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REVIEW

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Research routes on awake bruxism metrics: Implications of the updated bruxism definition and evaluation strategies

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Abstract

Background: With time, due to the poor knowledge on it epidemiology, the need to focus on awake bruxism as a complement of sleep studies emerged.

Objective: In line with a similar recent proposal for sleep bruxism (SB), defining clinically oriented research routes to implement knowledge on awake bruxism (AB) metrics is important for an enhanced comprehension of the full bruxism spectrum, that is better assessment and more efficient management.

Methods: We summarised current strategies for AB assessment and proposed a research route for improving its metrics.

Results: Most of the literature focuses on bruxism in general or SB in particular, whilst knowledge on AB is generally fragmental. Assessment can be based on non-instrumental or instrumental approaches. The former include self-report (questionnaires, oral history) and clinical examination, whilst the latter include electromyography (EMG) of jaw muscles during wakefulness as well as the technology-enhanced ecological momentary assesment (EMA). Phenotyping of different AB activities should be the target of a research task force. In the absence of available data on the frequency and intensity of wake-time bruxism-type masticatory muscle activity, any speculation about the identification of thresholds and criteria to identify bruxers is premature. Research routes in the field must focus on the improvement of data reliability and validity.

Conclusions: Probing deeper into the study of AB metrics is a fundamental step to assist clinicians in preventing and managing the putative consequences at the individual level. The present manuscript proposes some possible research routes to advance current knowledge. At different levels, instrumentally based and subject-based information must be gathered in a universally accepted standardised approach.

KEYWORDS
awake, bruxism, assessment, bruxism, evaluation, STAB

1 | INTRODUCTION

According to the updated bruxism definition, awake bruxism (AB) is described as a masticatory muscle activity during wakefulness that is characterised by repetitive or sustained tooth contact and/or by bracing or thrusting of the mandible and is not a movement disorder in otherwise healthy individuals.[1] Compared to the first consensus paper on bruxism definition,[2] AB has been clearly separated from sleep bruxism (SB). Furthermore, a couple of noteworthy observations can be described. First, both circadian manifestations of bruxism have been specified as not being a disorder in otherwise healthy individuals, viz., a certain amount of harmless bruxism can be present as part of the normal sleep architecture or wakefulness behaviours.[3–5] Second, an enlarged spectrum of various jaw muscle activities without tooth contact, such as mandible bracing or thrusting, has been included under the umbrella term "bruxism". This represents an important paradigm shift with respect to the early concept that bruxism is a sleep-time motor activity featuring a specific pattern of masseter contraction (i.e., rhythmic masseter muscle activity [RMMA]) and being accompanied by teeth grinding sounds.[6,7]

The evolution of the bruxism definition was based on the increasing knowledge about the aetiology and consequences of different jaw muscle activities as well as on the need to provide a homogeneous conceptual framework for assessing such activities over a 24-hour timespan, possibly for multiple days.[8] Bruxism activities may indeed fluctuate over time, and this complicates the evaluation of the potential clinical impact.[9–13] For instance, when the polysomnographic (PSG) criteria based only on RMMA identification and counting were applied, sleep studies were inconclusive, not showing a clear-cut association with either tooth wear or pain in spite of these two signs/symptoms being commonly labelled as potential negative consequences of bruxism.[14–16] A series of comprehensive reviews on the relationship between bruxism and temporomandibular disorders (TMDs), summarising the literature of three consecutive decades, provided a nice overview of the research shortcomings.[17–19]

With time, due to poor knowledge on its epidemiology, the need to focus on AB as a complement of sleep studies emerged.[20] In parallel, the diagnostic grading that for years placed strategies and criteria to identify RMMA/phasic SB atop of the diagnostic hierarchy was increasingly questioned.[21] A group of experts worked on the conceptualisation of a comprehensive multidimensional evaluation system for bruxism – the STAB (Standardised Tool for the Assessment of Bruxism).[22–24] A short screening version (i.e., BruxScreen) has also been prepared.[25] The full version of the STAB includes two axes for the evaluation of several items concerning bruxism aetiology, status, comorbid conditions, and consequences, thereby providing a comprehensive adoption of data collection strategies based on the individual, the examiner, and instruments.[24]

Within these premises, similar to what has been recently proposed for SB,[26] defining clinically oriented research routes to implement knowledge on awake bruxism is of paramount importance for a better comprehension of the full bruxism spectrum. In this manuscript, we aim to summarise knowledge on AB as a starting point to discuss the present strategies for its assessment and to propose a research route for future improvements.

2 | CURRENT KNOWLEDGE ON AWAKE BRUXISM

A literature search showed that most literature focuses on bruxism in general or sleep bruxism in particular. In support of this notion, a search in the Scopus database performed on March 1, 2023, identified 6409 articles retrieved with the keyword "bruxism", of which only 272 remained after adopting only the keywords "awake bruxism". The number of articles/year has markedly increased over the past decade, from 10 articles/year to 48 in the peak year 2021 (Figure 1). The literature has been mainly produced by a limited number of researchers, most of which are involved as coauthors of this publication.

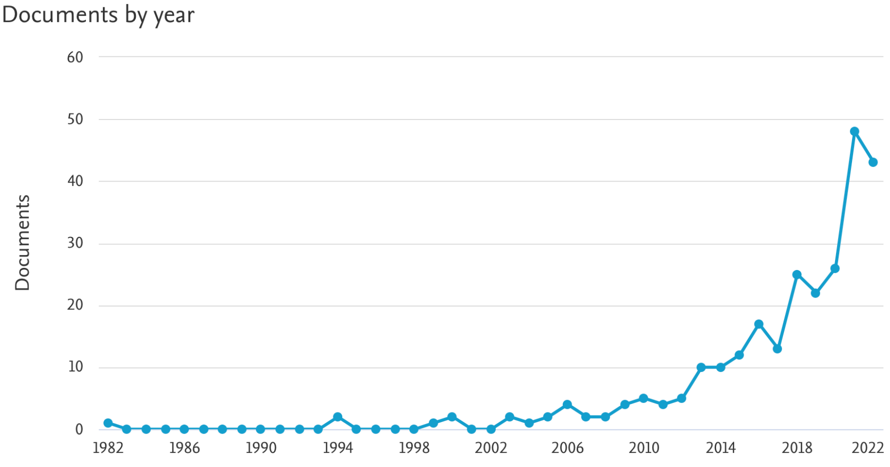

FIGURE 1 Number of publications per year retrieved with the Keywords "Awake Bruxism" (source: Scopus Database, access March 1st, 2023).

The prevalence of self-reported AB has been reported to be up to 30% across populations,[20] but knowledge is fragmental due to the limited epidemiological data on AB and the adoption of different assessment strategies.[27] Additionally, most of the information on AB prevalence has been reported from researches on single-observation point studies.[28,29] The development of EMA strategies allowed evaluating the frequency of AB behaviours report compared to the self-reported activities identified in questionnaires.[30–32] As a general remark, it emerged that about one-third of the times an individual received an alert he/she is engaged in some type of AB activity (i.e., teeth contact, clenching, grinding, or mandible bracing)[5,33] and that bracing is the most frequent report.[34,35] Currently, prevalence data on EMG-measured AB are not available, but studies are pending.

From an etiological viewpoint, AB may be viewed as a stress-coping habit that, especially in patients with musculoskeletal symptoms, is associated with psychological factors.[36,37] Indeed, whilst the past literature was very unspecific on this issue,[38,39] more recent evidence supports of a close association between AB and certain personality traits.[40–43] Other factors and comorbid conditions that may be of interest for a potential relationship with SB (e.g., obstructive sleep apnea, gastroesophageal reflux, medication or substance intake, neurological disorders, and genetic issues)[44–54] or to specific disorders with awake manifestations (e.g., ADHD, medications or substance assumption)[52,55] may also play a role, even if indirect.

The consequences of AB are poorly studied as well. Due to the extremely low frequency of teeth grinding,[35] a direct link between AB and tooth wear can be reasonably excluded in most individuals. On the other hand, patients with TMDs have reported a two-fold frequency of AB activities, and mandible bracing in particular, as compared to healthy individuals.[56] These findings are in line with previous observations, when higher teeth contacting habits in patients with TMD symptoms were reported.[57–59] This suggests that repetitive, low-level, tonic activity, that is typical of teeth contact and mandible bracing, may play an important role in the onset and maintenance of musculoskeletal symptoms in the orofacial area, thus constituting a target for clinical research purposes. Such hypothesis is hard to test with experimental studies performed in healthy individuals, as suggested by the low-to-moderate self-reported symptoms after supervised and standardised bracing and thrusting short-lasting exercises with the mandible.[60] This could indicate that, as discussed below, phenotyping AB and identifying factors that are responsible for symptoms onset at the individual level is a goal of future researches.

3 | AWAKE BRUXISM ASSESSMENT

AB assessment can be based on non-instrumental or instrumental approaches. The former include self-report (questionnaires, history taking) and clinical examination, whilst the latter include electromyography (EMG) of jaw muscles during wakefulness as well as the technology-enhanced EMA .[1,34,61]

3.1 | Non-instrumental assessment

Self-reported information can be obtained from questionnaires and history taking oral interviews, allowing collection of data on perceived awake bruxism activities and their possible associated factors.[48,50,62,63] Whilst the advantage of this approach is intuitively represented by the possibility to recruit large samples and to screen for the possible presence of bruxism at the individual level, the limitations are also well known. In particular, the intensity and duration of specific masticatory muscle activities cannot be exactly quantified via self-report. In addition, it cannot be excluded that the bruxism-psyche relationship could affect self-reporting, reflecting either distress or a patient's belief rather than masticatory muscle activity per se.[64–67] Factors such as discriminatory ability, cognitive awareness and memory may also influence the report[68] and, subsequently, the derived evaluation of bruxism status.

As pointed out in an early paper on the STAB project, there are currently no universally adopted questionnaires specifically designated for the assessment of AB.[22] Thus, depending on the case-by-case need, researchers have used AB items included in self-report instruments that were designed for broader scopes. The timespan and frequency in which the report of AB is referred varies amongst the different questionnaires. Examples of such instruments are the BRUX scale,[69] the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD),[70] and the Oral Behaviours Checklist (OBC).[71]

Amongst those, the OBC has been selected for the STAB[24] and a modified version of the BRUX scale has been included in the BruxScreen.[25] The OBC is widely used to investigate the prevalence of various oral behaviours,[72,73] and it contains four questions referring to behaviours that may be part of the AB spectrum (i.e., teeth grinding, teeth clenching, teeth contact, mandible bracing).[71] The questions are formulated in the form of "How often do you do each of the following activities, based on the last month?". For each item, a score of 0–4 points is assigned, which for awake questions is based on the following coding: 0, none of the time; 1, a little of the time; 2, some of the time; 3, most of the time; 4, all of the time. Whilst scoring criteria exist for the full OBC,[71] the psychometric properties of the four selected questions have never been tested.

Self-reported data collection may benefit from implementation strategies based on EMA, also called experience sampling methodology (ESM).[74,75] In this mode of assessment, subjects may be asked to monitor and report their behaviour in real time over a certain period of time (e.g., one or multiple weeks with or without interval time) after being informed of the possible conditions belonging to the spectrum of AB behaviours (i.e., clenching, bracing, thrusting, teeth contact habit).[76] This multiple time-point reporting in real time over an observation period can be performed through the use of pagers, paper diaries, or even smartphone apps.[77–80] Several studies recommended the use of such EMA strategies in the field of AB and compared it to single time-point reports, such as the OBC.[30,31] However, patients' compliance and comprehension of questions emerged as critical factors for the internal validity of findings.[32,79]

Concerning the clinical examination, there are two issues that must be considered as important limitations to its usefulness to identify AB status: 1. As a general remark, clinical assessment is actually deemed to evaluate the presence of purported consequences of bruxism, rather than current bruxism status itself,[61,81,82] and 2. Clinical signs related to AB are hard, if not impossible, to distinguish from the consequences of SB.[16,61,83,84] Based on the STAB recommendations, a comprehensive clinical examination should include an extraoral evaluation and an intraoral inspection to identify signs putatively related with bruxism. The extraoral evaluation should assess the jaw muscles (e.g., evident muscle hypertrophy), the TMJ (e.g., presence of TMJ noises, suggestive of disc displacement or joint degeneration), the presence of pain (e.g., jaw-muscle pain, TMJ pain, headache, and other types of orofacial pains), and functional symptoms (e.g., difficulty with wide mouth opening). The intraoral inspection consists of a dental examination (e.g., tooth wear, tooth enamel chipping, cracks and fractures of natural teeth, restoration failures, tooth mobility, periodontal ligament widening on radiographic imaging) and an inspection of the mucosa of the cheeks, lips, and tongue (e.g., linea alba, tongue indentations, traumatic lesions) as well as the presence of intraoral pain (e.g., teeth soreness / pain and/or hypersensitivity, lateral pterygoid muscles pain).[24] Given the above-mentioned shortcomings concerning the lack of specificity for AB, all clinical signs and symptoms should thus be assessed within the framework of a comprehensive differential diagnostic process.

3.2 | Instrumental assessment

Instrumental approaches have been available for years to record SB activities, where EMG and PSG findings are fundamental to study the role of SB within the sleep architecture.[1,6,21] In line with this, measurement of muscle activities is also recommended for AB evaluation. Such EMG recording requires a combination of hardware (e.g., electrode quality and positioning, long-duration battery, miniature size, wireless functioning) and software (e.g., data analysis, graphical interface) features,[85] which are not easy to fit for wake-time use. Recent developments on the technical perspective are promising, but field studies are yet to be performed, especially as far as the discrimination between muscle activities belonging, or not belonging to the AB spectrum is concerned.[86,87] Artificial intelligence (AI) analysis of AB muscle activities will probably contribute to such advancement.

Wake-time EMG has been included in the STAB domain purported to AB assessment, under the general premise that details for standardised data collection should be developed in the near future. Based on that, the area of instrumental measurement of AB should surely be an important focus of clinical research.

The recent introduction of smartphone applications based on EMA principles also belongs to the category of instrumental approaches, even if data are gathered via self-report. This approach will drive an era of potentially combined approaches to AB assessment that help recruiting large study samples whilst concurrently trying to gather real time information on the type and frequency of bruxism activities. Early studies were based on pagers, paper diaries, cell phone, or wrist clock alerts,[58,88,89] and the recent optimisation of applications with user-friendly interface yields promising perspectives, opening up a new era for the EMA approach.[78] Until now, most EMA data have been based on convenience samples of healthy young adults and non-representative populations, such as university students, but findings are interesting as far as the low coefficient of daily variation for the report of the relaxed jaw-muscle condition is concerned.[5,33] Compliance and comprehension studies suggest that both aspects are fundamental to enhance the internal validity of findings and to optimise the self-reported discrimination of the different AB activities.[32,79]

4 | RESEARCH ROUTES ON AWAKE BRUXISM METRICS

The suggestion of adopting the appropriate metrics for the evaluation of a phenomenon or a condition, in terms of the ideal outcome assessment for clinical and research purposes, has been recently discussed for obstructive sleep apnea.[90] Subsequently, an expert committee provided an elaboration on the best strategies to improve SB metrics and identified 15 pathways to improve validity and clinical relevance.[26] In the field of SB, focus should be mainly directed to the adaptation of currently available technological devices to the updated bruxism definition. Such task requires strong efforts after three decades of education and training based on the concept that SB criteria should address the identification of cut-offs for presence/absence of a certain number of RMMA.[91]

Within these premises, the same needs can be perceived in the field of AB, with two notable differences: 1. A metrics to assess AB should be proposed for the first time, rather than discussing/adjusting traditional approaches as for SB; 2. Alongside instrumental measurements (e.g., EMG), indirect approaches based on patients' report can be useful tools to retrieve information based on valid metrics, which is not possible for self-reported SB.

4.1 | Identification of AB status

The rationale behind the development of the STAB was the need "to assess an individual's bruxism in a reliable, valid, and relevant way".[22] The word "relevant" is important because of its implication that, in addition to the presence or absence of masticatory muscle activity, the clinicians should be able to determine the point at which bruxism is likely to be associated with clinical consequences.[1] The simple fact that the current definition of bruxism includes different muscle activities, both for the type of muscle contraction and for the presence of teeth contact, makes it impossible to envisage that a single parameter can be used as a standard of reference for identifying AB status. In addition to that, no literature data are available on the relevance of AB, viz., when, which, and how much activity can be considered a manifestation of clinically meaningful AB. The same considerations that emerged for SB, which can be harmless and even potentially associated with positive health outcome in some cases, should be applied to AB. Indeed, a multitude of vulnerability factors influence the occurrence of symptoms at the individual level.[92] In the case of AB, a certain amount of activity could be even considered a physiological strategy to cope with stress.[93–96]

Thus, the diagnostic grading (i.e., possible, probable, definite) that was originally proposed in the first consensus publication[2] has been progressively reconceptualised.[21] Based on that, the STAB is a multidimensional instrument aiming to collect as much information as possible without any preconceived assumption of standard of reference.[22–24] Nonetheless, instrumental measurement remains atop of the assessment hierarchy, having the potential to identify the different activities of the bruxism spectrum.

In this context, phenotyping of AB activities should be the target of a research task force. In the absence of available data on the frequency and intensity of wake-time bruxism-type masticatory muscle activity, any attempt to define thresholds and criteria to identify bruxers is premature. The epidemiology of bracing, clenching, grinding, together with the mixed and intermediate-force activities should be investigated at the general population level. Only in the aftermath of the accomplishment of such a huge task, further considerations on AB in selected populations with certain risk factors/comorbid conditions and/or potential clinical consequences will be possible.

4.1.1 | Research strategies for detecting AB/EMG events

As stated above, EMG measurement of the different masticatory muscle activities belonging to the bruxism spectrum should be a fundamental target for research, given the relevant clinical implications. Two types of concerns must be considered for designing the future research routes, viz., the implementation of hardware and the refinement of software.

Devices for studying AB should be developed under the premise that wearing them during everyday life is possible only if they satisfy the highest standard as far as miniaturisation, wireless function, and electrode comfort are concerned. The discussion of these technical issues is beyond the scope of a dental journal. The implementation of electrode quality, the reduction of cross talk, and a correct elaboration and amplification of EMG signal are just some examples of features that, from a clinical researcher's perspective, must be considered responsibility of the engineering and manufacturing companies.[85,97]

Importantly, software analysis should be adjusted to the more recent conceptualisation and definition of bruxism. Research projects should be routed to identify the EMG patterns of the most common AB activities (e.g., teeth clenching, teeth contact habit, mandible bracing) as well as the less frequent ones (e.g., teeth grinding, mandible thrusting) and discriminate them from functional (e.g., chewing, swallowing, talking, yawning) and other non-functional oral behaviours (e.g., nail, cheek, lip biting). The basic premise for designing such studies is that not all bruxism events are equal in terms of duration and EMG amplitude. Thus, as anticipated in the STAB,[24] parameters based on the amount or time of bruxism (e.g., bruxism time index, duty factor, bruxism work index) might emerge as the ideal targets for software analysis.[98–100]

The discrimination between bruxism-related and the aforementioned functional activities will thus emerge as a compelling need, also concerning the analysis of SB. Some studies have attempted to depict the different patterns of EMG signals during different orofacial motor events (OME),[101–105] but standardised protocols are necessary to advance clinical bruxism research within the framework of the updated definition. Many challenges can be expected to label the different bruxism activities based on specific patterns of EMG activation in terms of duration, intensity, rhythm of contraction, presence of teeth contact and its influence on motor recruitment, and interindividual anatomical variability. Indeed, whilst tonic prolonged activities such as bracing/clenching and phasic short-lasting activities such as grinding can be considered the two extremes of muscle recruitment, EMG traces commonly show a variety of findings that do not fit exactly with the theoretical label of a clenching or grinding episode.

The next step of the research route might be phenotyping the most common functional activities. Artificial intelligence analysis can be then used to screen and exclude them from the evaluation of potential bruxism-related muscle activities, also considering that many confounding factors (e.g., skeletal class, body mass index, muscle volume, fat tissues, dentition status, age, gender) might have an impact on the inter-individual differences in the expression of such activities. An assessment of the baseline activity is also needed for the data normalisation process. Afterwards, a complex task will be the identification of the many activities belonging to the bruxism spectrum. Until now, bruxism events have been identified by the detection of muscle activations featuring a certain amount of EMG signal amplitude with respect to the potential maximum voluntary clenching.[85] Threshold has been usually set at 10% or, in a minority of studies, at 20% of MVC or at n times the baseline levels.[106,107] This approach has been inconclusive to retrieve clinically relevant findings, likely due to the lack of information on prolonged low threshold activities, which are unlikely to be as strong as it is needed to be recorded over 10% or even 20% of MVC.[19]

The clinical importance of long-lasting contractions and background activity has been hypothesized by several authors.[21,108,109] In the clinical setting, this kind of activity is likely reconductable to the bracing and mild clenching activities that are included in the updated bruxism definiton.[1,2] Some recent studies are supportive of this hypothesis.[59,110] Based on that, the necessity to identify EMG patterns of prolonged, tonic, isometric activities is evident.[111–113] Such identification over a 24-hour timespan, also including AB, is therefore a fundamental step to provide the foundation for the whole bruxism spectrum as a risk factor for clinical consequences.

4.1.2 | Research strategies for subject-based information

In the STAB, the subject-based assessment includes self-report (e.g., questionnaires, history taking) of current bruxism status; a history report of bruxism behaviour; and a report of complaints possibly related to bruxism.[24] Complaints due to awake and sleep bruxism can hardly be discriminated. Also, subject-based information on SB, both current and past, is not necessarily reliable,[61] and is mostly related with the report of putative consequences upon awakening (e.g, functional limitation, muscle stiffness, pain).[114,115] However, the collection of self-reported data based on activities performed during wakefulness offers promising developments.[34]

As a general remark, studies on self-reported bruxism have always been considered biased due to the purported questionable reliability and validity of this approach, which has a poor correlation with PSG and EMG findings in SB.[116–118] Actually, it can now be suggested that self-reported and instrumental strategies can be considered simply as two different domains of evaluation, with different features, advantages, and shortcomings. For instance, SB scores based on the number of RMMA events cannot be compared with a self-reported clenching-type bruxism, since the two approaches do not address the same muscle activity, or they do so only partially.[21] In addition, such considerations do not apply to AB, for which correlation studies between self-reported and measurement strategies do not exist. The role of AB gained importance in the clinical setting because it may represent a main risk factor for orofacial musculoskeletal signs and symptoms, thus being the focus of several recent researches.[56,62,95,110,119–122] Data collection on AB can be more easily conceptualised than SB.[34] Based on that, a detailed specific domain for subject-based assessment (i.e., self-reported information) has been provided in the STAB.[24]

Research routes in the field must be tracked onto the improvement of data reliability and validity.[123] As for reliability, very little information exists on the repeated use of single-observation point questionnaires. Interestingly, administering the Italian version of the OBC questionnaire at a two-week interval, with focus on tooth-clenching wake-time behaviours, showed excellent reliability, even if the authors recommend that further subjects' instructions are needed.[37] Similar findings were retrieved for the original English version and for a culturally adapted Portuguese version.[73,124] No information is currently available on the reliability of any other single-observation point data collection strategy based on questionnaires or interviews, thus limiting any conclusions on the epidemiology of AB.[20] On the other hand, reliability of approaches based on real time report of AB in the natural environment finds support in a recent study, which showed that giving adequate information to both the clinicians who prescribe the use of smartphone-EMA and to the patients who use it allowed to achieve similar reported AB prevalence between two university samples of healthy students.[33] In particular, it can be suggested the use of the same supporting educational materials (viz., slides, images, videos) presented by the same investigators is an important factor to enhance homogeneity of information and to "calibrate" self-report at the individual and group levels. Besides, adequate user training to help them understand the intended meaning of the terms that are formulated to indicate the different AB conditions improves the test–retest repeatability of reports.[32] Thus, the challenge for the future is to collect subject-based information with carefully organised and standardised educational sessions. Factors such as the features of a study population might influence the results of all educational efforts, since participants with different age, educational level and socioeconomic status, and even concurrent health problems, may differ in response to educational sessions and in compliance to the observation protocols.[63,79,125,126]

Concerning validity, information is actually lacking due to the absence of a standard of reference approach for the assessment of the different activities of the AB spectrum. To this aim, validation studies should be performed to test the hypothesis that the strategy to report AB correlates with the actual jaw muscle activity, as discussed in the section below.

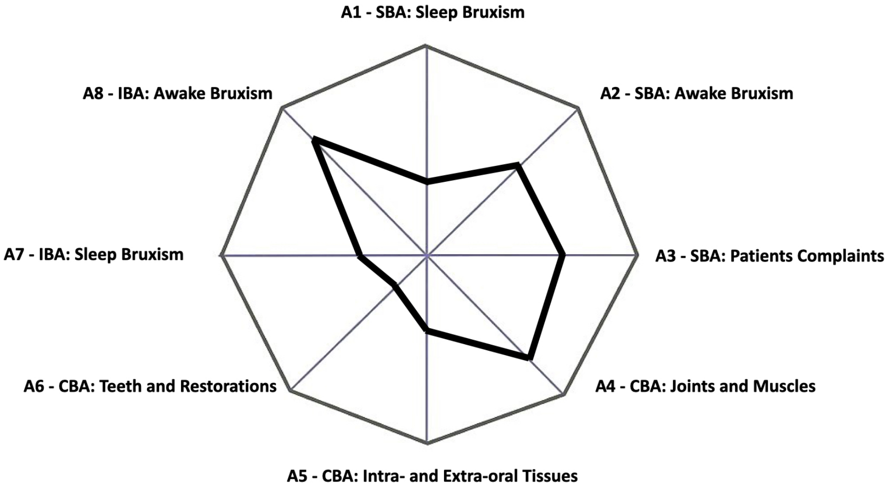

FIGURE 2 Hypothetical bruxism network representation of a patient with high levels of awake bruxism and musculoskeletal complaints.

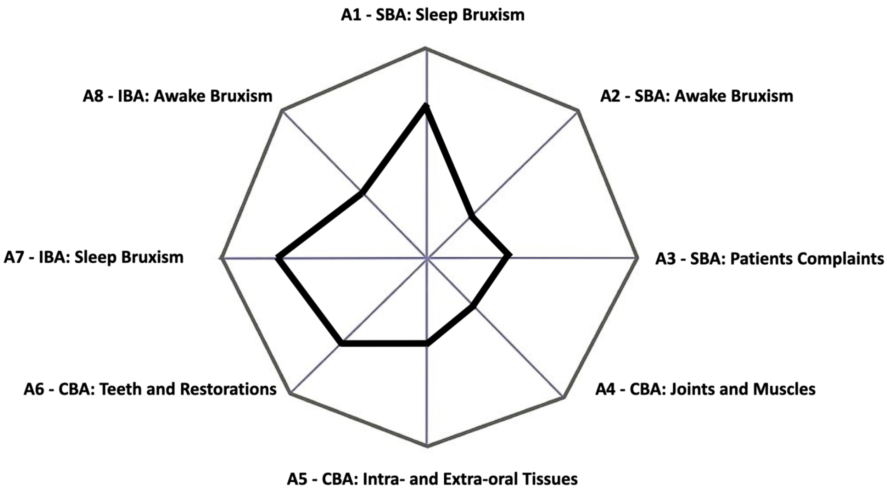

FIGURE 3 Hypothetical bruxism network representation of apatient with high levels of sleep bruxism and dental complaints (e.g., tooth wear, damage to restorations).

4.1.3 | Research strategies to cross-correlate findings

Cross-correlating findings of AB assessment gathered with different approaches may be useful to refine the assessment strategies both for self-reported and instrumental strategies, in line with the recent expert recommendations.[1,24,34] In particular, the circular reasoning that has characterised two decades of research on SB should be avoided. PSG/SB criteria were proposed as a screening strategy based on the best compromise between the sensitivity and specificity to identify individuals with a report and some potential clinical signs/symptoms related with SB,[6] but they were then assumed as the standpoint to validate all the other approaches.[116] The research on the purported validity of history report or clinical findings with respect to PSG is still ongoing,[127,128] but it might lead to unfruitful debates if the different bruxism phenotypes are not considered as the ultimate targets.[45,129–132] In as much as the RMMA/SB events may be considered markers of arousal-related phasic short-lasting SB (with or without tooth grinding), and not of bruxism as a whole, other EMG patterns must be identified as markers to recognise tonic long-lasting clenching or bracing activities.

In the field of AB, approaches to measuring the broad spectrum of activities have just emerged. Their reliability and their clinical validity have not been tested yet.[86] Thus, as per STAB recommendations, it is important to collect as much data as possible with the three different subject-based, clinically based, and instrumentally based approaches, and elaborate them with AI strategies before any diagnostic hierarchy construct is built. AI data mining has already been suggested, for instance, for studies on the interaction between sleep and pain.[133] In the field of bruxism, TMDs and orofacial pain, an important step will also be the acceptance of digitalization processes in data gathering and analysis, to facilitate machine learning strategies based on large scale epidemiological information. Within these premises, "measured" bruxism still remains the ideal target for comparison with other approaches and for the identification of bruxism status proxies as well as to test other technologies.[134–137] Deeper probing into this area will allow for an increase in knowledge on several aspects of AB, even including the clinical validity of subject-based information and the association with consequences. The natural course and fluctuations of signs and/or symptoms, the relationship with SB, and the exposure to etiological factors are other examples of issues that can be further explored with a comprehensive approach.

The use STAB and the BruxScreen[24,25] will allow getting deeper into the epidemiology of the various items at the individual (e.g.,

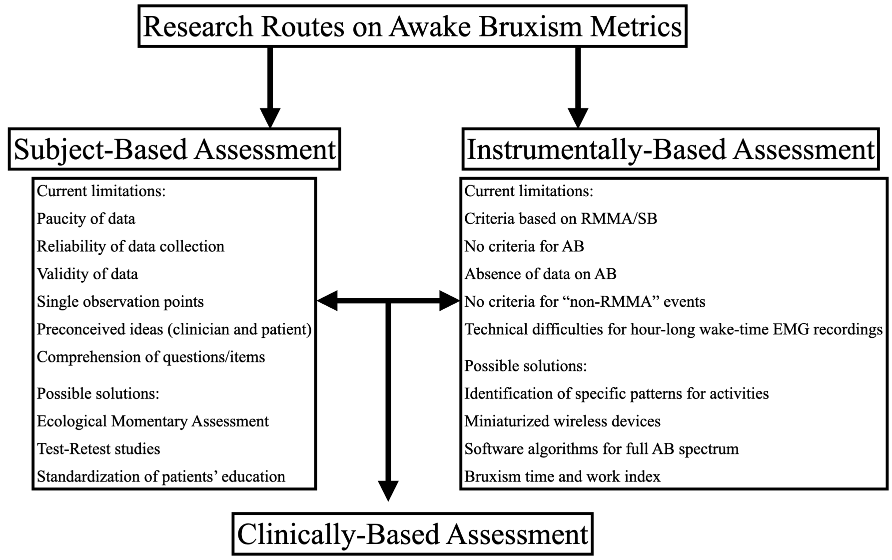

FIGURE 4 Summary of research routes on awake bruxism metrics. For both subject-based and instrumentally based assessments the current limitations and possible solutions are suggested. On-field studies should lead to integrate findings with information derived from clinically based assessment.

case series) as well as at the population level (e.g., cross-sectional and longitudinal large-sample studies). Data will be used to standardise future reports for comparison purposes. As an important clinical implication, self-reported strategies to monitor bruxism evolution over time should be initially validated for diagnostic purposes. However, they might find their better placement as part of a cognitive-behavioural approach to bruxism management (i.e., ecological momentary intervention).[75,138]

In the STAB, as part of a bigger goal to implement and standardise metrics for bruxism as a whole, scores and ratings for both subject-based (Domain A2) and instrumentally based (Domain A8) assessment for AB should be determined. Based on that, in line with similar approaches adopted for other fields of dentistry and medicine, a bruxism network can be visualised to phenotype the activity based on the aetiology and the potential consequences.[139,140] Based on the current evidence of an association between AB, TMDs, and psychological factors,[2,56] the possible bruxism network representation of a patient phenotype with high anxiety scores, poor stress coping skills, and high AB scores can be hypothesized in Figure 2, with a predominance of musculoskeletal complaints rather than damage to teeth and restorations. On the other hand, a possible phenotype of an individual with high levels of RMMA-SB and tooth wear, with low awake bruxism scores, is hypothesized in Figure 3. Research is needed to create scoring criteria and test the feasibility of the above-hypothesized graphical visualisation.

5 | CONCLUSIONS

Advancing the study of AB metrics is a fundamental step to assist clinicians in preventing and managing the possible consequences at the individual level. The present manuscript proposes some possible research routes to advance current knowledge, which can be summarised in Figure 4. At different levels, instrumentally based and subject-based information must be gathered in a standardised approach and correlated to each other. This will help, amongst others, to compensate the potential disadvantages of using a stand-alone strategy and to identify the potential clinical consequences that are predictors of a bruxism status.

A comprehensive approach, including a combination of self-reported and measurement strategies, will thus likely emerge as the gold standard for evaluating awake bruxism and standardise its metrics.

AUTHOR CONTRIBUTIONS

Authors A.B., A.C., D.M. conceptualised the paper and wrote a first draft. All the other authors contributed to manuscript refinement and finalisation.

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REFERENCES

1. Lobbezoo F, Ahlberg J, Raphael KG, et al. International consensus on the assessment of bruxism: report of a work in progress. *J Oral Rehabil*. 2018;45(11):837-844.
2. Lobbezoo F, Ahlberg J, Glaros AG, et al. Bruxism defined and graded: an international consensus. *J Oral Rehabil*. 2013;40(1):2-4.
3. Lavigne GJ, Khoury S, Abe S, Yamaguchi T, Raphael K. Bruxism physiology and pathology: an overview for clinicians. *J Oral Rehabil*. 2008;35(7):476-494.
4. Carra MC, Huynh N, Fleury B, Lavigne G. Overview on sleep bruxism for sleep medicine clinicians. *Sleep Med Clin*. 2015 Sep;10(3):375-384. xvi.
5. Bracci A, Diukic G, Favero L, Salmaso L, Guarda-Nardini L, Manfredini D. Frequency of awake bruxism behaviours in the natural environment. A 7-day, multiple-point observation of real-time report in healthy young adults. *J Oral Rehabil*. 2018;45(6):423-429.
6. Lavigne GJ, Rompré PH, Montplaisir JY. Sleep bruxism: validity of clinical research diagnostic criteria in a controlled polysomnographic study. *J Dent Res*. 1996;75(1):546-552.
7. Rompré PH, Daigle-Landry D, Guitard F, Montplaisir JY, Lavigne GJ. Identification of a sleep bruxism subgroup with a higher risk of pain. *J Dent Res*. 2007;86(9):837-842.
8. Manfredini D, Ahlberg J, Lobbezoo F. Bruxism definition: past, present, and future – what should a prosthodontist know? *J Prosthet Dent*. 2022 Nov;128(5):905-912.
9. Lavigne GJ, Guitard F, Rompré PH, Montplaisir JY. Variability in sleep bruxism activity over time. *J Sleep Res*. 2001;10(3):237-244.
10. Muzalev K, Visscher CM, Koutris M, Lobbezoo F. Long-term variability of sleep bruxism and psychological stress in patients with jaw-muscle pain: report of two longitudinal clinical cases. *J Oral Rehabil*. 2018;45(2):104-109.
11. Colonna A, Segù M, Lombardo L, Manfredini D. Frequency of sleep bruxism behaviors in healthy young adults over a four-night recording span in the home environment. *Applied Sciences*. 2021;11:195.
12. Dias R, Vaz R, Rodrigues MJ, Serra-Negra JM, Bracci A, Manfredini D. Utility of smartphone-based real-time report (ecological momentary assessment) in the assessment and monitoring of awake bruxism: a multiple-week interval study in a Portuguese population of university students. *J Oral Rehabil*. 2021;48(12):1307-1313.
13. Ohlmann B, Bömicke W, Behnisch R, Rammelsberg P, Schmitter M. Variability of sleep bruxism-findings from consecutive nights of monitoring. *Clin Oral Investig*. 2022;26(4):3459-3466.
14. Svensson P, Jadidi F, Arima T, Baad-Hansen L, Sessle BJ. Relationships between craniofacial pain and bruxism. *J Oral Rehabil*. 2008;35(7):524-547.
15. Abe S, Yamaguchi T, Rompré PH, De Grandmont P, Chen YJ, Lavigne GJ. Tooth wear in young subjects: a discriminator between sleep bruxers and controls? *Int J Prosthodont*. 2009;22(4):342-350.
16. Manfredini D, Lombardo L, Visentin A, Arreghini A, Siciliani G. Correlation between sleep-time masseter muscle activity and tooth Wear: an electromyographic study. *J Oral Facial Pain Headache*. 2019;33(2):199-204.
17. Lobbezoo F, Lavigne GJ. Do bruxism and temporomandibular disorders have a cause-and-effect relationship? *J Orofac Pain*. 1997;11(1):15-23.
18. Manfredini D, Lobbezoo F. Relationship between bruxism and temporomandibular disorders: a systematic review of literature from 1998 to 2008. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;109(6):e26-e50.
19. Manfredini D, Lobbezoo F. Sleep bruxism and temporomandibular disorders: a scoping review of the literature. *J Dent*. 2021 Aug;111:103711. doi:10.1016/j.jdent.2021.103711
20. Manfredini D, Winocur E, Guarda-Nardini L, Paesani D, Lobbezoo F. Epidemiology of bruxism in adults: a systematic review of the literature. *J Orofac Pain*. 2013;27(2):99-110.
21. Manfredini D, Ahlberg J, Wetselaar P, Svensson P, Lobbezoo F. The bruxism construct: from cut-off points to a continuum spectrum. *J Oral Rehabil*. 2019;46:991-997.
22. Manfredini D, Ahlberg J, Aarab G, et al. Towards a standardised tool for the assessment of bruxism (STAB) – overview and general remarks of a multidimensional bruxism evaluation system. *J Oral Rehabil*. 2020;47:549-556.
23. Manfredini D, Ahlberg J, Aarab G, et al. The development of the standardised tool for the assessment of bruxism (STAB): an international road map. *J Oral Rehabil*. 2022:1-14. doi:10.1111/joor.13380
24. Manfredini D, Ahlberg J, Aarab G, et al. Standardised tool for the assessment of bruxism. *J Oral Rehabil*. 2023:1-6. doi:10.1111/joor.13411
25. Lobbezoo F, Ahlberg J, Verhoeff MC, et al. The bruxism screener (BruxScreen): development, pilot testing, and face validity. *J Oral Rehabil*. 2023:1-8. doi:10.1111/joor.13442
26. Lavigne G, Kato T, Herrero Babiloni A, et al. Research routes on improved sleep bruxism metrics: toward a standardised approach. *J Sleep Res*. 2021;30(5):e13320.
27. Manfredini D, Colonna A, Bracci A, Lobbezoo F. Bruxism: a summary of current knowledge on aetiology, assessment, and management. *Oral Surgery*. 2020;13:358-370.
28. Ahlberg J, Piirtola M, Lobbezoo F, et al. Correlates and genetics of self-reported sleep and awake bruxism in a nationwide twin cohort. *J Oral Rehabil*. 2020;47(9):1110-1119.
29. Serra-Negra JM, Dias RB, Rodrigues MJ, et al. Self-reported awake bruxism and chronotype profile: a multicenter study on Brazilian, Portuguese and Italian Dental Students. *Cranio*. 2021;39(2):113-118.
30. Emodi-Perlman A, Manfredini D, Shalev T, et al. Awake bruxism-single-point self-report versus ecological momentary assessment. *J Clin Med*. 2021;10(8):1699.
31. Bucci R, Manfredini D, Lenci F, Simeon V, Bracci A, Michelotti A. Comparison between ecological momentary assessment and questionnaire for assessing the frequency of waking-time non-functional Oral Behaviours. *J Clin Med*. 2022;11(19):5880.
32. Nykänen L, Manfredini D, Lobbezoo F, et al. Ecological momentary assessment of awake bruxism with a smartphone application requires prior patient instruction for enhanced terminology comprehension: a multi-center study. *J Clin Med*. 2022;11(12):3444.
33. Zani A, Lobbezoo F, Bracci A, et al. Smartphone-based evaluation of awake bruxism behaviours in a sample of healthy young adults: findings from two university centres. *J Oral Rehabil*. 2021;48(9):989-995.
34. Bracci A, Lobbezoo F, Häggman-Henrikson B, et al. International network for orofacial pain and related disorders methodology INfORM. Current knowledge and future perspectives on awake bruxism assessment: expert consensus recommendations. *J Clin Med*. 2022;11(17):5083.
35. Colonna A, Bracci A, Ahlberg J, et al. Ecological momentary assessment of awake bruxism behaviors: a scoping review of findings from smartphone-based studies in healthy young adults. *J Clin Med*. 2023;12:1904.
36. Manfredini D, Lobbezoo F. Role of psychosocial factors in the etiology of bruxism. *J Orofac Pain*. 2009;23(2):153-166.
37. Donnarumma V, Cioffi I, Michelotti A, Cimino R, Vollaro S, Amato M. Analysis of the reliability of the Italian version of the Oral Behaviours checklist and the relationship between oral behaviours and trait anxiety in healthy individuals. *J Oral Rehabil*. 2018;45(4):317-322.

38. Pierce CJ, Chrisman K, Bennett ME, Close JM. Stress, anticipatory stress, and psychologic measures related to sleep bruxism. *J Orofac Pain*. 1995;9(1):51-56.
39. Manfredini D, Landi N, Fantoni F, Segù M, Bosco M. Anxiety symptoms in clinically diagnosed bruxers. *J Oral Rehabil*. 2005;32(8):584-588.
40. Emodi Perlman A, Lobbezoo F, Zar A, Friedman Rubin P, van Selms MK, Winocur E. Self-reported bruxism and associated factors in Israeli adolescents. *J Oral Rehabil*. 2016;43(6):443-450.
41. Câmara-Souza MB, Carvalho AG, Figueredo OMC, Bracci A, Manfredini D, Rodrigues Garcia RCM. Awake bruxism frequency and psychosocial factors in college preparatory students. *Cranio*. 2020;14:1-7.
42. Emodi-Perlman A, Manfredini D, Shalev T, Bracci A, Frideman-Rubin P, Eli I. Psychosocial and behavioral factors in awake bruxism-self-report versus ecological momentary assessment. *J Clin Med*. 2021;10(19):4447.
43. Rofaeel M, Chow JC, Cioffi I. The intensity of awake bruxism episodes is increased in individuals with high trait anxiety. *Clin Oral Investig*. 2021;25(5):3197-3206.
44. Manfredini D, Guarda-Nardini L, Marchese-Ragona R, Lobbezoo F. Theories on possible temporal relationships between sleep bruxism and obstructive sleep apnea events. *An Expert Opinion Sleep Breath*. 2015;19(4):1459-1465.
45. Manfredini D, De Laat A, Winocur E, Ahlberg J. Why not stop looking at bruxism as a black/white condition? Aetiology could be unrelated to clinical consequences. *J Oral Rehabil*. 2016;43(10):799-801.
46. Manfredini D, Arreghini A, Lombardo L, et al. Assessment of anxiety and coping features in bruxers: a portable electromyographic and electrocardiographic study. *J Oral Facial Pain Headache*. 2016;30(3):249-254.
47. Li Y, Yu F, Niu L, Long Y, Tay FR, Chen J. Association between bruxism and symptomatic gastroesophageal reflux disease: a case-control study. *J Dent*. 2018;77:51-58.
48. Ahlberg J, Wiegers JW, van Selms MKA, et al. Oro-facial pain experience among symphony orchestra musicians in Finland is associated with reported stress, sleep bruxism and disrupted sleep-independent of the instrument group. *J Oral Rehabil*. 2019;46(9):807-812.
49. Wetselaar P, Manfredini D, Ahlberg J, et al. Associations between tooth wear and dental sleep disorders: a narrative overview. *J Oral Rehabil*. 2019;46(8):765-775.
50. van Selms M, Kroon J, Tuomilehto H, et al. Self-reported sleep bruxism among Finnish symphony orchestra musicians: associations with perceived sleep-related problems and psychological stress. *Cranio*. 2020;30:1-8.
51. de Baat C, Verhoeff M, Ahlberg J, et al. Medications and addictive substances potentially inducing or attenuating sleep bruxism and/or awake bruxism. *J Oral Rehabil*. 2021;48(3):343-354.
52. Colonna A, Cerritelli L, Lombardo L, et al. Temporal relationship between sleep-time masseter muscle activity and apnea-hypopnea events: a pilot study. *J Oral Rehabil*. 2022;49(1):47-53.
53. Li D, Kuang B, Lobbezoo F, Vries N, Hilgevoord A, Aarab G. Sleep bruxism is highly prevalent in adults with obstructive sleep apnea: a large-scale polysomnographic study. *J Clin Sleep Med*. 2022;19:443-451. doi:10.5664/jcsm.10348
54. Huang Z, Zhou N, Chattrattrai T, et al. Associations between snoring and dental sleep conditions: a systematic review. *J Oral Rehabil*. 2023;50:416-428. doi:10.1111/joor.13422
55. Gomes AA, Parchão C, Almeida A, Clemente V, Pinto de Azevedo MH. Sleep-wake patterns reported by parents in hyperactive children diagnosed according to ICD-10, as compared to paired controls. *Child Psychiatry Hum Dev*. 2014 Oct;45(5):533-543.
56. Câmara-Souza MB, Bracci A, Colonna A, Ferrari M, Rodrigues Garcia RCM, Manfredini D. Ecological momentary assessment of awake bruxism frequency in patients with different temporomandibular disorders. *J Clin Med*. 2023;12(2):501.
57. Glaros AG, Williams K, Lausten L. The role of parafunctions, emotions and stress in predicting facial pain. *J Am Dent Assoc*. 2005;136(4):451-458.
58. Chen CY, Palla S, Erni S, Sieber M, Gallo LM. Nonfunctional tooth contact in healthy controls and patients with myogenous facial pain. *J Orofac Pain*. 2007;21:185-193.
59. Cioffi I, Landino D, Donnarumma V, Castroflorio T, Lobbezoo F, Michelotti A. Frequency of daytime tooth clenching episodes in individuals affected by masticatory muscle pain and pain-free controls during standardized ability tasks. *Clin Oral Investig*. 2017;21(4):1139-1148.
60. Kothari SF, Visser M, Timmerman K, et al. Painful and non-painful symptoms evoked by experimental bracing and thrusting of the mandible in healthy individuals. *J Oral Rehabil*. 2021;48(9):1004-1012.
61. Koyano K, Tsukiyama Y, Ichiki R, Kuwata T. Assessment of bruxism in the clinic. *J Oral Rehabil*. 2008;35(7):495-508.
62. Manfredini D, Winocur E, Guarda-Nardini L, Lobbezoo F. Self-reported bruxism and temporomandibular disorders: findings from two specialised centres. *J Oral Rehabil*. 2012;39(5):319-325.
63. Serra-Negra JM, Lobbezoo F, Correa-Faria P, et al. Relationship of self-reported sleep bruxism and awake bruxism with chronotype profiles in Italian dental students. *Cranio*. 2019;37(3):147-152.
64. Van Selms MKA, Visscher CM, Knibbe W, Thymi M, Lobbezoo F. The association between self-reported awake Oral behaviours and orofacial pain depends on the belief that these behaviours are harmful to the jaw J Oral facial. *Pain Headache*. 2020;34:273-280.
65. Osiewicz M, Lobbezoo F, Ciapała B, Pytko-Polończyk J, Manfredini D. Pain predictors in a population of temporomandibular disorders patients. *J Clin Med*. 2020;9(2):452.
66. Van Der Meulen MJ, Ohrbach R, Aartman IHA, Naeije M, Lobbezoo F. TMD patients' illness beliefs and self-efficacy related to bruxism. *J Orofac Pain*. 2010;24:367-372.
67. Manfredini D, Ciapparelli A, Dell'Osso L, Bosco M. Mood disorders in subjects with bruxing behavior. *J Dent*. 2005;33(6):485-490.
68. Panek H, Nawrot P, Mazan M, Bielicka B, Sumisławska M, Pomianowski R. Coincidence and awareness of oral parafunctions in college students. *Community Dent Health*. 2012;29(1):74-77.
69. Van der Meulen MJ, Lobbezoo F, Aartman IH, Naeije M. Self-reported oral parafunctions and pain intensity in temporomandibular disorder patients. *J Orofac Pain*. 2006;20(1):31-35.
70. Schiffman E, Ohrbach R, Truelove E, et al. International RDC/TMD consortium network, international association for dental research; orofacial pain special interest group, International Association for the Study of Pain. Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the international RDC/TMD consortium network* and orofacial pain special interest group. *J Oral Facial Pain Headache*. 2014;28(1):6-27.
71. Markiewicz MR, Ohrbach R, McCall WD Jr. Oral behaviors checklist: reliability of performance in targeted waking-state behaviors. *J Orofac Pain*. 2006;20(4):306-316.
72. Reda B, Lobbezoo F, Contardo L, et al. Prevalence of oral behaviors in general dental patients attending a university clinic in Italy. *J Oral Rehabil*. 2023;50:370-375. doi:10.1111/joor.13427
73. Kaplan SE, Ohrbach R. Self-report of waking-state Oral parafunctional behaviors in the natural environment. *J Oral Facial Pain Headache*. 2016;30(2):107-119.
74. Stone AA, Shiffman S. Ecological momentary assessment (EMA) in behavioral medicine. *Ann Behav Med*. 1999;16:199-202.
75. Runyan JD, Steinke EG. Virtues, ecological momentary assessment/intervention and smartphone technology. *Front Psychol*. 2015;6:481.

76. Zani A, Lobbezoo F, Bracci A, Ahlberg J, Manfredini D. Ecological momentary assessment and intervention principles for the study of awake bruxism behaviors, part 1: general principles and preliminary data on healthy young Italian adults. *Front Neurol*. 2019;10:169.
77. Glaros AG, Williams K, Lausten L, Friesen LR. Tooth contact in patients with temporomandibular disorders. *Cranio*. 2005 Jul;23(3):188-193.
78. Manfredini D, Bracci A, Djukic G. BruxApp: the ecological momentary assessment of awake bruxism. *Minerva Stomatol*. 2016;65(4):252-255.
79. Colonna A, Lombardo L, Siciliani G, et al. Smartphone-based application for EMA assessment of awake bruxism: compliance evaluation in a sample of healthy young adults. *Clin Oral Investig*. 2020;24(4):1395-1400.
80. Poluha RL, Canales GT, Bonjardim LR, Conti PCR. Oral behaviors, bruxism, malocclusion and painful temporomandibular joint clicking: is there an association? *Braz Oral Res*. 2021;6(35):e090.
81. Paesani DA, Lobbezoo F, Gelos C, Guarda-Nardini L, Ahlberg J, Manfredini D. Correlation between self-reported and clinically based diagnoses of bruxism in temporomandibular disorders patients. *J Oral Rehabil*. 2013;40(11):803-809.
82. Castroflorio T, Bargellini A, Rossini G, Cugliari G, Deregibus A, Manfredini D. Agreement between clinical and portable EMG/ECG diagnosis of sleep bruxism. *J Oral Rehabil*. 2015;42(10):759-764.
83. Manfredini D, Poggio CE, Lobbezoo F. Is bruxism a risk factor for dental implants? A systematic review of the literature. *Clin Implant Dent Relat Res*. 2014;16(3):460-469.
84. Chrcanovic BR, Kisch J, Albrektsson T, Wennerberg A. Bruxism and dental implant failures: a multilevel mixed effects parametric survival analysis approach. *J Oral Rehabil*. 2016;43(11):813-823.
85. Thymi M, Lobbezoo F, Aarab G, et al. Signal acquisition and analysis of ambulatory electromyographic recordings for the assessment of sleep bruxism: a scoping review. *J Oral Rehabil*. 2021 Jul;48(7):846-871.
86. Colonna A, Noveri L, Ferrari M, Bracci A, Manfredini D. Electromyographic assessment of masseter muscle activity: a proposal for a 24 h recording device with preliminary data. *J Clin Med*. 2022;12(1):247.
87. Prasad S, Paulin M, Cannon RD, Palla S, Farella M. Smartphone-assisted monitoring of masticatory muscle activity in freely moving individuals. *Clin Oral Investig*. 2019;23(9):3601-3611.
88. Funato M, Ono Y, Baba K, Kudo Y. Evaluation of the non-functional tooth contact in patients with temporomandibular disorders by using newly developed electronic system. *J Oral Rehabil*. 2014;41:170-176.
89. Glaros AG, Marszalek JM, Williams KB. Longitudinal multilevel modeling of facial pain, muscle tension, and stress. *J Dent Res*. 2016;95:416-422.
90. Pevernagie DA, Gnidovec-Strazisar B, Grote L, et al. On the rise and fall of the apnea-hypopnea index: a historical review and critical appraisal. *J Sleep Res*. 2020;29(4):e13066.
91. Lavigne GJ, Kato T, Kolta A, Sessle BJ. Neurobiological mechanisms involved in sleep bruxism. *Crit Rev Oral Biol Med*. 2003;14(1):30-46.
92. Greene CS, Manfredini D. Transitioning to chronic temporomandibular disorder pain: a combination of patient vulnerabilities and iatrogenesis. *J Oral Rehabil*. 2021;48(9):1077-1088.
93. Weijenberg RA, Lobbezoo F. Chew the pain away: oral habits to cope with pain and stress and to stimulate cognition. *Biomed Res Int*. 2015;2015:149431.
94. Soto-Goñi XA, Alen F, Buiza-González L, et al. Adaptive stress coping in awake bruxism. *Front Neurol*. 2020;9(11):564431.
95. Colonna A, Guarda-Nardini L, Ferrari M, Manfredini D. COVID-19 pandemic and the psyche, bruxism, temporomandibular disorders triangle. *Cranio*. 2021 Oct;15:1-6. doi:10.1080/08869634.2021.1989768
96. Dias R, Lima R, Prado IM, et al. Impact of confinement by COVID-19 in awake and sleep bruxism reported by Portuguese dental students. *J Clin Med*. 2022;11(20):6147.
97. Lobbezoo F, Aarab G, Ahlers MO, et al. Consensus-based clinical guidelines for ambulatory electromyography and contingent electrical stimulation in sleep bruxism. *J Oral Rehabil*. 2020;47(2):164-169.
98. Iwasaki LR, Gonzalez YM, Liu H, Marx DB, Gallo LM, Nickel JC. A pilot study of ambulatory masticatory muscle activities in temporomandibular joint disorders diagnostic groups. *Orthod Craniofac Res*. 2015;18(Suppl 1(0 1)):146-155.
99. Van Der Zaag J, Lobbezoo F, Visscher CM, Hamburger HL, Naeije M. Time-variant nature of sleep bruxism outcome variables using ambulatory polysomnography: implications for recognition and therapy evaluation. *J Oral Rehabil*. 2008;35(8):577-584.
100. Manfredini D, Fabbri A, Peretta R, Guarda-Nardini L, Lobbezoo F. Influence of psychological symptoms on home-recorded sleep-time masticatory muscle activity in healthy subjects. *J Oral Rehabil*. 2011;38(12):902-911.
101. Gallo LM, Lavigne G, Rompré P, Palla S. Reliability of scoring EMG orofacial events: polysomnography compared with ambulatory recordings. *J Sleep Res*. 1997;6(4):259-263.
102. Farella M, Palla S, Erni S, Michelotti A, Gallo LM. Masticatory muscle activity during deliberately performed oral tasks. *Physiol Meas*. 2008;29(12):1397-1410.
103. Farella M, Palla S, Gallo LM. Time-frequency analysis of rhythmic masticatory muscle activity. *Muscle Nerve*. 2009;39(6):828-836.
104. Po JM, Gallo LM, Michelotti A, Farella M. Comparison between the rhythmic jaw contractions occurring during sleep and while chewing. *J Sleep Res*. 2013;22(5):593-599.
105. Miettinen T, Myllymaa K, Muraja-Murro A, et al. Polysomnographic scoring of sleep bruxism events is accurate even in the absence of video recording but unreliable with EMG-only setups. *Sleep Breath*. 2020;24(3):893-904.
106. Manfredini D, Ahlberg J, Castroflorio T, Poggio CE, Guarda-Nardini L, Lobbezoo F. Diagnostic accuracy of portable instrumental devices to measure sleep bruxism: a systematic literature review of polysomnographic studies. *J Oral Rehabil*. 2014;41(11):836-842.
107. Casett E, Réus JC, Stuginski-Barbosa J, et al. Validity of different tools to assess sleep bruxism: a meta-analysis. *J Oral Rehabil*. 2017;44(9):722-734.
108. Farella M, De Oliveira ME, Gallo LM, et al. Firing duration of masseter motor units during prolonged low-level contractions. *Clin Neurophysiol*. 2011;122(12):2433-2440.
109. Raphael KG, Janal MN, Sirois DA, et al. Masticatory muscle sleep background electromyographic activity is elevated in myofascial temporomandibular disorder patients. *J Oral Rehabil*. 2013;40(12):883-891.
110. Ramanan D, Palla S, Bennani H, Polonowita A, Farella M. Oral behaviours and wake-time masseter activity in patients with masticatory muscle pain. *J Oral Rehabil*. 2021;48(9):979-988.
111. Monteiro UM, Soares VBRB, Soares CBRB, et al. Electromyographic patterns and the identification of subtypes of awake bruxism. *Front Hum Neurosci*. 2021;28(14):601881.
112. Yoshida Y, Suganuma T, Takaba M, et al. Association between patterns of jaw motor activity during sleep and clinical signs and symptoms of sleep bruxism. *J Sleep Res*. 2017;26(4):415-421.
113. Toyota R, Fukui KI, Kamimura M, et al. Sleep stage-dependent changes in tonic masseter and cortical activities in young subjects with primary sleep bruxism. *Sleep*. 2022;45(4):zsab207. doi:10.1093/sleep/zsab207

114. Manfredini D. No significant differences between conservative interventions and surgical interventions for TMJ disc displacement without reduction. *Evid Based Dent*. 2014;15(3):90-91.
115. Shimada A, Castrillon EE, Svensson P. Revisited relationships between probable sleep bruxism and clinical muscle symptoms. *J Dent*. 2019;82:85-90.
116. Raphael KG, Janal MN, Sirois DA, et al. Validity of self-reported sleep bruxism among myofascial temporomandibular disorder patients and controls. *J Oral Rehabil*. 2015;42(10):751-758.
117. Yachida W, Arima T, Castrillon EE, Baad-Hansen L, Ohata N, Svensson P. Diagnostic validity of self-reported measures of sleep bruxism using an ambulatory single-channel EMG device. *J Prosthodont Res*. 2016;60(4):250-257.
118. Stuginski-Barbosa J, Porporatti AL, Costa YM, Svensson P, Conti PC. Agreement of the international classification of sleep disorders criteria with polysomnography for sleep bruxism diagnosis: a preliminary study. *J Prosthet Dent*. 2017;117(1):61-66.
119. Greene CS, Manfredini D. Treating Temporomandibular Disorders in the 21st Century: can We Finally Eliminate the "Third Pathway"? *J Oral Facial Pain Headache*. 2020;34(3):206-216.
120. Silva TB, Ortiz FR, Maracci LM, et al. Association among headache, temporomandibular disorder, and awake bruxism: a cross-sectional study. *Headache*. 2022;62(6):748-754.
121. Greene CS, Manfredini D. Overtreatment "successes"– what are the negative consequences for patients, dentists, and the profession? *J Oral Facial Pain Headache*. 2023;37(2):1-10.
122. Donnarumma V, Ohrbach R, Simeon V, Lobbezoo F, Piscicelli N, Michelotti A. Association between waking-state oral behaviours, according to the oral behaviors checklist, and TMD subgroups. *J Oral Rehabil*. 2021;48(9):996-1003.
123. Roberts P, Priest H. Reliability and validity in research. *Nurs Stand*. 2006;20(44):41-45.
124. Barbosa C, Manso MC, Reis T, Soares T, Gavinha S, Ohrbach R. Cultural equivalence, reliability and utility of the Portuguese version of the Oral Behaviours checklist. *J Oral Rehabil*. 2018;45(12):924-931.
125. Ahlberg J, Lobbezoo F, Ahlberg K, et al. Self-reported bruxism mirrors anxiety and stress in adults. *Med Oral Patol Oral Cir Bucal*. 2013;18(1):e7-e11.
126. Manfredini D, Lobbezoo F, Giancristofaro RA, Restrepo C. Association between proxy-reported sleep bruxism and quality of life aspects in Colombian children of different social layers. *Clin Oral Investig*. 2017;21(4):1351-1358.
127. Restrepo C, Manfredini D, Castrillon E, et al. Diagnostic accuracy of the use of parental-reported sleep bruxism in a polysomnographic study in children. *Int J Paediatr Dent*. 2017;27(5):318-325.
128. Ohlmann B, Rathmann F, Bömicke W, Behnisch R, Rammelsberg P, Schmitter M. Validity of patient self-reports and clinical signs in the assessment of sleep bruxism based on home-recorded electromyographic/electrocardiographic data. *J Oral Rehabil*. 2022;49(7):720-728.
129. Raphael KG, Santiago V, Lobbezoo F. Is bruxism a disorder or a behaviour? Rethinking the international consensus on defining and grading of bruxism. *J Oral Rehabil*. 2016;43(10):791-798.
130. Svensson P, Lavigne G. Clinical bruxism semantics beyond academic debates: normo- and patho-bruxism as a new proposal. *J Oral Rehabil*. 2020;47(5):547-548.
131. Lobbezoo F, Ahlberg J, Aarab G, Manfredini D. Why using 'harmless behaviour', 'risk factor' and 'protective factor' as terms describing the various possible consequences of bruxism is still the best option. *J Oral Rehabil*. 2021;48(6):762-763.
132. Ahlberg J, Manfredini D, Lobbezoo F. STAB-A response to the commentary "questions on the clinical applicability on the international consensus on the assessment of bruxism" by Skarmeta and Hormazabal Navarrete. *J Oral Rehabil*. 2020;47(12):1574-1576.
133. Herrero Babiloni A, De Koninck BP, Beetz G, De Beaumont L, Martel MO, Lavigne GJ. Sleep and pain: recent insights, mechanisms, and future directions in the investigation of this relationship. *J Neural Transm (Vienna)*. 2020;127(4):647-660.
134. Takeuchi H, Ikeda T, Clark GT. A piezoelectric film-based intrasplint detection method for bruxism. *J Prosthet Dent*. 2001;86(2):195-202.
135. McAuliffe P, Kim JH, Diamond D, Lau KT, O'Connell BC. A sleep bruxism detection system based on sensors in a splint – pilot clinical data. *J Oral Rehabil*. 2015;42(1):34-39.
136. Maoddi P, Bianco E, Letizia M, Pollis M, Manfredini D, Maddalone M. Correlation between a force-sensing Oral appliance and electromyography in the detection of tooth contact bruxism events. *J Clin Med*. 2022;11(19):5532.
137. Pollis M, Maoddi P, Letizia M, Manfredini D. Customized appliance device for force detection in bruxism individuals: an observational study. *Int J Dent*. 2022;14(2022):2524327.
138. Smith KE, Juarascio A. From ecological momentary assessment (EMA) to ecological momentary intervention (EMI): past and future directions for ambulatory assessment and interventions in eating disorders. *Curr Psychiatry Rep*. 2019;21(7):53.
139. Mazel A, Belkacemi S, Tavitian P, et al. Peri-implantitis risk factors: a prospective evaluation. *J Investig Clin Dent*. 2019;10(2):e12398.
140. Ferrari M, Pontoriero DIK, Ferrari Cagidiaco E, Carboncini F. Restorative difficulty evaluation system of endodontically treated teeth. *J Esthet Restor Dent*. 2022;34(1):65-80.

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