facial activities (e.g. sight, coughing and talking) cannot be discriminated from

sleep bruxism (12, 14, 18, 47, 99). Also, other sleep disorders cannot be ruled out or other physiological changes related to sleep bruxism (e.g. microarousal, tachycardia and sleep-stage shift) cannot be monitored (12, 14). The implement for recording the heart rate was recommended as one of the compensatory measures for improving the accuracy of sleep bruxism recognition (47, 101). Also, a surface EMG electrode with a built-in buffer-amplifier (102) and a cordless type of EMG measurement system (103) was developed to improve the reliability of recordings.

Miniature self-contained EMG detector–analyser

Recently, a miniature self-contained EMG detector–analyser (BiteStrip[®]) was developed as a screening test for moderate- to high-level bruxers (42). The device, which is comprised of EMG electrodes, an amplifier, a central processing unit (CPU) with software, a display which presents the outcome in the morning, a light-emitting diode and a lithium battery records the number of masseter muscle activities above a preset threshold. The special feature of this device is that the number of bruxism events can be objectively estimated by simply attaching it to the skin over the masseter muscle. Minakuchi and Clark (42) examined the sensitivity and specificity of the BiteStrip[®] recording versus masseter EMG recordings during a polysomnogram in five suspected bruxers. Overall, there was good specificity for all subjects but fair sensitivity for subjects that exhibit moderate- to high-levels of EMG determined bruxism. The device might be a cost-effective tool for screening moderate- to high-level bruxism subjects.

More recently, a miniature self-contained EMG detector–analyser with a biofeedback function (Grindcare[®]) was developed as a detector and biofeedback device for sleep bruxism (43) (Fig. 2). It is comprised of EMG and stimulation electrodes, a microprocessor, a memory for data storage, a display for user interface, light-emitting diodes, a rechargeable battery, a plug-in USB connector for data connection to a PC and to a battery charger, and a strap for carrying the apparatus around the forehead. It enables the online recording of EMG activity of the anterior temporalis muscle, online processing of EMG signals to detect tooth grinding and clenching and also biofeedback stimulation for reducing sleep bruxism activities. Although scientific confirmation is needed for a large population, it is considered as



Fig. 2. Miniature self-contained EMG detector–analyser with biofeedback function (Grindcare[®]) (courtesy of Prof. Peter Svensson).

one of the potent devices for detecting and also for managing sleep bruxism.

The portable EMG recording system enables multiple-night recording in a natural environment for the subject with minimal expense. It is generally recognized that the quality of EMG signals can be affected by the location of the electrodes, positioning of the head and body, and the levels of skin resistance (104). A critical artefact is induced if the electrode is detached from the skin over the muscle. The movements of the wire and/or electrode could result in contamination of the signals. It is difficult to control these factors in the subject's home environment perfectly. Moreover, other confounding oro-facial activities cannot be discriminated from sleep bruxism if audio and video recordings are not simultaneously conducted (12, 14, 47). In spite of these problems, EMG recordings taken from the jaw-closing muscles have been the most frequent source for detailed information about actual sleep bruxism activity. Finally, a miniature self-contained EMG detector–analyser seems to be a potentially useful device for

detecting sleep bruxism if its reliability is verified in a large population.

Polysomnography

Polysomnographic (sleep laboratory) recordings for sleep bruxism generally include electroencephalogram, EMG, electrocardiogram and thermally sensitive resistor (monitoring air flow) signals along with simultaneous audio–video recordings. Sleep bruxism activity is assessed based on EMG activity in the masticatory muscles (masseter and/or temporalis). Because the sleep laboratory setting offers a highly controlled recording environment, other sleep disorders (e.g. sleep apnoea and insomnia) can be ruled out and sleep bruxism can be discriminated from other oro-facial activities (e.g. myclonus, swallowing and coughing) that occur during sleep (14, 44, 105). Physiological changes related to sleep bruxism (e.g. microarousal, tachycardia and sleep-stage shift) can also be monitored. Hence, a polysomnographic study allows for multidimensional analyses of sleep-related physiological behaviours and studies on sleep laboratory EMG-based assessments are reported to be very reliable (45–47).

Although polysomnography is considered as the gold standard, there are certain problems. One major limitation is that a change in the environment for sleep may influence the actual behaviour of bruxism. Another limitation with polysomnography is that the multiple-night recording is very expensive but because the occurrence of sleep bruxism varies over a number of nights (54, 58), multiple-night recording is necessary to understand the entities of sleep bruxism (56).

Conclusion

There are no definitively reliable methods for assessing bruxism in the clinic which have reasonable diagnostic validity, technical validity, effects on therapeutic decisions and cost-effectiveness to date.

As questionnaires and clinical examination are easiest to apply in everyday practice, it is considered that one future direction should be to refine the items for questionnaires and clinical examination. The clinical diagnostic criteria of the AASM seem to be useful among the diagnostic tools that have been reported to date and their clinical validity might be improved with modifications. Although, in general, tooth wear is considered to be analogous to bruxism, the severity of

tooth wear does not always reflect the patient's bruxism level because tooth wear could be the result of combinations of three processes namely attrition, abrasion and erosion. One must be very careful as to whether the result or effect of bruxism should be examined, or whether the bruxism activity itself should be assessed when selecting/arranging the items for questionnaires and clinical examination.

Another possible future direction for the assessment of bruxism, which should be addressed, is to establish a method that can directly measure actual bruxism activity objectively using a handy device which can be routinely applied to patients. In this regard, devices such as a miniature self-contained EMG detector–analyser have potential if they are scientifically verified in a large population and proven to be useful in the clinic in terms of easy use as well as cost-effectiveness.

Research on bruxism has generally been focused on issues in conjunction with sleep, pain and TMD. From the dentist's point of view, however, more clinical studies, which examine the clinical impact on oral structures and influence the decision-making process for successful dental treatment, are expected.

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