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Review Article
Bruxism physiology and pathology: an overview for clinicians*

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SUMMARY Awake bruxism is defined as the awareness of jaw clenching. Its prevalence is reported to be 20% among the adult population. Awake bruxism is mainly associated with nervous tic and reactions to stress. The physiology and pathology of awake bruxism is unknown, although stress and anxiety are considered to be risk factors. During sleep, awareness of tooth grinding (as noted by sleep partner or family members) is reported by 8% of the population. Sleep bruxism is a behaviour that was recently classified as a 'sleep-related movement disorder'. There is limited evidence to support the role of occlusal factors in the aetiology of sleep bruxism. Recent publications suggest that sleep bruxism is secondary to sleep-related micro-arousals (defined by a rise in autonomic cardiac and respiratory activity that tends to be repeated 8–14 times per hour of sleep). The putative roles of hereditary (genetic) factors and of upper airway resistance in the genesis of rhythmic masticatory muscle activity and of sleep bruxism are under investigation. Moreover, rhythmic masticatory muscle activity in sleep bruxism peaks in the minutes before rapid eye movement sleep, which suggests that some mechanism related to sleep stage transitions exerts an influence on the motor neurons that facilitate the onset of sleep bruxism. Finally, it remains to be clarified when bruxism, as a behaviour found in an otherwise healthy population, becomes a disorder, i.e. associated with consequences (e.g. tooth damage, pain and social/marital conflict) requires intervention by a clinician.

KEYWORDS: bruxism, awake, sleep, tooth grinding, movement disorders, pathophysiology, scoring, monitoring

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Tooth grinding (TG) is an activity of major concern to dentists because of its consequences: tooth destruction, breakage of dental restoration or rehabilitation, exacerbation of temporomandibular disorders or induction of temporal tension headache and grinding sounds that may interfere with the sleep of family or life partners. The common belief that tooth wear is a specific marker of bruxism is outdated because the cause (bruxism) and the effect (tooth wear) could have occurred months and years before the patient consultation. One of the main challenges for the dentist is to identify whether the patient presents awake or sleep bruxism (SB) according to the patient's motive for the consultation, i.e. consequences, such as tooth damage, pain or complaints of noise. Electronic recordings (muscles, heart, respiration and brain activity) made in a laboratory or home environment are a recognized method for quantifying SB frequency. The specificity of scoring is increased when audio and video signals are collected in parallel because numerous usual oromandibular activities such as chewing, swallowing and sleep talking can be

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recorded and are difficult to discriminate from clenching or oromandibular tics. The primary focus of this paper is to describe the physiology and pathology of SB. The word pathophysiology is used with the following definition: *Pathophysiology is the functional change that accompanies a particular syndrome or disease*. (Merriam–Webster)(1).

Definition, prevalence and consequences of both awake and SB

Bruxism is defined as a diurnal or nocturnal parafunctional activity that includes clenching, bracing, gnashing and grinding of teeth (Table 1) (2–4). In awake subjects, bruxism is defined as the awareness of jaw clenching. The prevalence of bruxism is reported to be 20% among the adult population. Bruxism occurs predominantly among females. Awake bruxism can be associated with tics (medical definition), or with a 'parafunction' that is believed to be associated with life stress caused by familial responsibilities or work pressure (5–7). Such suggestions are not strongly evidence based; they are mainly derived from the existing knowledge and the practical experience of clinicians or academics. Daytime unusual oromandibular activities or awake bruxism need to be discriminated from several types of usual activities. Usual orofacial activities include functional chewing, swallowing and speaking. Unusual activities (or parafunctions) are non-functional oromandibular or lingual activities that may include, alone or in combination: jaw clenching, bruxism, TG (rarely observed during daytime in the absence of medication or a neurological disorder such as tardive dyskinesia), tooth tapping, cheek, lip or tongue biting, nail biting, tongue pushing against teeth, licking lips, tongue protrusion, gum chewing, object biting (e.g. cigarette, pipe, pencil, candy and instrument), hypersalivation/swallowing, backward or forward or lateral head or jaw posture (e.g. telephone resting on shoulder and computer work)(8–10). According to self-reports, most oral 'parafunctions' such as clenching, nail biting and even TG during sleep persist over years (11, 12). It is easy for dentists to evaluate whether the 'parafunction' is voluntarily induced (e.g. gum chewing) or if it is an involuntary activity related to a habit or a tic (e.g. tongue pushing, clenching). However, it is much more difficult to discriminate awake bruxism with or without TG from early signs of Parkinson's disease or other neurodegenerative diseases such as multiple system atrophy or tardive dyskinesia (i.e. jaw tremor or lip biting not because of stress, tongue fly-catcher movements)(13–16). Dentists need to be able to recognize the oromandibular manifestations of the above-mentioned movement disorders so that patients can be referred to a neurologist for diagnosis and management. In addition, dentists need to evaluate the quality of the dental prosthesis. Our group recently showed that unstable dentures exacerbate oromandibular manifestations (17). Moreover, for these patients, dental treatments are to be restricted to the essential, i.e. periodontal maintenance. Extensive oral rehabilitations such as prosthodontic and orthodontic treatments are not indicated.

Sleep bruxism is an oromandibular behaviour that is defined as a stereotyped movement disorder occurring during sleep and characterized by TG and/or clenching (18). Sleep bruxism was recently classified as a 'sleep-related movement disorder' according to the recent International Classification of Sleep Disorder (3). It remains to be assessed when SB, as a behaviour found in the sleep of otherwise healthy subjects, becomes a disorder. This 'grey zone' is most frequently encoun-

Table 1. Definition of both awake and sleep bruxism

Source	Definition
American Academy of Orofacial Pain (2008)	A diurnal or nocturnal parafunctional activity including clenching, bracing, gnashing, and grinding of the teeth. In the absence of subjective awareness, past bruxism can be inferred from presence of clear wear facets that are not interpreted to be the result of masticatory function. Contemporary bruxism can be observed through sleep laboratory recordings.
The Academy of Prosthodontics (2005)	1. The parafunctional grinding of teeth. 2. An oral habit consisting of involuntary rhythmic or spasmodic non-functional gnashing, grinding or clenching of teeth, in other than chewing movements of the mandible, which may lead to occlusal trauma – called also tooth grinding, occlusal neurosis.
The International Classification of Sleep Disorders (2005)	Sleep-related bruxism is an oral activity characterized by grinding or clenching of the teeth during sleep, usually associated with sleep arousals.

tered: (i) in diagnoses based on the consequences of SB (i.e. presence of tooth damage, complaint of headache and orofacial pain or concomitant temporomandibular disorder and interference in social/marital relations); (ii) when discrimination is made between usual and unusual oromandibular activities during sleep using ambulatory or laboratory polygraph as discussed below; (iii) when the physiology or the pathology is under investigation.

Movement disorders during sleep can be further classified as simple such as SB or periodic limb movement during sleep (PLMS) or as complex, such as rapid eye movement (REM) behaviour disorder (RBD) or epileptic motor activity (19). In the presence of medical disorders, medication or drug use, TG (either while awake or asleep) is described as secondary or iatrogenic (5, 20, 21). In normal subjects, SB-TG is described as primary and is reported by 8% of the adult population. Based on self-report, its prevalence decreases with age from 14% to 18% in childhood to 3% in the elderly (22–25). No gender difference is observed. Some of the consequences of SB are tooth destruction, temporomandibular joint and muscle pain or jaw lock, temporal headaches, cheek-biting (worse in the presence of xerostomia) and marital problems as a result of grinding sounds (5, 26). Interestingly, some studies based on self-report show an estimated odds ratio (OR = ratio of the odds of events occurring in one group to the odds of it occurring in another group) of temporomandibular disorders or chronic myofascial pain in masticatory muscles from 4·2 up to 8·4 (27, 28). Up to 65% of SB patients may report headaches mainly in the temporal area. This finding may suggest a link with either stress or respiratory disturbance (29, 30). The noise generated by TG can greatly disturb the sleep of room partners; some SB patients prefer to sleep alone because of the embarrassing noises generated during sleep. The following major risk factors have been suggested to exacerbate SB-TG: (i) smoking, caffeine and heavy alcohol drinking (24, 31); (ii) type A personality – anxiety (5, 24, 32–34); (iii) sleep disorders such as snoring (OR = 1·4), sleep apnoea (OR = 1·8) or PLMS (concomitant) in 10% (22, 24, 26, 35). Note that approximately 60% to 80% of SB episodes are associated with brief non-periodic body movements (36, 37). For a better understanding of the following sections, we would like to remind readers that sleep is divided into non-REM (light stages 1 & 2, deep stages 3 & 4 sleep) and REM (active sleep) periods that are repeated every 90–110 min (the ultradian cycle)(38). The evidence shows that most SB episodes tend to occur during light non-REM sleep stages 1 & 2, about 10% of SB episodes occur during REM sleep and the frequency of the episodes peaks during the period of sleep transition preceding REM sleep (39).

Based on a questionnaire in the absence of direct measurements, researchers have estimated that an overlap between awake and SB is present in one out of five patients in the general population (6). In a SB patient population observed in a sleep laboratory, researchers found the presence of concomitant awareness of TG as a complaint of clenching in over 74% of subjects (40).

Recognition and diagnosis of awake and SB: criteria and methodological issues

Researchers identify 'parafunctions' during an awake state by means of direct questions and visual observation of patient behaviour. If the dentist suspects tardive dyskinesia based on the patient's description of the unusual movement, he/she may suggest the use of home video recordings to confirm the patient's report because such atypical movements may not be present during a rapid dental examination. The most atypical movements are observed when the patient is going about daily routines (e.g. oral dyskinesia in schizophrenic patients). It is tempting to use single electromyograms (EMG) in this case, but again, discriminating between usual and unusual movements is a major challenge and clinicians must be able to distinguish usual orofacial activities such as chewing, swallowing and speaking from unusual activities (41, 42). An unusual activity is empirically recognized as being an oromandibular movement that is too frequent and/or too intense/powerful and that interferes with function (such as speaking or eating) and social activities. These movements may have medical causes or may have a psychosocial source even in the absence of any imaging or laboratory medical findings. The types of movement disorders encountered in the oromandibular area include: 'involuntary' chewing-like movements, oromandibular myoclonus (e.g. tooth tapping during wake or sleep states that could be associated with epilepsy), excessive swallowing, oral tardive or idiopathic dyskinesia (e.g. tongue protrusion, air expiration or lip sucking), Parkinsonian tremor (chin, lip and tongue),

Gilles de la Tourette syndrome (14, 43). Oromandibular movements can be described as 'usual'; 'unusual but acceptable' or 'abnormal'.

During sleep, the most frequent unusual oromandibular or orofacial movements include SB-TG, grunting, tics, snoring or sleep apnoea. All of these movements can be discriminated or diagnosed based on: (i) the report of a sleeping partner or parent of the unusual oromandibular activity and/or sounds generated; (ii) clinical examination confirming the presence of tooth wear or jaw muscle hypertrophy (a less reliable method as these signs may have no direct temporal link with the patient's complaint or motive for consultation)(5, 65); (iii) polygraphic and audio-video recording of muscle activity with at least one EMG channel of masseter and ideally with full montage including muscle activity from EMGs of jaws and legs, heart rate from electrocardiogram (ECG), brain activity from electroencephalogram (EEG), eye movement for REM scoring from electrooculogram (34, 42, 44–54). As sleep recordings may be made in a home setting with an ambulatory system or in a sleep laboratory with either a standard or an ambulatory system (e.g. amplifiers with dedicated software for data acquisition and analysis), the major challenge is to discriminate the oromandibular activity of interest from other motor behaviour. The use of audio and video recordings together with sleep polygraphic recordings remains the standard mode of assessing sleep movement disorders because it permits a more valid and reliable quantitative assessment of oromandibular activities. However, laboratory recording is expensive and time consuming in terms of data analysis and it is not very representative of sleep in the natural milieu. Some researchers have proposed alternatives to the so-called gold standard tool for diagnosis (e.g. polygraphic and audio-video recording)(55). These alternatives include recordings made with a digital camera set up beside the bed in the home setting or the use of a tooth contact sensor inserted in an oral appliance or a mandibular movement sensor (47, 56, 57). However, a comparison of these alternatives with the so-called gold standard remains to be made under controlled and blind conditions. Interestingly, a bite force strain-gauge measurement system (between maxillary and mandibular teeth) has also been developed (58, 59). However, this measurement system remains to be validated in relation to the current standard.

Scoring is a mandatory task that requires training and precision no matter what standard laboratory or ambulatory recording system a researcher uses. As described in detail elsewhere, three types of EMG signals can be scored for SB diagnosis (3, 49, 60). Phasic or rhythmic episodes are recognized if at least three brief EMG bursts (0·25 to 2·0 seconds) are observed and are separated by two interburst intervals. Tonic or sustained episodes are scored if the EMG burst is longer than 2 seconds. A combination of these two patterns is called a mixed episode. As described above, please note that most SB-TG EMG activities are scored in light sleep stages 1 and 2 and more rarely in REM (less than 10%)(39, 49, 61, 62). As approximately 90% of EMG events related to SB-TG in healthy young subjects are composed of phasic and mixed types of EMG episodes, we have suggested that the most typical EMG pattern related to SB be called rhythmic masticatory muscle activity (RMMA)(49, 63). In normal subjects, RMMA occurs during sleep about once per hour in comparison to 2–12 times per hour in SB patients. Again, whatever method researchers use to measure SB, a specific assessment of the type of oromandibular activity is mandatory because we have observed that non-functional chewing-like movements, repetitive opening-closing eye movements and lip sucking or biting represent close to 85% of masseter and temporalis muscle EMG signals recorded in normal subjects. Only 15% of these EMG signals are typical of the RMMA that usually characterizes SB (49). In SB patients, non-specific oromandibular activities represent about 30% of all EMG signals. Moreover, researchers need to identify the presence of non-SB-related oromandibular activities such as myoclonus (observed in 10% of SB patients in the absence of epileptic-related spikes on an EEG), swallowing, coughing, grunting and tooth tapping in quantitative studies that test physiological hypotheses or control for the effect of an oral appliance or medication in randomized controlled trials (49, 60, 64).

On the basis of our sleep laboratory data from young and healthy subjects, we suggest that the final diagnosis of *moderate to severe* SB be based on the following criteria: (i) the presence of frequent grinding noise during sleep for at least five nights a week for the past 3–6 months as confirmed by a sleeping partner; (ii) one of the following: tooth wear (at least one sextant afflicted), enamel reduction to dentine with some loss of crown height according to classes 1 and 2, masseteric muscle hypertrophia (empirical criteria = a 2–3-fold

volume increase from rest to maximal voluntary contraction); (adapted from 65) (iii) positive polygraphic diagnosis of SB according to our validated criteria: at least two episodes of grinding noise per night, more than four episodes of SB and more than 25 bruxism bursts per hour of sleep (49, 60, 66). These *SB research diagnostic criteria* (SB-RDC) can correctly classify 83·3% of moderate to severe bruxers (grinding >5 nights per week) and 81·3% of controls. We recently revised the above SB-RDC using a large sample of 100 SB patients that included mild (occasional) tooth grinders to severe (frequent) tooth grinders. We found that when such a wide spectrum of the SB population is used, the sensitivity ('power' to detect patients) drops to 55% and the specificity ('power' to exclude normal subjects) remains at 84% (40). Moreover, the analysis revealed three clusters of SB patients: (i) a low frequency (LF) group (mean ± s.e. RMMA per hour of sleep = 2·3 ± 0·2; n = 49 subjects); (ii) a moderate group (mean ± s.e. RMMA per hour of sleep = 6·2 ± 0·3; n = 37 subjects); (iii) a high group (mean ± s.e. RMMA per hour of sleep = 9·6 ± 0·8; n = 13 subjects). It is interesting to note that 100% of subjects in the high group, 89% in the moderate group and 47% in the low group reported TG occurring at least three times a week at the recruitment interview. It was also surprising to find that 8 out of the 42 controls used for this study showed grinding episodes per night.

Obviously, we need to make further investigation of the application of this research 'mean cut off' criteria to the clinical setting in terms of using it to identify SB behaviour versus disorder. Figure 1 shows a possible distribution of SB patients based on research findings using polygraph, audio, video recording and scoring methods. Interestingly, compared with control subjects, all SB patients have an OR of 4·5 for reporting occasional to frequent headaches or migraines. Moreover, morning fatigue is reported by 41% of SB patients from whom an OR of 7·7 was extracted in comparison with controls (67). These data suggest that SB patients may have several somatic complaints or co-morbidities that need more comprehensive investigation to capture the cause and consequences of chronic SB, pain and headache. Finally, researchers need to be aware that the so-called 'first night effect' in the sleep laboratory may result in an overestimation and an increase in the variability of sleep parameters. It has also been recognized that SB varies across nights (68); for example, the estimated variability from night to night for the

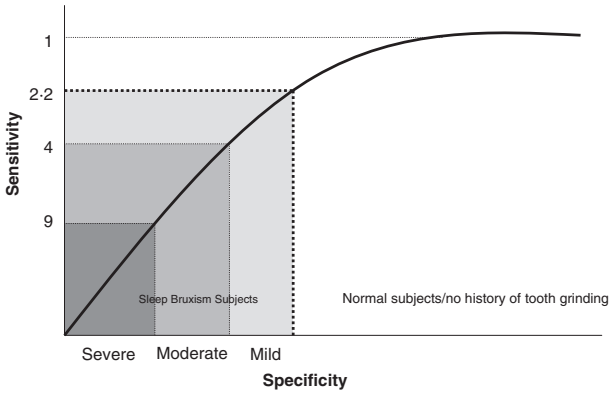

Fig. 1. Distribution (cut-off range) of the frequency of orofacial muscle activity during sleep. The sensitivity scale represents the 'power' to detect SB patients. The specificity represents the 'power' to exclude normal subjects. Sleep bruxism (SB) subjects and controls are separated by the dark dotted line and the three clusters of SB subjects (mild, moderate, severe) are separated by pale dotted lines.

frequency of SB motor activity (# SB episode per hour sleep) is 24% and the estimated variability of TG sounds is over 50% (50, 69).

When planning a clinical study or research trial, the investigator is required to identify whether the patient is using psychotropic medication or drugs known to influence sleep or motor behaviour such as amphetamines, benzodiazepines, L-dopa, neuroleptics, tricyclic or selective serotonin reuptake inhibitor (SSRI) antidepressants, regular alcohol or cigarette smoking. In addition, investigators need to check for the presence of concomitant neurological or psychiatric disorders, more specifically epilepsy, Parkinson's disease and schizophrenia with or without oral tardive dyskinesia (8, 10, 14). Also, researchers may observe concomitant sleep disorders such as PLMS (identified with EMG of anterior tibialis muscle), snoring and sleep apnoea-hypopnoea syndrome (SAHS) and more rarely epileptic sleep activity, RBD (8).

Respiratory Disturbances (RD) during sleep

Dentists studying SB also need to be aware that sleep breathing disorders such as snoring and airway resistance with or without apnoea-hypopnoea may be concomitant with SB. The first and most prevalent RD during sleep is snoring, which is defined as an oropharyngeal sound caused by air turbulence inducing soft tissue vibrations. Several conditions may make

snoring worse: sleeping in a supine position, obesity, retrognathia, deep palate, large tonsil-adenoids, alcohol or food intake and sleep deprivation. Like SB-TG, most complaints about snoring come from sleep partners. Snoring is present in over 30% of the adult population and in 3–10% of children. It has been suggested that snoring is a risk factor for obstructive sleep apnoea (70).

Upper airway resistance syndrome (UARS) is characterized by an increase of inspiratory effort (flow limitation <50%) and an increase in the number of sleep micro-arousals (MAs). Micro-arousals constitute one of the markers of sleep fragmentation and are possibly linked to daytime fatigue and sleepiness. The airway resistance is mainly because of the narrowing of the pharynx, but unlike sleep apnoea, there is no oxygen desaturation below 4%. It was recently suggested that this respiratory problem be named 'Respiratory Effort-related Arousal' (3). A recent survey in a medical clinic found that patients suffering from respiratory syndromes related to airway limitation tend to report more somatic complaints such as insomnia, headaches, irritable bowel syndrome and interestingly for this paper, bruxism, without knowing if it was the awake or sleep type (70).

Sleep apnoea-hypopnoea syndrome (SAHS) can be obstructive or central (lack of neuronal drive) or mixed. SAHS is characterized by the repetitive absence of ventilation with cessation of breathing for 10 seconds and oxygen desaturation exceeding 4%. An index of RD is given for the number of apnoea (complete cessation of breathing) and hypopnoea (partial cessation) per hour of sleep (RDI). Subjects with an RDI of 5 to 15 are scored as mild while, at the other extreme, those over 30 are scored as severe. In the general patient population, the prevalence of obstructive SAHS is reported at 4% for men and 2% for women; these values exceed 15% in subjects over 50 years old. SAHS occurs mainly in light sleep stages 1 and 2 and REM sleep. Sleep apnoea-hypopnoea syndrome is associated with sleep awakenings, reports of fatigue and daytime sleepiness (SAHS also carries a risk of vehicle accident between 3 and 9 times higher), and risk of concomitant cardiovascular disease (71–73).

The literature contains reports of a weak to moderate association between bruxism either awake or asleep and sleep respiratory disturbances. Interestingly, a sleep laboratory study reveals that 35% of tooth grinders also present snoring and that only 4/24 patients present SAHS; these values are close to the respective prevalence of respiratory disorders found in the general population (29). Based on self-reports and questionnaires, close to 50% and 30% of UARS and SAHS patients complain of bruxism, respectively (70). In a large telephone survey of the general population, researchers found that the OR of reported TG and snoring was 1·4 and for SAHS-related symptoms it was 1·8 (24). Therefore, dentists need to be aware of the signs and symptoms of a sleep breathing disorder in a bruxism patient. These signs can include: complaints of 'alarming' respiratory sounds as reported by the sleep partner, concomitant snoring, frequent daytime sleepiness, recent unexplained mood and cognitive alterations, the presence of hypertension, a large neck, retrognathia, deep palate and large tonsil-adenoids. In the presence of these signs, the dentist should request a sleep evaluation by a pneumologist in a recognized sleep clinic. SAHS may trigger secondary sleepiness with a higher risk of traffic accidents, low cognitive function (memory) and an elevated risk of cardiovascular problems (e.g. hypertension, vascular cerebral accident). Also, several medical conditions are concomitant with SAHS: obesity, hypertension, sexual dysfunction, PLMS, etc. The familial aggregation of some of these variables suggests a form of heritability as a risk factor for obstructive SAHS (3, 71, 73–80). The prevention of sleep breathing problems in children with palatal expansion is an avenue of interest for researchers in dental sleep medicine and in public health (81).

Physiology and pathology of bruxism

In this section, it is important that the reader understands that physiology and pathology are inter-related. It is not known whether bruxism is just the extreme manifestation of a physiological activity. In other words, is bruxism a more frequent or more intense (i.e. powerful) motor manifestation of a usual orofacial/oromandibular activity instead of being a specific pathological entity? All of us have observed that clenching can be present in a large number of asymptomatic subjects, and some bruxism patients may be at risk of pain or jaw dysfunction and that sleep-related RMMA is also observed in non-TG subjects (5, 40, 49, 50). Clinical complaints and associated damage or pain may justify the classification of bruxism as a wake-time 'parafunction' or sleep-related movement disorder but the mechanisms underlying the genesis of bruxism

remain under investigation because of the lack of a standardized methodology.

In the section below, we review some findings that support various explanations of the pathophysiology of bruxism. To advance our understanding of bruxism, researchers will need to integrate research with clinical current knowledge as well as make further investigations (see Fig. 2). For the past few decades, the search for the aetiology and physiology of SB has been restricted to mechanical factors (e.g. occlusion) to adoptive or maladaptive behaviour (e.g. stress) and in extreme cases to a medical dysfunction of dopamine (DA) (see Fig. 3). New avenues for investigation have now emerged and are described in more detail below (see Figs 3). Table 2 shows a tentative estimate of the amount of evidence available for putative mechanisms underlying the multidimensional pathophysiology of bruxism according to Sackett criteria, as performed recently for sleep-related movement disorders (19, 55).

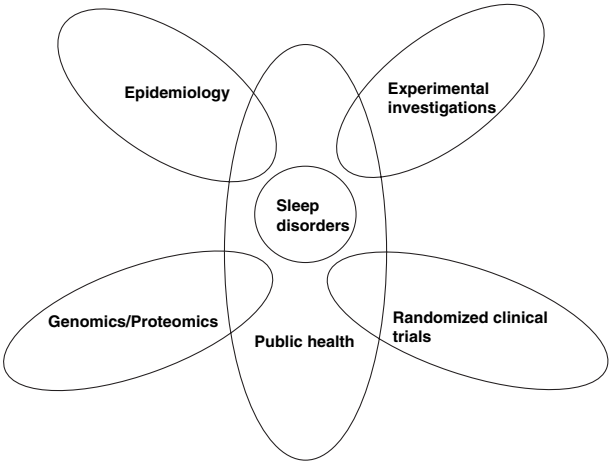

Fig. 2. Integrative 'BUTTERFLY' for understanding bruxism.

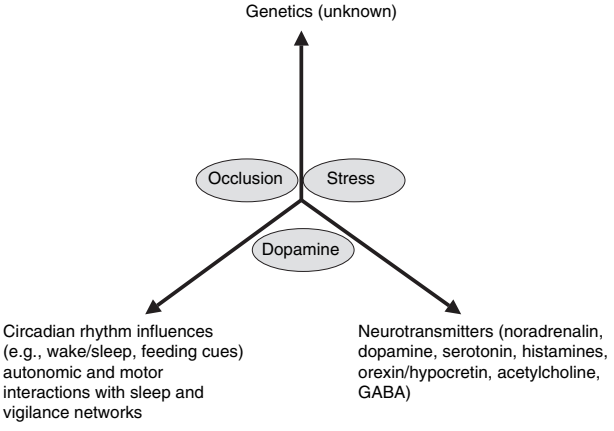

Fig. 3. Evolution of the aetiology and pathophysiology of sleep bruxism (circles = older theories; arrows = new avenues). GABA, gamma-aminobutyric acid.

Bruxism may be linked to multiple genetic factors or to a familial learned behaviour

Initial evidence of a genetic basis for a given motor behaviour or disorder is usually extracted from concordance in a population of twins or dominance in familial distribution. Studies based on questionnaires or tooth wear estimation in monozygotic and dizygotic twins show that there is a high genetic determinant in bruxism and TG. A high concordance rate exists for the pattern of mastication in monozygotic twins (0·97) and dizygotic twins (0·61) (11, 82, 83). On the other hand, a recent twin study did not find any genetic determinant for temporomandibular joint-related signs and symptoms (84).

A study using the Finnish twin cohort shows that childhood SB persists in a large number of adults (greater than 86·9%) (11). These results are consistent with findings suggesting that the wake-time oral parafunction, clenching and TG at night persist in most patients up to 20 years later (12). Moreover, the presence of a given motor behaviour in a large number of first degree relatives further supports the search for gene candidates. Based on self-reports of bruxism, 20% to 50% of SB patients have an immediate family member who reports TG in childhood (85–87). To initiate a genetic search based on family prevalence, all positive and negative bruxism cases need to be entered into a Mendelian tree. Again, if the assessment of bruxism is only based on self-report, the exercise may be imprecise. Ideally, researchers need to make a quantitative and valid assessment of the presence of bruxism. The use of sleep recordings of SB-TG will certainly improve the quality of the assessment.

In our cohort, we found that 37% of positive tooth grinders in the sleep laboratory had at least one family member also reporting TG and that the estimate dropped to 15% with two or more family members (S. Khoury *et al.*, unpublished data). The second level of our genetic research will include about 100 patients with positive TG during sleep recordings. Specific analysis of gene candidates can be made from blood collection, i.e. DNA sampling under blind conditions for linkage analysis. Because of the difficulty of finding a

Table 2. Evidence table for sleep bruxism reliability studies

First author	Year	Evidence level	Study design	Significant findings
Okesson (29)	1990	5	Clinical series	Older patients present 3·03 episodes of masseter activity hour per sleep; those with dentures had 2·6 fewer episodes; each event lasted 5·95 s. Interestingly, 20 out of 30 patients slept on their back.
Lavigne (49)	1996	2	Reliability/ validity	Cut-offs for different bruxing parameters – More than 30 bruxing episodes per night – More than four bruxing episodes per hour – More than six bruxism bursts per episode – More than one bruxing episode with grinding noise
Ikeda (45)	1996	5	Clinical series	Technical study suggesting minimal criteria for ambulatory recordings of EMG. EMG change >3% = threshold interval between events >5 s.
Lavigne (31)	1997	5	Case series	Patients with pain had fewer episodes of bruxism per hour, but an equal number of bursts per episode and amplitude.
Bader (29)	1997	4	Observational studies	A mean of 79 bruxism episodes per hour of sleep mostly in stage 2, preceded by alpha activity in EEG and tachycardia at onset of episodes
Bader (36)	2000	3	Case–control study	More body movements were observed in bruxers without any relationship with masseter EMG activity, suggesting a central aetiology common to both.
Kato (141)	2001	3	Observational studies	RMMA were preceded by autonomic (increased HR – one cycle before EMG onset) and cortical (increased alpha delta power minus 4 s) activation.
Lavigne (63)	2001	5	Reliability/ validity	The clinical definition of SB did not change over the span of repeated studies. There was significant variability in specific PSG measures.

EMG, electromyograms; EEG, electroencephalogram; RMMA, rhythmic masticatory muscle activity; HR, hazard ratio; SB, sleep bruxism; PSG, polysomnography.
Level 1 = randomized well designed trials with low alpha and beta errors; level 2 = randomized trials with high beta errors; level 3 = non-randomized controlled or concurrent cohort studies; level 4 = non-randomized historical cohort studies; level 5 = case series. From Walters *et al.* 2007 (55).

large family of SB patients, the identification of specific genes will require multicenter studies of patients with a valid confirmation of bruxism (i.e. clinical examination and EMG with audio-video), controlling for several variables such as anxiety, stress, medication, etc. To our knowledge, such investigations are not being currently carried out.

Many limitations reduce the likelihood of finding genes directly associated with bruxism. SB is frequently concomitant with another sleep parasomnia, sleep talking; the shared genetic effect of both conditions is about 30% (23, 88, 89). This evidence suggests that awake or SB types will probably not be explained by single gene expression; it is more likely that gene heterogeneity drives the apparition of an oral motor behaviour or activity. Moreover, it is difficult to isolate the influence of the stress and anxiety that may cause a sequence of gene and protein activations in relation to observed changes in the autonomic and cerebral arousal systems (as described below). Oromotor activity, such as jaw clenching and TG may be related to the release of catecholamine as suggested in the literature on SB (90–91). Furthermore, the search for a specific gene candidate will require investigators to assess the role and influence of familial-environmental factors (11). In fact children tend to mimic their parents' behaviours: a child may learn to clench by watching a parent react to stress, anger or frustration. Genomic and proteomic bruxism studies will only be feasible if researchers employ precise methods to establish a phenotype and to standardize multicentre studies using valid tools.

Occlusion and bruxism: absence of evidence-based data

The concept that dental occlusion may play a role in the genesis of bruxism is based on clinicians' observations from the mid 20th century. Using tooth interference to explain bruxism became very popular following the publication of a study suggesting that occlusion may influence muscle activity, but it is important to note

that this suggestion was based on EMG data collected during the daytime (92). Recent literature contains little evidence to support the role of occlusion in the genesis of bruxism (93, 113). The argument that selective occlusal adjustments continue to have *'une raison d'être'* in the dental curriculum and in therapy is based on existing knowledge and practice that operates irrespective of the concepts and methods of evidence-based dentistry (94). Although we recognize the role of occlusion when dentists complete full mouth or orthodontic rehabilitation, there is a lack of evidence justifying the use of occlusal therapies for managing bruxism in the case of healthy dentition; the practice remains rather controversial (95–99). A recent experimental study showed that occlusal interference was not associated with temporomandibular disorder or orofacial pain and did not significantly raise the frequency of EMG masseter muscle activity in young healthy female subjects (100). More importantly, clinicians tend to forget that tooth contact is not a dominant activity over a 24-hour cycle. Tooth contact has been suggested to occur for approximately 17·5 min over a 24-hour period (101). On the basis of the results of a few sleep laboratory studies, we estimated that SB-related muscle activity lasted approximately 8 min over a complete sleep period that usually lasted between 7 and 9 h (29, 49, 61, 102).

The fact that some patients do report relief from so-called 'dental discomfort', pain or headache after an oral rehabilitation or an orthodontic treatment is not a sufficient proof to justify extensive treatment. Other factors such as the patient and dentist relationship, the patient's belief in a mechanical operative treatment and his or her readiness to be under the care of a charismatic clinician, the natural healing history and fluctuations of signs and symptoms during extensive and long dental treatments may all contribute to subjective reports of patient satisfaction. In the absence of a randomized and controlled study design using a control arm (i.e. a group of patients under observation or a waiting list) together with data collection analysis under blind conditions and valid outcome assessments, the debate on the role of occlusion and bruxism will remain.

Stress and anxiety: contributing or triggering factors?

Many dentists share the opinion that bruxism, either clenching while awake or grinding during sleep, is associated with stress and anxiety (5, 24, 32–34). Concomitant anxiety and hyperactivity have also been described as causes of bruxism despite studies that have used the Minnesota Multiphasic Personality Inventory and the Cornell Medical Index to arrive at different conclusions (5, 103). Interestingly, two studies showed that patients with bruxism had elevated levels of catecholamines in their urine in comparison to non-bruxism subjects; such findings support a link between emotional stress and bruxism (90, 104).

Most young and otherwise healthy bruxism patients interviewed for our clinical trials or experimental sleep laboratory studies failed to reveal any major pathological anxiety level of the kind identified in the Diagnostic and Statistical Manual (DSM-IV) manual for diagnosis of psychiatric disorders. Our 'clinical perception' is that most bruxism patients report that they clench their teeth in periods of intense or frequent familial duties or increased work load. We further note that patients tend to define such periods as being too intense, with many important tasks to be performed within a short deadline, together with the desire to maintain a high standard of performance. Obviously, the impact, validity and relevance of such patients' descriptors need to be further investigated.

In a controlled and blind experimental study design in which normal subjects and moderate to severe SB-TG patients were exposed to both attention and motor reaction tasks, we noted that SB patients tended to score higher on the level of tasks related to anxiety and competitiveness (32). Interestingly, in that study, we noted that none of the SB patients showed an increase in wake-time jaw muscle activity or any obvious clenching behaviour during the experimental task. Such findings are in accordance with the results of two ambulatory studies in which SB patients being recorded over several nights also filled in questionnaires to assess self-reported daily stress or physical activity or anger. No correlation was found between daytime data and EMGs of one masseter muscle or with the frequency of bite-clench behaviours (estimated using a sensor in a bite splint) during sleep (34, 47). An interesting case report of one patient with a history of orofacial pain and TG observed over 13 weeks with a one channel EMG system suggested that the presence of evening pain was explained by daytime clenching and tongue sucking habits (48). Obviously such reports need further validation in a study with a larger sample size. For more information regarding the interaction

between bruxism and pain, readers may consult the paper by Svensson (105).

The above findings and observations raise again the issue of probable overlap among various types of oral 'parafunctions' such as clenching or tongue pushing or finger nail biting. Some studies have shown that in individuals, such activities tend to occur in clusters (12, 23, 88). It is also important to reiterate that most evidence for the role of anxiety and stress related to bruxism is derived from questionnaires. These methods may be subject to bias, such as the natural fluctuation in bruxism motor activity over time, the risk of poor or imprecise recall regarding bruxism or anxiety and the lack of awareness of the current behaviour (such as TG) in single sleepers (5, 50). To add a further note of caution, the majority of our young and healthy SB patients were not aware of clenching during the daytime until their dentist informed them that they were bruxers based on his/her observation of tooth wear.

The literature demonstrates that self-report and clinical observation of tooth wear are one means of assessing bruxism in relation to the role of anxiety and stress (106). However, such methods have several limitations. Tooth wear has been described as a weak indicator of current bruxism and does not discriminate clenching from grinding bruxism (5, 65, 107). To our surprise, when we initiated our SB studies in the early nineties, we observed that some of our moderate to severe tooth grinders (as scored in a sleep laboratory) did not show remarkable tooth wear, in contrast, some patients with little TG activity during sleep presented greater evidence of tooth wear. Other researchers have made similar observations (5, 7, 107). Tooth wear magnitude may be influenced by enamel density or by saliva quality and lubricating efficacy (5, 65, 108, 109).

Finally, in the clinic, dentists need to be vigilant about recognizing psychological or psychiatric disorders, such as severe or pathological anxiety, mood and personality disorders. The expertise of a psychologist may be useful in those cases. This approach is further supported by a multicountry telephone survey in a large sample of subjects with a wide age range. The results of the survey reveal that subjects with an anxiety disorder (compatible to DSM-IV criteria) are slightly more at risk of reporting TG (OR = 1·3) (24). Furthermore, a recent sleep laboratory study reveals that 4 out of 10 children with SB also present elevated scores of dysfunction in attention and behaviour (110). Children with concomitant sleep respiratory disorders are more at risk of presenting similar problems which may have a major impact on familial and school behaviour (111). Obviously, future studies in this field will need to take into consideration the influence of the following variables: age, anxiety, use of medication or drugs (e.g. cocaine, ecstasy), the presence of medical neurological disease, smoking habits, pain and other sleep disorders (5, 24, 112, 113).

To understand the causes of bruxism, we recognize that it is very difficult to isolate the role of stress and anxiety from concomitant changes in autonomic and motor excitability and a state of altered physiological vigilance. Heterogeneity in psychosocial and biological markers may concur to prevent a clear, simple and valid description of the causative relationship among stress, anxiety and bruxism.

Bruxism is associated with a high level of oromotor activity in jaw muscles

Most current evidence supports the hypothesis that bruxism is centrally mediated under autonomic and brain arousal or vigilance influences. Among the various hypotheses proposed to explain SB, the most recent ones support the role of the central nervous and autonomic nervous systems in the genesis of oromandibular activity during sleep (5, 7, 18, 109, 114–116). In this sub-section, we will summarize some of the findings related to the neurochemistry and sleep-related mechanisms that may contribute to the increased motor activity underlying the genesis of SB and RMMA (see Fig. 4). We will also suggest that a reduction in airway patency and/or low or absent lubrication of the oral and oesophageal tissues may have a role in the genesis of RMMA during sleep.

Catecholamine and neurochemistry

Our current understanding of the pathophysiology of SB in relation to the role of neurochemistry is mainly based on case reports or randomized clinical studies using various medications (115). In the following sections, we will only review the evidence supporting an explanation for SB pathophysiology [for information on the benefits of medication in managing SB and potential risk or counter indications, refer to the paper by Lobbezoo (68)].

Historically, the first evidence suggesting that TG can be associated with DA is based on a case report in which

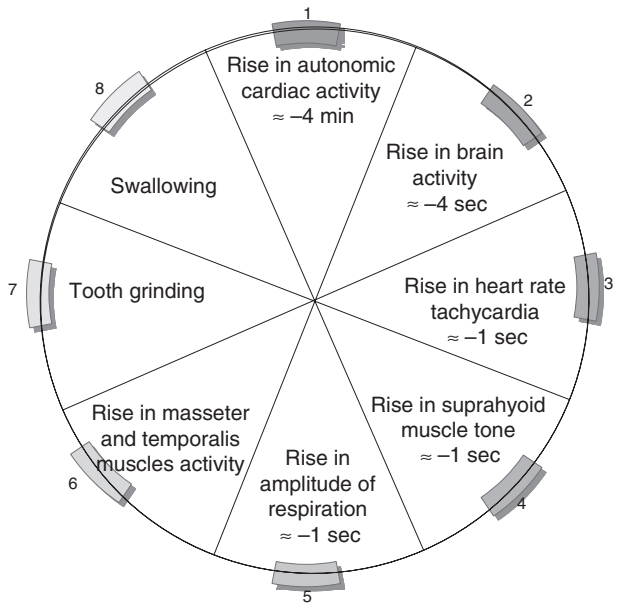

Fig. 4. The 'wheel' of sleep bruxism pathophysiology in relation to repetitive sleep arousals.

one Parkinsonian patient was treated with L-dopa (5, 115). L-dopa is a precursor of catecholamine such as DA and noradrenaline (NA). The putative role of DA in oromandibular movement disorder is indirectly supported by the presence of chewing-like and TG activity in schizophrenic patients treated with neuroleptics that act mainly on DA receptors (5, 20, 117). As none of these patients were 'healthy' (both already had altered nigrostriatal neurons because of disease and/or to medication), we completed a series of cross-over polygraphic placebo and double-blind randomized controlled trials (RCT) in young and otherwise healthy SB subjects, using L-dopa, a DA receptor agonist bromocriptine and two adrenergic medications, a peripheral beta receptor blocker, propranolol and an alpha 2 agonist, clonidine. With L-dopa, we found a modest but significant reduction in SB-RMMA frequency in comparison to placebo (117). With bromocriptine administered (with domperidone a peripheral DA blocker to prevent side effects such as nausea or vomiting), we failed to show either a reduction in SB motor episodes or a change in DA striatal binding (119). Note that it remains possible that the administration of a more specific and more potent DA antagonist such as pergolide or pramipexole may have exerted a different effect on SB-RMMA. This is in part supported by a brain imaging study in nuclear medicine showing asymmetrical distribution of DA binding sites at the nigrostriatal level in SB patients but not in control subjects (120). Similar findings have been shown in previous studies of both torticollis and parkinsonian patients (121–124).

An open label study performed in one SB patient over one night without medication and many months later on another night with propranolol resulted in a remarkable reduction in the SB index (125). Furthermore, propanolol was also used in patients presenting secondary TG in relation to antipsychotic drug exposure (126). These results provided the ground of our RCT with propanolol and clonidine (127). Unlike the reports mentioned above, we did not find a significant reduction in SB-RMMA with propranolol. However, the use of clonidine significantly reduced the SB-RMMA index by 60% in comparison to placebo. This effect was in part associated with a concomitant reduction in the cardiac-autonomic sympathetic dominance that precedes RMMA, as described below. Note that our studies were designed to test mechanisms that may contribute to explain the genesis of SB. These studies were carried out under medical supervision because clonidine induces severe morning hypotension; a major side effect observed in 20% of our study participants. Moreover, chronic use of cardioactive medications is known to influence sleep quality and architecture, to increase the numbers of awakenings and nightmares, as well as to exacerbate respiratory disorders in some individuals (128, 129).

The role of serotonin in SB pathophysiology is more obscure. The administration of a serotonin precursor, tryptophan or of the antidepressant amitriptyline does not reveal any effect on SB (130–132). However, SSRI antidepressant medications are reported to trigger clenching in some susceptible individuals (115, 133).

A few reports suggest that gamma-aminobutyric acid (GABA) may also have a role in SB. Substances with an affinity or structural analogy to GABA, such as clonazepam (also a muscle relaxant and anxiolitic), tiagabine and gabapentin have been reported to reduce SB-TG (134–136). However, as gabapentin does not directly interact with GABA receptors or GABA reuptake, the reduction of SB-TG by gabapentin does not provide any direct information on the role of GABA in relation to SB (136).

The role of the cholinergic system (e.g. acetylcholine-related medication) on the genesis of SB is unknown. The observation that TG is exacerbated by smoking provides an indirect clue to the potential interaction of nicotinic receptors with mechanisms responsible for SB

(31, 113, 137). However, it remains to be discriminated if smoking increases the risk of bruxism as an oral habit or if it is an effect of nicotine on the cholinergic system, which is heavily involved in vigilance and related brain-arousal networks.

Interactions are another possibility. It has been suggested that in patients with both awake and SB (as described above, this represents about 20% of all bruxism patients) a different mechanism may operate in the genesis of bruxism with an interaction of both DA and NA. A subjective reduction (no recordings were made using EMG, or audio-video) in bruxism activity was observed in three older patients (over 67 year old) receiving metoclopramide (a DA receptor 2 antagonist medication); no effect was observed following a previous administration of either L-dopa or bromocriptine. Interestingly, the reduction of bruxism was associated with a reperfusion of the prefrontal cortex during wake-time (138). The authors were audacious in proposing that this action is mediated by noradrenergic pathways through the 'emotional' area of the brain (ventral tegmentum). This challenging suggestion may be a means of reconciling the role of the stress-related axis with the role of the autonomic nervous system in the genesis of bruxism. Obviously, such findings need to be replicated under blind and controlled conditions with polygraphic assessments of bruxism.

Bruxism-related motor activation: role of arousal

The ascending and descending arousal systems play an important role in vigilance and sleep; neurochemicals (e.g. acetylcholine, monoamine, NA, serotonin, DA, orexin/hypocretin, histamine, etc.) in networks located in the lower brain up to the hypothalamus are secreted differently for either wake or sleep states (109, 116). Awake bruxism is associated with stress and increased vigilance (a condition known to increase autonomic cardiac activity). Most SB episodes are under the transient influence of cardiac sympathetic activity (as a promoter of arousal), as shown in a rapid rise in heart rate at the onset of RMMA (time domain estimate of heart rate acceleration (i.e. tachycardia) or deceleration (i.e. bradycardia)) during recurrent sleep arousal (39, 61, 139–142). Arousal consists of a repetitive rise in heart rate, muscle tone and brain activity at a frequency between 8 and 15 times per hour of sleep, as described below (62, 116, 141, 143, 144).

Cardiac autonomic estimate in relation to SB

The method for assessing cardiac autonomic activity is non-invasive and simple. Heart rate signals need to be recorded at a frequency between 128 and 1000 Hz depending on test duration. Data from ECGs are collected either for a long period, such as during sleep or during cardiovascular function testing such as a tilt table test. The outcome variables of interest are then derived from the ECG of the QRS wave and heart rate measurements using the RR peak (being the distance between two R peaks in the QRS signal) to peak interval duration. The variable of interest can be either the ratio of the RR interval before and during SB or RMMA activity (time domain) or variability based on SD estimates using dedicated software for spectral analysis (frequency domain). It is then possible to extract quantitative estimates of the sympathetic and parasympathetic autonomic cardiac dominance using Fast Fourier Transform analysis. The spectral components of the RR signals are decomposed into very LF (VLF, less than 0·05 Hz); LF (0·05–0·15 Hz) and high frequency (HF; 0·15–0·4 Hz) activities (145). The heart rate variability is then presented as: (i) the parasympathetic-respiratory tone dominance represented by HF dominance calculation [HF/(total frequency − VLF) × 100]; (ii) the sympathovagal balance evaluated by both ratios LF/HF and LF/(LF + HF)(146, 147). The sympathetic dominance represents heart rate acceleration, whereas the parasympathetic dominance is like a physiological 'breaking system' on the cardiac output. All of us have demonstrated that SB is under a sympathetic dominance (39, 127, 142). These estimates were made in the course of studies attempting to understand SB mechanisms or pathophysiology.

Sleep structure and recurrent-cyclic arousals in relation to SB

A sleep cycle is composed of non-REM and REM periods of 90–110 min of sleep. A night of sleep is composed of 3 to 5 cycles. Non-REM sleep is further divided into light sleep with sleep stages 1 and 2, and deep sleep with sleep stages 3 and 4 (38). As reported, most SB episodes are observed in light non-REM sleep, whereas about 10% occur in REM sleep in association with sleep arousal (39, 62, 110). Again, micro-arousals occur during sleep and are defined as 3–10 s abrupt

shifts in EEG activity with a rise in heart rate and muscle tone (EEG arousals)(148). Arousals tend to recur 8–15 times an hour of sleep in young healthy subjects (149, 150). Interestingly, it has been observed that SB tends to occur in relation to recurrent arousal within the so-called cyclic alternating pattern (CAP), which repeats every 20–60 s during non-REM sleep (62, 149–151). This finding is further supported by the observation that most SB episodes occur in clusters in relation to CAP (39, 62, 152). Cyclic alternating pattern-related arousal are described as a natural process that act as a sensor for maintaining body homeostasis and as a protection sentinel during sleep (153).

In one of our studies, we challenged the role of MA in the genesis of SB in an experimental protocol using a sensory vibrator during sleep. We explored the role of arousal as a physiological state that may or may not increase the probability of initiating an SB episode. We found that in over 80% of trials, the experimentally induced arousal were followed by TG, but in SB patients only, not in control subjects (154). Our laboratory has further demonstrated that the onset of SB is related to a sequence of physiological activations within arousal (39, 141) (see Fig. 4). In brief, the genesis of most SB episodes follows: (i) a rise in sympathetic cardiac activity at −8 to 4 min (39); (ii) a rise in the frequency of EEG activity at −4 s (141); (iii) heart rate tachycardia starting at −1 heart beat (141, 154); (iv) an increase in jaw-opener muscle activity probably responsible for mandible protrusion and airway opening (63); (v) an associated major increase in the amplitude of the respiratory ventilation (155); (vi) observable EMG incidents scored as SB-RMMA with or without TG. In about half of SB-RMMA episodes, we observed major swallowing activity; no swallowing was observed for several minutes before RMMA-TG episodes, which may suggest that SB patients have a lower oral salivary volume (see next section) (93).

As an indirect proof of concept and as described in the previous subsection on catecholamine, we have found that the use of clonidine reduces sympathetic cardiac activation (step 1 of SB sequence) as well as the probability of RMMA by 60% in SB patients (40). Furthermore, the use of a mandibular advancement appliance, a recognized treatment for respiratory sleep disorder, also reduces the number of SB episodes by at least 50%, probably by slightly opening the airway during step 4 of the SB sequence (156).

Another putative role for increased orofacial/oromandibular activity during sleep: airway patency and oropharyngeal lubrication

Respiration is another avenue of interest in the investigation of SB pathophysiology. Researchers have found some differences in the respiratory pattern of SB patients. As sleep is usually associated with a jaw opening-retruded position, tongue muscle relaxation (e.g. geniogloss) and a reduction in airway patency, and as most SB episodes occur when patients sleep in the supine position (as is the case with snoring and other breathing disorders), we have suggested that the sleep of SB patients may be associated with either a reduction in the airway passage or an increase in its resistance (109, 157–160). The use of an oral device that opens the airway significantly reduces the frequency of SB-RMMA episodes (156).

The role of saliva in the tooth wear of bruxism patients is a surprisingly neglected area of research (65). It is known that salivary flow is lower during sleep (108, 161, 162). Assessments of salivary function (i.e. flow, consistency, etc.) or direct measurement of salivary flow is difficult to perform during sleep. Salivary flow collection is usually performed by asking the patient to spit into a tube, which is obviously an activity that interrupts sleep continuity. The use of a canula inserted in the canals of salivary glands is too invasive and may interfere with TG movements because of the presence of tubes coming out of the mouth. One method, although an indirect one in estimating salivation during sleep in a non-invasive manner is to use a strain gauge to measure the frequency and pattern of swallowing movements (93). While awake, we swallow between 25 and 60 times per hour, but during sleep, swallowing frequency drops to between 2 and 9 times per hour (163). Using a laryngeal-swallowing movement sensor in both control and SB subjects, we found that most SB patients rarely swallow during sleep (suggesting a low salivary rate) and that about half of TG episodes ended with a large swallowing movement (163). We hypothesized that RMMA could be associated with the need for an increase in salivary flow during sleep to lubricate the oro-oesophageal tissues (5, 108, 109). It remains to be demonstrated whether medications improving salivary flow during sleep will reduce RMMA, TG and tooth wear. Furthermore, gastro-intestinal reflux is another

possible exacerbating factor for tooth wear that probably deserves more consideration in SB patients with respiratory disorders (93, 160).

Conclusions about SB pathophysiology

The genesis of SB mandibular movements is probably very different from chewing activity, as we have previously proposed (5, 109, 116). Sleep bruxism is mainly a rhythmic motor activity: (i) occurring without any food triturating purposes; (ii) associated with a co-contraction of both jaw closing and opening muscles without a typical alternating pattern as seen during chewing; (iii) occurring without cortical involvement, unlike chewing, which is initiated at the cortical level. This last observation is supported by the fact that the jaw opening reflex and cortico-bulbar pathways are depressed during the sleep of primate (5, 109, 116). Moreover, a study using transcranial magnetic stimulation in human suggests that bruxism may be mainly under the influence of brainstem networks (109, 164).

It remains to be specifically demonstrated that SB and RMMA come under the influence of the excitatory and inhibitory networks (and neurotransmitters) that tend to shift the balance between the brainstem and cortical sleep system towards a transient state of vigilance and arousal. Sleep bruxism occurs in clusters of transient arousals that ready a sleeping brain to act as necessary following a sudden awakening from sleep.

New and emerging imaging systems may allow researchers to identify networks activated during sleep with the onset of motor activity such as SB or limb movement. To illustrate this point, it is interesting to reiterate that a massive GABA inhibition occurs at the same time as the initiation of non-REM sleep, thus reversing the influence of the arousal-wake promoter system. The level of arousal is maintained by activity from the hypothalamus where orexin/hypocretin plays a dominant role, as well as other networks with acetylcholine, NA, histamine and serotonin (143, 144). Dopamine neurons are generally not very active during sleep but they have been associated with a modulating role that promotes arousal and indirectly contributes to a rise in muscle tone during the wake state with networks simultaneously initiating hypotonia during non-REM and REM sleep. During sleep, such networks come under the influence of noradrenergic neurons from the locus coeruleus projections to the peduculopontine tegmentum neurons and of GABA and glycine inhibition of both brainstem and spinal cord motor neurons (144, 165–167). Again, note that most SB episodes have been observed in association with transitions between sleep stages, either towards arousal (from a deeper to a lighter sleep state) or in the transition from stage 2 sleep to the very active REM sleep characterized by major muscle hypotonia. Periods of sleep transition are also associated with a re-activation of neurochemical, autonomic and brain networks, and a de-activation of the motor system in REM sleep that initiates the reduction in muscle tone, behavioural atonia or physiological hypotonia that characterizes REM sleep (39, 144, 168).

Finally, we suggest that until our evidence base develops further, research should focus on bruxism behaviour rather than bruxism as a disorder. Investigators will need to undertake systematic studies to determine the dividing line between bruxism as a normal variation of behaviour as opposed to a pathogenic behaviour that increases the risk of negative consequences such as tooth damage, pain, and societal/marital tension. We consider that a behaviour that does not increase the risk of negative health consequences, irrespective of how statistically extreme that behaviour may be, should not be treated or viewed as a disorder.

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