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Classical negative consequences, clinical experiences, and novel diagnostic approaches

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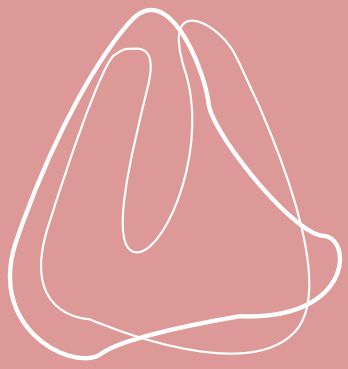

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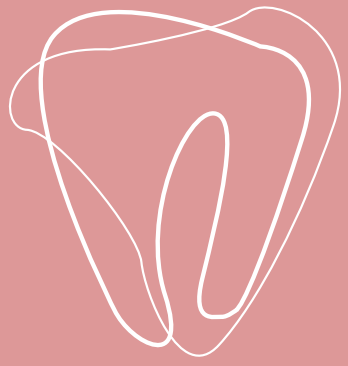

MAGDALINI THYMI

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and novel diagnostic approaches

Magdalini Thymi

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“Mystery is never more than a mirage that vanishes as we draw near to look at it.”

Simone de Beauvoir, The Second Sex

“In those days, thank God, I acquired from my master the desire to learn and a sense of the straight way, which remains even when the path is tortuous.”

Umberto Eco, The Name of the Rose

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Chapter 1

General introduction

GENERAL INTRODUCTION

Bruxism is a fascinating phenomenon with a bad reputation. In the literature, teeth grinding scenes have been written to illustrate hostility and anger. Fyodor Dostoevsky's Underground Man introduces himself as follows: *"When petitioners used to come for information to the table at which I sat, I used to grind my teeth at them, and felt intense enjoyment when I succeeded in making anybody unhappy. I almost did succeed"* [1]. In a similar negative fashion, bruxism is often reported as a source of complications in dental literature [2]. The latter concept has been strongly questioned in the past years [3], alongside with important developments in bruxism definitions and diagnostic systems [4]. This thesis mainly focuses on whether bruxism should indeed be considered a behavior with negative implications. Furthermore, it presents research on specific aspects related to bruxism diagnosis.

The introductory chapter starts with a brief theoretical background on the current status regarding the definition of bruxism. It continues by outlining possible negative consequences of bruxism, as well as diagnostic challenges. The chapter ends by providing an overview of the research questions and studies which were carried out to answer them.

Bruxism definition

Bruxism is a masticatory muscle activity that can occur during sleep, wakefulness, or both [4]. Its definition has been evolving over the past decades [5], and a single umbrella definition has been replaced by one that distinguishes between the two manifestations of the activity. Currently, sleep bruxism is defined as "a masticatory muscle activity during sleep that is characterized as rhythmic (phasic) or non-rhythmic (tonic) and is not a movement disorder or a sleep disorder in other-wise healthy individuals" [4]. Awake bruxism is defined as "a masticatory muscle activity during wakefulness that is characterized 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" [4].

The international acceptance of these two definitions of bruxism is a major step towards improvement of research in the field. However, when it comes to bruxism, both clinicians and researchers face two other major challenges. The first involves its consequences; the second, its diagnosis [4,6].

Consequences of bruxism

Traditionally, bruxism has been considered a source of overload and thus, as a parafunction, i.e., a behavior with negative health consequences [2]. This concept is increasingly being challenged [3], with certain positive outcomes being reported over the years [7], as currently supported by international experts' consensus [4]. Examples of such positive outcomes are lubrication of the oroesophageal tissues during sleep by mechanical stimulation of the salivary flow [8] and reduction of negative emotional arousal [9]. In addition, bruxism may also be seen as a condition without positive or negative consequences, meaning, a condition that 'just' is . Research on the topic of whether bruxism is a pathologic condition as opposed to a behavior with no, or even positive health outcomes is strongly encouraged [4,6,7]. The studies presented in this thesis have mainly focused on the 'negative' side of the spectrum of the possible consequences of bruxism.

Negative consequences of bruxism on the masticatory system are grossly divided into two categories, namely its effects on the musculoskeletal tissues and its effects on the dentition [2]. The former category involves signs and symptoms like musculoskeletal pain and limitations in mandibular movements. The latter category involves tooth wear and complications of dental restorations, including dental implants [2]. This thesis will focus on possible consequences of bruxism related to musculoskeletal signs and symptoms, and to dental implant complications.

Musculoskeletal signs and symptoms

The relationship between bruxism and musculoskeletal signs and symptoms has been a topic of interest for decades, and research in the field is of considerable extent. Through theoretical frameworks, such as the psychophysiologic theory [10] and the pain adaptation model [11], researchers have attempted to explain how loading of the masticatory muscles might be related to pain. Current evidence suggests that overloading of the masticatory structures fits into a multifaceted model to explain the occurrence and persistence of pain [12]. The specific contribution of bruxism in this context has been extensively investigated, mainly through the scope of painful temporomandibular disorders (TMDs) [13](, for reviews see [14–16]). These literature reviews point to the fact that, mainly due to methodological limitations of studies, robust conclusions on this topic are difficult to draw [14–16]. Such limitations involve inadequate case definitions of bruxism, bruxism diagnosis, and outcome measures. Moreover, symptoms other than pain, e.g., sensations of tenderness, tiredness, and unpleasantness in the masticatory muscles, have been used as indirect signs of bruxism activity [17], even though literature objectifying this relation is scarce (e.g., [18,19]). Interestingly, prospective cohort research has shown that such sensations in the orofacial region may be

precursors of subsequent pain [20]. Thus, a more thorough understanding of their presence and their relationship with bruxism is needed.

Furthermore, in theory, bruxism may be a source of microtrauma for the temporomandibular joints (TMJs), which, in turn, may be related to functional signs and symptoms, such as joint sounds and restricted mouth opening [21]. This topic has been investigated in the TMD research field (e.g. [22–24]), but to date, no consensus on the existence and strength of this relation has been reached.

In the present thesis, the relationship between bruxism and musculoskeletal signs and symptoms of the masticatory system is investigated by means of a systematic literature review and a clinical study. (Chapters 2 and 3)

The effects on oral implants

Oral implants are effective treatment options for partial or complete loss of the dentition [25]. Despite their high success rates, some complications are expected to occur [25,26]. There are two main categories of implant complications, namely biological and technical [26]. The former involves inflammation and loss of the peri-implant soft and hard tissues, i.e., mucositis, peri-implantitis, and loss of osseointegration [26], and the latter amongst others, failures of implant components, e.g., implant fracture, abutment screw loosening and fracture, chipping of veneers and fracture of bars [26].

Bruxism can be a significant source of occlusal loading, and as such, may be related to the occurrence of implant complications [27]. Literature reviews have shown an association between bruxism and implant loss [28] and between bruxism and technical implant complications [29,30]. However, similarly to what is encountered in the field of musculoskeletal consequences, these reviews point out the shortcomings of included studies, and especially the lack of valid bruxism assessments [28–30].

There is insufficient evidence to support an association between bruxism and biological implant complications [30]. Altogether, the question of whether occlusal overload contributes to peri-implant bone loss remains largely unanswered, due to the lack of appropriately designed clinical studies [31]. Limited evidence from animal studies supports that occlusal overload will not lead to loss of peri-implant tissues in the absence of dental plaque [32]. Interestingly, clinicians in different countries have divergent beliefs on the topic of whether adverse loading can be related to peri-implant disease [33,34].

This thesis presents a prospective cohort study and a qualitative study designed to investigate the association between bruxism and implant complications. (Chapters 5, 6, and 7)

Diagnosis of bruxism

The presence of bruxism is hard to objectify. The assessment of both sleep and awake bruxism by either self-report and/or clinical examination unfortunately lacks validity [4]. Self-report overestimates the presence of sleep bruxism [35], while unacceptable false-positive and false-negative rates have been found for assessments based on clinical signs [36]. Assessing awake bruxism via self-report is common practice, and requires the individual to be aware of this activity [37]. Interestingly, evidence suggests that chronic pain sufferers may have reduced awareness of oral habits under stressful conditions [9,38], while other data showed that reporting awake oral behaviors is influenced by the belief that these behaviors are harmful for the jaw when myalgia is present (van Selms et al., unpublished data). Evidence to support validity of clinical examination for the diagnosis of awake bruxism is practically absent.

Currently, instrumental methods are recommended over self-report and clinical examination for the assessment of awake and sleep bruxism in order to overcome the abovementioned issues [4]. Electromyographic (EMG) and ecological momentary assessment (EMA) methods can provide valuable data on awake bruxism [6,37], while EMG recordings during sleep are needed for the assessment of sleep bruxism [6]. All these approaches pose significant challenges for clinicians and researchers in terms of costs and practicality [4,7], and it is safe to hypothesize that they may have significant implications for patients as well, in terms of burden and invasiveness.

Progress of bruxism research requires diagnostic tools that are both valid and pragmatic in their implementation. In this thesis, the topic of assessing bruxism is addressed from the perspective of clinicians, and patients by means of a qualitative study and a mixed-methods study. (Chapters 4 and 7)

Overview of the thesis

Main research questions

- To what extent is bruxism associated with musculoskeletal signs and symptoms? (Chapter 2)
- To what extent are masticatory muscle symptoms present in probable sleep bruxers, and how are these symptoms associated with masticatory muscle activity during sleep? (Chapter 3)
- What are the attitudes and experiences of oral implantologists when dealing with bruxing patients in a non-academic setting? (Chapter 4)
- Is sleep bruxism a risk factor for (peri-)implant complications? (Chapters 5 and 6)
- How do study participants experience the use of a portable, single-channel EMG device for the diagnosis of sleep bruxism? Which factors facilitate and/or hamper the use of the device? (Chapter 7)

Thesis chapters

Chapter 1 presents a general introduction

Chapter 2 provides a comprehensive and critical overview of the literature on the relationship between bruxism and the multiple facets of masticatory musculoskeletal signs and symptoms. The following parameters are considered: a) population age, i.e., children and adults, b) bruxism subtype, i.e., awake, sleep, or no distinction, c) bruxism assessment methods, i.e., self-report, a combination of self-report and clinical examination, and instrumental assessments, and d) type of outcome, i.e., functional signs and symptoms, pain, and symptoms other than pain.

Chapter 3 presents an investigation of the relationship between sleep bruxism and clinical symptoms of the masticatory muscles. More specifically, the study aims to investigate, in a sample of probable sleep bruxers with and without a diagnosis of a painful TMD, a) the presence of, and relationships between muscle symptoms, and b) the association between these symptoms with masticatory muscle activity during sleep. Ambulatory, multiple-night electromyographic (EMG) recordings are used for the assessment of muscle activity. Evaluated symptoms are pain, unpleasantness, tiredness, tension, soreness, and stiffness.

In **chapter 4**, the focus shifts towards the relationship between bruxism and treatment modalities involving oral implants. This topic is dealt with from the clinician's point of view, and a qualitative study design with semi-structured interviews is applied.

Chapter 5 describes the protocol of a prospective cohort study, designed to investigate whether sleep bruxism might be a risk factor for (peri-)implant complications. Here too, ambulatory, multiple-night EMG recordings are used for the assessment of muscle activity during sleep, and important covariates and confounders are considered.

Chapter 6 presents the outcomes and challenges that were encountered during the data collection of the study described in chapter 5.

Chapter 7 investigates the use of a portable, single-channel EMG device that pairs with a smartphone for the assessment of masticatory muscle activity during sleep. For this purpose, a mixed methods cohort study is carried out, in which participants performed multiple overnight recordings and reported their experiences in a diary.

Chapter 8 provides a general discussion and recommendations for future research and clinical practice.

Chapters 9 and 10 present summaries of this thesis in English and Dutch respectively.

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Chapter 2

To what extent is bruxism associated with musculoskeletal signs and symptoms? A systematic review

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ABSTRACT

The aim of the present systematic review was to answer the overall research question: "To what extent is bruxism associated with musculoskeletal signs and symptoms?". The review was performed in accordance with the PRISMA guidelines. A PubMed search of articles published until November 23, 2017 was conducted. The search string included both MeSH terms and text words. Results were presented in categories according to study design, study population (e.g., adults, children), bruxism sub-type (awake, sleep), assessment methods for bruxism and musculoskeletal symptoms (self-report, validated test), and type of outcome (pain, non-painful musculoskeletal symptoms). It could be concluded that bruxism is to some extent associated with musculoskeletal symptoms, even though the evidence is conflicting and seems to be dependent on many factors, such as age, whether the bruxism occurs during sleep or wakefulness, and also the quality of the diagnostic methodology regarding bruxism and musculoskeletal signs and symptoms. The literature does not support a direct linear causal relationship between bruxism and such symptoms, but points more in the direction of a multifaceted relationship dependent on the presence of other risk factors. Pain is by far the most commonly assessed symptom, whereas non-painful musculoskeletal symptoms have generally not been systematically evaluated. In the light of recent findings indicating that non-painful symptoms may precede TMD pain, it is suggested to increase the scientific focus on non-painful musculoskeletal symptoms in future studies. Also, future studies should use validated methods for case definition and outcome assessments.

Keywords

Bruxism, temporomandibular disorders, musculoskeletal symptoms, pain, unpleasantness, muscle fatigue

BACKGROUND

Until recently, bruxism was defined as "a repetitive jaw-muscle activity characterized by clenching and grinding of the teeth and/or by bracing or thrusting of the mandible". [1] Bruxism activity may occur during wakefulness or sleep. [1] An updated definition was recently published, stating that "sleep and awake bruxism are masticatory muscle activities that occur during sleep (characterized as rhythmic or non-rhythmic) and wakefulness (characterized by repetitive or sustained tooth contact and/or by bracing or thrusting of the mandible), respectively". [2] The possible relationship between bruxism and different musculoskeletal symptoms of the masticatory system remains controversial, and the literature is conflicting on this matter. [3,4] Most often, a possible positive relationship between either awake or sleep bruxism and craniofacial pain has been hypothesized (for a review, please see [3]) and even sometimes presented as a true and simple cause-effect relationship in non-scientific literature. [3] However, it has become increasingly clear that the association between bruxism and craniofacial pain is much more complex, and efforts have been made to understand painful temporomandibular disorders (TMD) along with other chronic pain conditions in a biopsychosocial context, [5–8] thereby recognizing the important influence of psychosocial factors.

The study of the possible relationship between bruxism and craniofacial pain has been further challenged by the evolution of definitions and diagnostic criteria for bruxism.[2] More specifically, the concrete distinction between the two circadian manifestations of bruxism, i.e., awake and sleep, requires that the conditions are separately assessed.[1] Moreover, although the diagnostic criteria for sleep and awake bruxism are still a work in progress, since the 2013 proposal of a bruxism diagnostic grading system it is recognized that commonly used methods such as self-report and clinical inspection can at best only lead to the suggestion of probable sleep or awake bruxism. Instrumental approaches are required for definitive bruxism assessments.[1,2] These matters need to be taken into account when interpreting results of related studies.

Advances have also been made in the diagnostic criteria of craniofacial pain conditions, particularly in the field of TMDs. Without any doubt, the introduction of clear and operationalized criteria for TMD pain has been a major achievement in the scientific community with the Research Diagnostic Criteria for TMD, [5] and later the Diagnostic Criteria for TMD.[9] In contrast to the symptom of pain, other musculoskeletal symptoms that could be speculated to have possible link to bruxism activity, such as jaw muscle fatigue, tenderness,

tension, or weakness, are much more rarely evaluated systematically. One reason for that could be that only symptoms and clinical findings of spontaneous craniofacial pain, pain on palpation, changes in jaw movement capacity, and temporomandibular joint sounds may give rise to a definite TMD diagnosis.[5,9,10] Consequently, non-painful musculoskeletal symptoms are often not taken into account clinically, unless the patient decides to describe them as pain. Hence, the non-painful musculoskeletal complaints fall outside of the TMD umbrella term, and therefore do not qualify for any diagnosis.

Notwithstanding, non-painful symptoms, e.g., muscle fatigue, stiffness, soreness, weakness, etc. may also have a negative impact on the individual. Fields (1999) noted that, in addition to the sensory-discriminative component of noxious input and nociception and the related primary unpleasantness, there could also be a more contextually-dependent degree of unpleasantness – termed secondary unpleasantness.[11] In terms of muscle pain, this could mean that stiffness, fatigue, soreness, etc. could represent such non-painful symptoms resembling secondary unpleasantness. Most of the previous systematic reviews on the relationship between bruxism and pain may have focused on the sensory-discriminative component of pain and primary unpleasantness, leading to the general conclusion that there is little, if any, evidence to support a strong relationship.[3] Anecdotally, many clinicians will report that they have experienced an obvious relationship, but the controversy may rely on how pain and non-painful symptoms are reported and recorded. With this in mind, it seems appropriate to re-evaluate the relationship between bruxism and not only pain per se, but also to non-painful musculoskeletal symptoms.

The aim of the present systematic review was to answer the overall research question: “To what extent is bruxism associated with musculoskeletal signs and symptoms?”. To provide the best possible overview, results were reviewed in categories according to study design, study population (adults, children), bruxism sub-type (awake, sleep), assessment methods for bruxism and musculoskeletal symptoms (self-report, self-report and clinical examination, instrumental assessment), and type of outcome (pain, non-painful musculoskeletal symptoms).

METHODS

The present systematic review was performed in accordance to the PRISMA guidelines.[12] A PubMed search of articles published until November 23, 2017 was conducted. The search string is shown in Table 1. One of the authors (LBH) screened the yielded titles according to the following inclusion criteria: 1. *Bruxism* was present in title and/ or 2. The title was seemingly related to the research question; 3. If any doubt as to criteria 1 and 2: the title was included for abstract review. The abstracts of the chosen titles were then screened according to two criteria: 1. The article was seemingly related to the research question; 2. If any doubt or abstract was absent: the article as included for full text review. The chosen full text articles were assessed for eligibility by two of the authors independently (LBH and MT) according to the criteria in Table 2. In case of disagreement, authors FL and PS were consulted until consensus was reached. A review of the reference lists of the included articles was then performed, as well as a hand-search for possibly wrongfully omitted articles. Titles obtained were subjected to the same criteria as above. LBH and MT independently assessed the quality of the studies using the Newcastle Ottawa Scale (NOS) for Case Control Studies and Cohort Studies,[13] the Quality Assessment Tool for Experimental Bruxism Studies (Qu-ATEPS),[14] the Robins-I for assessment of risk of bias on non-randomized intervention studies,[15] and the Cochrane Collaboration´s tool for assessing risk of bias in randomized trials.[16] For the NOS and Qu-ATEPS, a cut-of value of 2 stars and 30 points, respectively, was used for including a study for data extraction. If no distinction was made between awake and sleep bruxism, the study was excluded. Data extraction was performed by MT onto a data extraction form (Please see supplementary material. Relevant data from the full text articles included study characteristics (viz., first author, year, journal), participant characteristics (viz., gender, mean age and age range, type of sample), assessed signs and symptoms, methodology used for bruxism assessment, and main results. LBH was consulted in case of any doubts, and consensus was reached through discussion with occasional inclusion of coauthors FL and PS.

A meta-analysis could not be performed due to the heterogeneity of the study designs and outcome parameters assessed of the included studies.

RESULTS

A flow chart of the article inclusion is provided in Fig. 1. In total, 81 studies were included in this review. There were 59 studies with a case-control or cross-sectional design, two studies with a prospective cohort design, 14 experimental studies, and six interventional clinical studies. The studies were published between 1978 and 2017, with almost half (48%) of them having been published between 2008 and 2017 (Fig. 2). Altogether, 40.491 participants were included (19.221 female, 13.902 male, 7.368 no data on gender [17–19]) (Table 3). For each included study, a comprehensive description of the definitions of both bruxism cases, as well as outcome measures, i.e., painful and non-painful musculoskeletal signs and symptoms is provided in the supplementary materials.

Case-control, cross-sectional and prospective cohort studies

The 59 case-control studies were assessed and are presented based on four axes (Table 4): 1) Population age (adults, i.e., participants 18 years or older, and children and/or adolescents, i.e., participants <18 years); 2) Bruxism assessment method (self-report, self-report plus clinical examination, instrumental, i.e., ecological momentary assessment (EMA) and/or single channel electromyography (EMG) for awake bruxism, and single-channel EMG or polysomnography for sleep bruxism); 3) Circadian type of bruxism (awake bruxism, sleep bruxism); and 4) Type of outcome. Regarding the bruxism assessment method, some studies were fit for more than one category. For example, Raphael et al. (2012) provide results for both self-reported, as well as instrumentally assessed sleep bruxism, [20] and is therefore included in two sections (Adults: Self report; Sleep bruxism, and Adults: Instrumental; Sleep bruxism, polysomnography). An overview of studies that are included in multiple categories is provided in Table 4.

Variation in the reported outcomes was of a considerable size. As to provide a clear and structured overview of all outcomes, these were grouped into six categories. For acquisition of these categories, all reported outcomes were listed and subsequently grouped based on them referring to a similar theme, a method resembling thematic analysis in qualitative research.[21] The categories are mutually exclusive, i.e., each reported outcome could only fit into one category. The six categories were:

a. Functional signs and symptoms: temporomandibular joint (TMJ) sounds (e.g., clicking, arthrosis /crepitation), disc-related (i.e., when a specific disc-related diagnosis was set by the authors, such as disc displacement), dysfunction (e.g., deviation, restriction, locking,

luxation of the mandible)

b. Muscle pain, or non-painful muscle symptoms (e.g., tenderness, soreness, fatigue, based on self-report and/or clinical examination)
c. TMJ pain, or non-painful TMJ symptoms (e.g., tenderness, soreness, based on self-report and/or clinical examination)
d. Function-related pain (e.g., pain only on movement or due to mastication)
e. Orofacial pain involving musculoskeletal structures, not fit for categories above (e.g., combination of muscle and joint pain, combination of pain with dysfunction) and/or pain characteristics (e.g., intensity)
f. Structured TMD diagnoses based on a diagnostic system other than RDC/TMD or DC/TMD. [5,9]

In case the assessment of functional signs and symptoms (category a) and pain (categories b, c & e) is not based on validated clinical criteria, i.e., non-RDC/TMD or DC/TMD clinical examinations or self-reported symptoms, they are listed using quotation marks. Non-painful muscle and TMJ symptoms (categories b & c) were assessed by unvalidated self-report measures, as standardized clinical criteria do not exist. Function-related pain (category d) was assessed by self-report. The description of outcomes in category e are not provided in detail in this manuscript, and the reader is referred to the original publications.

1. Adult populations

Adult populations were assessed in 25 studies (Table 4). To be assessed as an adult study, participants should be at least 18 years of age. Some studies reported results on mixed populations of children and adults, (e.g. [22]). These studies were included in the adult's pool, as long as the reported mean age was ≥ 18 years.

1.1. Adults: Self-report

1.1.1. Awake bruxism

A self-reported, i.e., report obtained by interview or written questionnaire, awake bruxism diagnosis was obtained in nine studies.

Functional symptoms: TMJ sounds were investigated in two studies.[23,24] Rossetti et al. [23] found no association between RDC/TMD assessed articular sounds and awake clenching, neither did Duckro et al. [24] between "popping or clicking jaw sounds" and awake clenching or grinding. However, Michelotti et al. [25] found awake clenching or grinding to be a significant risk factor for RDC/TMD diagnosed disc displacement. Daytime clenching was not found to

be associated with mouth opening in myofascial pain patients by Rossetti et al. [23], while Moss et al. [26] found a negative association between self-reported daily clenching of the teeth and restricted mandibular movements, or "TMJ dysfunction", and Huhtela et al. [27] a positive one between awake bruxism and "TMJ locking".

Muscle symptoms: The presence of RDC/TMD diagnosed myofascial pain was assessed in the studies of Rossetti et al. and Michelotti et al. [23,25] An association was found with awake clenching, and awake clenching or grinding, respectively. However, the intensity of the pain was not found to be associated with awake clenching. [23]

TMJ symptoms: RDC/TMD diagnosed arthralgia, arthritis, or arthrosis were assessed in the study of Michelotti et al., which did not show an association with awake clenching or grinding. [25]

Function-related pain: TMJ pain on jaw movement was found to be related with awake bruxism in the study of Huhtela et al. [27]

Orofacial pain: Macfarlane et al. [18] assessed the presence of "orofacial pain", i.e., pain in at least one of the following in the past month: jaw joint(s), area just in front of the ear(s), in or around the eyes, when opening the mouth wide, shooting pains in the face/cheeks, in the jaw joint when chewing, in and around the temples, tenderness of muscles at the side of the face, and prolonged burning sensation in the tongue/mouth, and an association was found with grinding the teeth during waking hours. However, when looking at each pain separately, the authors found an association only for pain in the TMJ. [18] Huhtela et al. [27] found a positive association between reported awake bruxism and "TMD pain", i.e. pain in the temples, TMJ, face, or jaw once a week or more often, while Leketas et al. [28] found significant associations between reports of frequent awake bruxism activity and a DC/TMD diagnosed TMD pain.

Non-RDC/TMD diagnoses: Two studies used diagnostic systems other than the RDC/TMD or DC/TMD to diagnose TMD complaints.[29,30] Macfarlane et al. found an association between grinding the teeth during waking hours and pain dysfunction syndrome. [29] Likewise, Schiffman et al. found an association between touching or holding the teeth together, clenching while awake, grinding while awake and/or holding the jaw rigid, and the "level of mandibular dysfunction". [30]

1.1.2. Sleep bruxism

Functional symptoms: RDC/TMD diagnosed locked joints and discopathy (with or without arthropathy) were not found to be associated with grinding or clenching the teeth during sleep in the study of Blanco Aguilera et al., [31] though Huhtela et al. [27] did find an association with "TMJ locking". "TMJ sounds" were not associated with grinding during sleep in the study of Duckro et al. [24]

Muscle symptoms: RDC/TMD diagnosed myofascial pain was found to be associated with self-reported tooth grinding during sleep in the study of Raphael et al. [20] However, the self-report results were in contrast to findings based on PSG-measures. Please refer to section 3.1.1.3.3.

TMJ symptoms: RDC/TMD diagnosed arthropathy with or without discopathy were assessed by Blanco Aguilera et al. [31], and no association was found with self-reported sleep bruxism.
Function-related pain: "TMJ pain on jaw movement" was found to be related with sleep bruxism in the study of Huhtela et al. [27]

Orofacial pain: Bivariate analyses in the study of Blanco Aguilera et al. [31] showed an association between sleep bruxism and RDC/TMD diagnosed muscle pain, when muscle pain coexisted with discopathy and/or arthropathy, however this association disappeared in subsequent binary analyses. In the same study, pain intensity of RDC/TMD diagnosed pain [31] was found to be associated with sleep bruxism. Leketas et al. [28] did not find an association with DC/TMD diagnosed TMD. Macfarlane et al. (2003) found "orofacial pain" (as described above) to be associated with nocturnal grinding of the teeth. [18] In the study of Huhtela et al. [27], an association was found for self-reported TMD pain and sleep bruxism.

Non-RDC/TMD diagnoses: As with self-reported awake bruxism, an association was found between "pain dysfunction syndrome" and grinding the teeth during the night, [29] and clenching or grinding during sleep and the level of "mandibular dysfunction". [30]

1.2. Adults: Self-report plus clinical examination

1.2.1. Awake bruxism

There were no studies on this topic.

1.2.2. Sleep bruxism

Two studies assessed sleep bruxism diagnosed by a combination of self-report and clinical examination. Manfredini et al. diagnosed sleep bruxism when grinding sounds during sleep were present at least five nights a week during the past six months, according to the participant's bed partner, and at least one of the following were present: tooth wear or shiny spots on restorations, report of morning masticatory muscle fatigue or pain, and masseteric hypertrophy upon digital palpation. [32] Similarly, Fernandes et al. required patient report or awareness of sounds of grinding during sleep, confirmed by a roommate, and the clinical criteria as described for Manfredini et al. above for their assessment of sleep bruxism. [33]

TMJ symptoms: RDC/TMD diagnosed TMJ pain was not associated with sleep bruxism in the Manfredini et al. study, unless combined with some occlusal factors (overbite ≥ 4 mm, "asymmetrical molar relationship", and "laterotrusive interferences"). [32]

Orofacial pain: RDC/TMD diagnosed TMD pain was associated with sleep bruxism in the study of Fernandes et al. [33]

There were no studies on the possible association between self-report plus clinical examination diagnosed sleep bruxism and functional symptoms, muscle symptoms, function-related pain, and non-RDC/TMD diagnoses.

1.3. Adults: Instrumental

In the following three sections, the methods used in each study are briefly presented in a separate paragraph, prior to the report of outcomes.

1.3.1. Awake bruxism, ecological momentary assessment (EMA) and single channel EMG

There were two studies in which awake bruxism was assessed with the aid of the EMA method. [34,35] EMA is a method used for tracking experiences and behaviours over time, as they happen in the natural environment of the participant. [36] Participants in the study of Glaros et al. [34] carried pagers for one week and reported on intensity of tooth contact, and jaw, face, or neck tension during wakefulness. Chen et al. [35] used wrist-vibrators for a 10-day period to alert the participants of their study to report on non-functional tooth contact while awake. On the

other hand, Mude et al. [37] performed whole-day EMG recordings of the masseter muscle in a group of participants reporting a history of pain or headache in the area of the masticatory system and a group without such history. Tonic episodes of muscle activity were measured for both sleep and awake states, and categorized based on duration, i.e., sustained or short, and intensity, i.e., percentages of maximum voluntary contraction (MVC). Alongside, sleep bruxism episodes were score according to established criteria. [38]

Functional symptoms: Disc displacement was associated with awake bruxism in the form of proportion of time of tooth contact, intensity of tooth contact, and tension in jaw, face, or neck in the study of Glaros et al. [34]

Muscle symptoms: RDC/TMD diagnosed myofascial pain was assessed in both of the abovementioned studies. [34,35] Glaros et al. [34] found a positive association between myofascial pain and tension, and myofascial pain and "effort", i.e., a composite variable, estimating the intensity of tooth contact in combination with the proportion of time in contact. Similarly, Chen at al. [35] found an association between myofascial pain and wake-time nonfunctional tooth-contact frequency.

Orofacial pain: The combination of RDC/TMD diagnosed myofascial pain and TMJ arthralgia was investigated by Glaros et al., [34] and an association was found with "tension in jaw, face, and neck", "proportion of time of tooth contact", "intensity of tooth contact", and "effort". Mude et al. [37] found that participants reporting pain showed a significantly higher incidence of sustained tonic EMG episodes (i.e., episodes lasting > 13.65 s), than those without. In the same study, a significantly higher incidence and total duration of sustained, low-intensity tonic EMG episodes were found in the pain history group.

There were no studies investigating the association between an instrumental awake bruxism diagnosis and TMJ symptoms, function-related pain, and non-RDC/TMD diagnoses.

1.3.2. Sleep bruxism, single channel EMG

In five studies, sleep bruxism was diagnosed with the aid of single channel EMG recordings. The study of Mude et al. [37] is described above. In the study of Baba et al., [39] the masseter EMG activity of participants without, or with minor TMD symptoms, was measured for 5 nights. The authors used predefined criteria to score muscle activity, i.e., all periods with EMG activity above a 20% MVC level were considered as potential bruxism events, and calculated the total duration of EMG activity per hour of sleep, averaged across the 5-night study period.

[39] Shedden Mora et al. [40] used single-channel EMG devices for recording nocturnal masseter EMG activity during three nights. The study sample consisted of participants with myofascial pain, pain-free sleep bruxism, and healthy controls. The authors used the Lavigne et al. [38] criteria and a 10 μV threshold to analyze and score EMG activity, and calculated the mean number and duration of EMG bursts per hour of sleep, the mean number and duration of rhythmic nocturnal masseter muscle activity (NMMA) episodes per hour of sleep, and number of EMG bursts per episode as bruxism outcome measures. [40] Yachida et al. [41] performed measurements of the EMG activity of the anterior temporalis muscle for at least 4 nights during a one-week period. EMG activity was analyzed using the Signal Recognition Algorithm described by Jadidi et al. [42] An EMG event was scored when the EMG activity exceeded the signal level at rest (i.e., when the participant was asked to relax the jaw muscles), plus 20% of the maximum EMG level as acquired during a 60% MVC clench. [42] The total number of EMG events, the number of EMG events per hour of sleep and the coefficient of variation (representing night-to-night variability in EMG activity) were used as bruxism outcome measures. Wei et. al [43] performed a pilot study with single-channel EMG recordings of the temporalis muscle from a group of women with both TMJ disc displacement and chronic myalgia/arthralgia (based on DC/TMD criteria), and a group without those conditions. The hypothesis that there were diagnostic group differences in frequency, duration and intensity of teeth clenching behavior was tested. The authors developed and validated an automated detection method for scoring sleep clenching behavior. [43]

Functional symptoms: Clinically evaluated “TMJ sounds” and “active mouth opening” were assessed by Baba et al., [39] and an association with sleep bruxism was found only for TMJ sounds.

Muscle symptoms: Shedden Mora et al. [40] investigated the presence of RDC/TMD diagnosed myofascial pain, and no association with sleep bruxism measures was found.

Orofacial pain: The combination of RDC/TMD diagnosed muscle and TMJ tenderness were investigated by Baba et al., [39] and no association with sleep bruxism was found. Shedden Mora et al. [40] reported on pain intensity of RDC/TMD diagnosed myofascial pain, jaw muscle tension in the morning after the EMG recording and TMD related symptoms (e.g., jaw pain, toothache, dizziness), and an association was found only between TMD related symptoms and the number of EMG bursts per episode (but not for EMG bursts per hour, EMG burst duration per hour, NMMA episodes per hour, NMMA episode duration per hour). Craniofacial pain (i.e., presence of RDC/TMD painful TMD or tension type headache) was assessed in the

study of Yachida et al., [41] and there, no association was found between EMG events per hour and pain, while a positive association was found between the coefficient of variation from multiple night EMG recordings and pain. In the study of Mude et al., [37] significantly longer mean EMG clenching durations and a higher EMG clenching-associated temporalis muscle duty factor (i.e., the sum of EMG clenching episode durations divided by the total recording time) were found in the pain group, compared to the non-pain group. The authors found no differences for the number of EMG clenching episodes per night, EMG episodes per hour and mean clenching bite force between groups. Wei et al. [43] found that clenching duration and clench-associated temporalis muscle duty factor were significantly higher in the patient group than in the control group. However, the authors did not find group differences for the number of clenching episodes per night and per hour, as well as for mean clenching bite force.

There were no studies investigating the association between a single-channel EMG diagnosed SB, and TMJ symptoms, function-related pain, and non-RDC/TMD diagnoses.

1.3.3. Sleep bruxism, polysomnography

Sleep bruxism was diagnosed by laboratory-based polysomnography in eight studies. Rossetti et al. [23] performed PSG with audiovisual recordings (PSG-AV) during one night (an adaptation night was carried out, but excluded from analysis). The authors used the Lavigne et al. [38] criteria to score the following sleep bruxism parameters: number of EMG episodes per night, EMG episodes per hour, EMG bursts per hour, EMG bursts per episode, EMG episodes with grinding noise, percentages of EMG episodes in each sleep stage (stage 1-5), and sleep bruxism status, i.e., sleep bruxer and non-sleep bruxer, according to the Lavigne et al. cut-off values, i.e. ≥ 4 EMG episodes per hour or ≥ 25 EMG bursts per hour of sleep. [38] In a smaller pilot study, the same research group used similar outcome measures when analyzing the PSG data from one night of participants with painful TMD and controls. [44] Abe et al. [45] performed PSG-AV during one night after an adaptation night was carried out, but excluded from analysis. The authors used the Lavigne et al. [38] criteria to analyze EMG activity of the masseter and temporalis muscles, in a manner similar to Rossetti et al., [23] with the exception of the percentages of EMG episodes in each sleep stage, which were not addressed. In their retrospective study, Lavigne et al. [46] investigated sleep bruxism outcomes based on a one-night PSG-AV recording, performed after an adaptation night, of sleep bruxers. The Lavigne et al. [38] criteria were used to quantify the number of EMG episodes per hour, EMG bursts per episode, and root-mean-square EMG level per bruxism burst. Smith et al. [47] performed two nights of PSG and auditory recordings and used the Lavigne et al. [38] cut-off criteria to diagnose

participants as sleep bruxers and non-sleep bruxers. A single night PSG-AV was performed in the study of Camparis et al. [22] In line with previously mentioned studies, the authors used the Lavigne et al. [38] criteria to score the number of EMG bruxism episodes and EMG bursts per hour, EMG bursts per episode, total duration of EMG episodes, percentage of EMG episodes in each sleep stage, percentage of bruxism episodes with micro-arousals, and mean bruxism episode amplitude. [22] In a sample with RDC/TMD diagnosed myofascial pain and a pain-free control group, Raphael et al. [20] performed one PSG-AV recording, after one adaptation night. As above, the authors used the Lavigne et al. [38] criteria to score EMG episodes and EMG bursts per hour of sleep, the number of EMG episodes with grinding sounds and the total EMG episode duration. [20] The authors assessed the sleep bruxism status, based on the Lavigne et al. [38] cut-off criteria. [20] Finally, the study of Muzalev et al. [48] was based on the same sample as in Raphael et al., [20] but aimed to investigate whether cases and controls differed in terms of time intervals between sleep bruxism episodes.

Functional symptoms: Rossetti et al. [23] investigated the presence of TMJ sounds, and restriction of mandibular movement, and no association was found with sleep bruxism measures.

Muscle symptoms: "Transient morning masticatory muscle pain" was assessed in the study of Abe et al. [45] and although the presence of pain in the total sample was low, it was found to be associated with the status of being a sleep bruxer. Within the sleep bruxism group, there were no statistically significant differences between sleep bruxers with and those without pain. [45] "Non-myofascial muscle pain", i.e., presence of pain that did not fulfil the RDC/TMD criteria for chronic myofascial pain, [46] and masseter pressure pain sensitivity measured with an algometer [47] were assessed in the studies of Lavigne et al. [46] and Smith et al. [47], respectively, both finding no association with the presence of PSG assessed sleep bruxism. RDC/TMD diagnosed myofascial pain was assessed in two studies. [20,23] Rossetti et al. [23] found a significant association between a PSG-based sleep bruxism status and myofascial pain, however, the study also showed that there was no difference between myofascial pain patients and controls in the percentages of phasic, tonic, and mixed sleep bruxism episodes. Within the myofascial pain group, sleep bruxism was not a significant predictor of TMD intensity index, pain duration, number of tender muscle sites to palpation, sensitivity of tender muscle sites to palpation, and period of worst pain within the day. [23] Within the sleep bruxer group, myofascial pain was negatively associated with tonic EMG episodes, i.e., sleep bruxers without pain had more tonic episodes that sleep bruxers with pain. [23] Raphael et al. [20] showed that no sleep bruxism measure was significantly higher in RDC/TMD diagnosed myofascial pain cases than controls, except that controls were more likely to present at least

two EMG episodes with grinding per recording than cases. Within the myofascial pain group, pain duration was similar for sleep bruxers and non-sleep bruxers, while characteristic pain intensity was lower for sleep bruxers compared to non-sleep bruxers. [20] Similarly, in the same group, participants with two or more EMG episodes with grinding noise had significantly lower levels of pain interference with daily activity than those without. [20] Muzalev et al. [48] found a similar duration of inter-episode intervals in both myofascial pain patients and controls.

TMJ symptoms: TMJ pain on RDC/TMD palpation was assessed by Rossetti et al. [23,44] who did not find an association with PSG assessed sleep bruxism.

Function-related pain: No studies were available.

Orofacial pain: The combination of muscular and TMJ pain was assessed in two studies. [22,44] Camparis et al. [22] found no significant difference in sleep bruxism variables between sleep bruxers with and without painful RDC/TMD diagnosed TMD (muscle pain with or without TMJ pain). However, participants without pain presented 20% more sleep bruxism-related EMG episodes per hour of sleep than those with pain. [22] Rosseti et al. [44] studied mixed muscle and/or TMJ types of RDC/TMD assessed TMD pain, and found no association with PSG diagnosed sleep bruxism for neither pain intensity at rest, nor pain on palpation of masticatory muscles and/or TMJs.

There were no PSG-based studies investigating the association between sleep bruxism and function-related pain or non-RDC/TMD diagnoses.

2.Children and adolescents

Children and adolescents cohorts were evaluated in 10 studies (Table 4).

2.1. Children and adolescents: Self-report

2.1.1. Awake bruxism

Functional symptoms: "TMJ sounds" were assessed in the studies of Carra et al. [17], van Selms et al. [19], Egermark et al. [49], Winocur et al. [50], and Şermet Elbay et al. [51] and All of these studies found an association between self-reported awake bruxism and "TMJ sounds", with the exception of Şermet Elbay et al., [51] who found the association for children living with their parents, but not for children living in child protection institutions. Chun and Koskinen-Moffett [52] and Şermet Elbay et al. [51] investigated clinically diagnosed "TMJ sounds", and found those not to

be related with self-reported awake bruxism. RDC/TMD diagnosed anterior disc displacement with reduction was assessed by Kalaykova et al., [53] who did not find an association with awake bruxism. Self-reported "TMJ locking" and RDC/TMD assessed anterior disc displacement with intermittent locking were found to be associated with self-reported awake bruxism in the studies of Carra et al. [17] and Kalaykova et al. [53] respectively, but Winocur et al. [50] found no relation between self-reported "locking, catching, or open lock" and self-reported awake bruxism, neither did Şermet Elbay et al. [51] for self-reported "TMJ sticking". "Range of mouth opening" was not associated with awake bruxism in the studies of Carra et al. [17] and Winocur et al., [50] but, on the other hand, Egermark et al. [49] found an association with "difficulties in mouth opening". An association between self-reported awake bruxism and "limited lateral mandibular movements" was shown by Carra et al. [17]

Muscle symptoms: "Jaw muscle fatigue upon awakening" was assessed by Carra et al., [17] who found an association with self-reported awake bruxism. Similarly, Şermet Elbay et al. [51] found an association between awake bruxism and reporting "pain or tiredness in the masticatory muscles", but only for children living in child protection institutions and not for those living with their parents. In the same study, palpation-induced masticatory "muscle tenderness" was associated with reporting awake bruxism in both groups of children. [51]

TMJ symptoms: Şermet Elbay et al. [51] found an association between reporting awake bruxism and palpation-induced "TMJ tenderness" in a group of children living in child protection institutions, but not for those living with their parents.

Function-related pain: "Tiredness in the jaw while chewing" and "pain in the jaw near the ear while chewing" were examined by Winocur et al., [50] and no association was found.

Orofacial pain: RDC/TMD diagnosed TMD pain (myofascial pain with or without limited mouth opening and/or TMJ arthralgia and/or TMJ osteoarthritis) was assessed by Fernandes et al., [54] who found an association with awake bruxism. "Orofacial pain" [19] and "pain in jaw or face at rest" [50] were assessed in the studies of van Selms et al. [19] and Winocur et al. [50], and an association with awake bruxism was found in the former, but not in the latter study. "Jaw fatigue" was assessed in the study of Egermark et al., [49] and an association was found with self-reported awake bruxism.

There were no studies on the association between self-reported awake bruxism and TMJ symptoms or non-RDC/TMD diagnoses.

2.1.2. Sleep bruxism

Functional symptoms: "TMJ sounds" were assessed in three of the previously mentioned studies. Egermark et al. [49] found an association with self-reported sleep bruxism, as did van Selms et al. [19] for "TMJ clicking", but not for "scraping sounds", while Carra et al. [17] did not find any of such associations. The same study did also not find any associations between sleep bruxism and "TMJ locking", "restricted lateral mandibular movements" and "maximal mouth opening". [17] On the other hand, Egermark et al. [49] did find an association with "difficulties in mouth opening".

Muscle symptoms: Jaw muscle fatigue was assessed by Carra et al., [17] who found an association with self-reported sleep bruxism.

Orofacial pain: RDC/TMD diagnosed TMD pain (myofascial pain with or without limited mouth opening and/or TMJ arthralgia and/or TMJ osteoarthritis) were assessed by Fernandes et al., [54] and an association was found. Van Selms et al. found an association between sleep bruxism and "jaw pain" or "tense feeling in the morning". [19] Similarly, Egermark et al. [49] found an association for "jaw fatigue".

There were no studies investigating the associations between self-reported sleep bruxism and TMJ symptoms, function-related pain, and non-RDC/TMD diagnoses.

2.2. Children and adolescents: Self-report plus clinical examination

2.2.1. Awake bruxism

No studies on this topic were found.

2.2.2. Sleep bruxism

Bruxism diagnosed based on self-report plus clinical examination was assessed in three studies.

Functional symptoms: Emodi-Perlman et al. [55] and Restrepo et al. [56] RDC/TMD assessed TMJ sounds in their studies, with the former showing no association, and the latter finding one. RDC/TMD diagnosed disc displacement was assessed by Kalaykova et al., [53] who did not find an association with sleep bruxism. Three studies investigated mandibular dysfunction. Emodi-Perlman et al. [55] did not find an association between sleep bruxism and "TMJ sticking", nor did Kalaykova et al. [53] for RDC/TMD based anterior disc displacement with intermittent locking. On the other hand, Restrepo et al. [56] found an association with (limitation of) the

range of mouth opening and with “deviation in mouth opening”.

Muscle symptoms: Reported “pain or tiredness of masticatory muscles” was assessed in the study by Emodi-Perlman et al., [55] and no association with sleep bruxism was found. RDC/TMD- based pain or tenderness of masticatory muscles on palpation were assessed in two studies. Emodi-Perlman et al. [55] found no association with pain on extraoral palpation, while Restrepo et al. [56] found no association with intraoral palpation, and a negative association for extraoral palpation.

TMJ symptoms: Sensitivity of the TMJ on RDC/TMD based palpation was assessed by Emodi-Perlman et al., [55] and no association was found.

Function-related pain: Pain when opening or chewing was assessed in the study of Restrepo et al., [56] and an association was found with sleep bruxism.

Orofacial pain: The presence of “pain in the temples, face, TMJs, or jaws” was also assessed in the study of Restrepo et al., [56] and no association with sleep bruxism was found.

There were no studies using non-RDC/TMD diagnoses.

2.3. Children and adolescents: Instrumental

2.3.1. Awake bruxism, EMA and single-channel EMG

There were no studies assessing awake bruxism in children or adolescent populations using EMA methods or single-channel EMG.

2.3.2. Sleep bruxism, single channel EMG

In one study, sleep bruxism was diagnosed by single-channel EMG. Nagamatsu-Sakaguchi et al. [57] performed a single night recording of the EMG activity of the masseter muscle in a group of adolescents (mean age 15.4 ± 0.5). The EMG device in this study automatically detected and counted EMG events that exceeded 30% of MVC. Participants were divided into two groups, based on the count of EMG events: a “severe” sleep bruxism group (≥ 125 EMG events) and a “non-severe” sleep bruxism group (< 125 EMG events). [57]

Functional symptoms: RDC/TMD assessed TMJ clicking was found to be associated with a “severe” sleep bruxism diagnosis, while limited mouth opening was not associated with “severe” sleep bruxism in females, while the variable was not observed in males. [57]

Muscle symptoms: RDC/TMD assessed sensitivity to palpation of masticatory and cervical muscles (digastric, masseter, temporalis, SLM, trapezius) were not associated with "severe" sleep bruxism, except for the digastric muscle in males. [57]

TMJ symptoms: RDC/TMD assessed sensitivity to palpation of the TMJ was, as well, not associated with "severe" sleep bruxism. [57]

There were no studies using single channel EMG for the detection of sleep bruxism that investigated its association with function-related pain, orofacial pain, and non-RDC/TMD diagnoses.

2.3.3. Sleep bruxism, PSG

There were no studies assessing sleep bruxism in children or adolescent populations using PSG.

3. Summary of findings from case-control, cross-sectional and prospective cohort studies

In summary, the included studies indicate that in adults, awake bruxism may be positively associated with pain located in the masticatory muscles, and in a more broad sense, with myofascial TMD pain. This association is supported both by studies using a self-report as well as an instrumental diagnosis of awake bruxism. There were too few studies to support a solid conclusion on the relation between awake bruxism and TMJ pain. Studies in children suggest a positive association between musculoskeletal pain and awake bruxism, but since all these studies utilized self-report only diagnoses for both bruxism, as well as musculoskeletal outcomes, these results should be taken with caution.

Studies using EMG or PSG to validate bruxism status are fairly consistent in showing that sleep bruxism status, i.e., receiving a positive assessment of sleep bruxism according to the Lavigne et al. [38] criteria, is not positively associated with musculoskeletal pain in adults. Evidence from the reviewed studies suggests that sleep bruxism variables, such as type and length of bruxism episodes, and night-to-night variability in sleep bruxism activity, may be associated with pain symptoms, but did not allow for a solid conclusion regarding the direction of this association. On the other hand, studies using a case definition based on self-reported bruxism, with or without clinical examination, i.e. a less valid case definition, seem to support a positive association with TMD pain diagnoses. However, some studies did not detect this association, especially those focusing on TMJ pain. EMG-based evidence in studies of children was very scarce, and pointed to sleep bruxism not being associated with pain symptoms.

Similar results were reported by studies utilizing self-report plus clinical examination. On the contrary, and similarly to adult populations, studies using only self-reported sleep bruxism did show associations with both pain and fatigue symptoms. However, when sleep bruxism was additionally assessed by clinical examination, such associations where no longer found.

There were too few studies assessing non-painful symptoms for allowing solid conclusions to be drawn as for whether these are related to awake and/or sleep bruxism, in both adult and children populations.

As for functional symptoms, results on self-reported TMJ sounds were consistently found to be associated with self-reported awake bruxism in populations of children. However, when clinical examination was used for the detection of TMJ sounds this association was no longer found. For all other types of functional symptoms, as for other awake and sleep bruxism assessment methods, either results of studies were contradicting, or sparse. Consequently, based on the reviewed literature above, it can be concluded that the association between bruxism and functional symptoms remains unclear.

Experimental studies

Fourteen experimental studies were included in this review. [58–71] The experimental conditions involved tooth-clenching tasks (9 studies), [58,59,61–63,65–67,70] tooth-grinding tasks (2 studies), [68,69] eccentric contraction of jaw muscles (2 studies), [58,67] and experimental EMG feedback studies (3 studies). [60,64,71] The studies evaluated the following range of musculoskeletal symptoms: pain intensity [58–69,71] and pain distribution, [68,69] soreness/tenderness, [65,68,69] unpleasantness, [63,65,68,69] fatigue/ physical tiredness/ exhaustion, [58,59,61–63,66,67] sensitization to pressure, [58,59,61,65–69] maximum voluntary bite force, [65–69] muscle endurance time, [62,70] clenching-related pain and headache pain since the last session, [71] and maximum pain-free mouth opening. [58,67]

Overall, the results from the experimental studies above indicate that increasing the masticatory muscle activity experimentally by either tooth-clenching, tooth-grinding, or consciously increasing EMG activity may lead to short-lasting pain and fatigue in healthy individuals. [58–71] However, none of the tasks of the included studies led to long-lasting pain. Rather, even repeating the task for 5 days resulted in fewer symptoms on day 5 compared with day 1, indicating an adaptation or training effect in the healthy individuals. [65] Using eccentric contractions, though, it was possible to induce delayed onset muscle soreness (DOMS) in the jaw muscles that was resolved after one week. [58,67]

DISCUSSION

The aim of the present systematic review was to answer the overall research question: "To what extent is bruxism associated with musculoskeletal signs and symptoms? It was decided to evaluate all types of musculoskeletal signs and symptoms, including non-painful symptoms, as they may lead patients to seek evaluation and may possibly precede development of pain. Hence, the aim was not to perform yet another review on the relationship between bruxism and pain. Due to the interest in non-painful symptoms, it was decided not to exclude studies using case definitions based on self-reports of bruxism and musculoskeletal symptoms, but rather to include such studies and report their results in separate paragraphs from studies involving validated diagnostic techniques and assessment methods. Of course, results based on self-reports alone should be interpreted with great caution and is it recommended that future studies always include excellent methodology and valid measures of bruxism and musculoskeletal signs and symptoms.

Non-painful musculoskeletal symptoms

A few case-control, cross-sectional, or prospective cohort studies included evaluations of musculoskeletal symptoms other than pain, yet none of them as the primary outcome parameter. [17,19,39,49] The assessed and reported non-painful symptoms were muscle tenderness [39] and muscle fatigue. [17,49,55] However, conclusions are conflicting and vary between studies, although most of them are in favor of an association between bruxism and the studied symptoms. Since the non-painful symptoms were generally not the primary outcome parameter, there is a possibility of publication bias, as it could be speculated that authors might feel more inclined to report significant associations, whereas lack of association between bruxism and a secondary outcome parameter might be left out. Importantly, the risk of Type I error should be taken into account when assessing studies with multiple outcome parameters. Also, the lack of validated assessment methods and potential recall-bias for non-painful musculoskeletal symptoms are important limitations and results should be interpreted with caution. However, in the experimental studies, non-painful symptoms were much more often taken into account and systematically quantified and reported. Fatigue and sensitization to pressure stimuli were the non-pain symptoms, which were most often reported after a tooth-clenching or grinding task. [58,59,62,63,65–68]

Assessment of non-painful symptoms could be considered important, since they may be the reason to seek treatment and, recently, a large prospective cohort study showed that reports of three or more non-specific orofacial symptoms, defined as jaw stiffness, cramping,

fatigue, pressure, soreness, and ache, can predict subsequent onset of TMD pain. [72] Hence, a more systematic approach to the evaluation of non-pain musculoskeletal symptoms seems warranted for both clinical and research purposes.

The concept of primary and secondary unpleasantness vs. algosity, suggested by Fields in 1999, [11] could also be further explored. Fields suggested that algosity could be seen as the unique sensory-discriminative aspect of pain that separates it from other unpleasant sensations, such as itch or dysesthesia. [11] Primary unpleasantness is an aspect of unpleasantness, which is strictly stimulus-bound and therefore should be considered in the context of a sensory-discriminative feature. [11] In contrast, secondary unpleasantness is linked to higher-order cognitive processing and largely determined by memories and contextual features. [11] It could be speculated that a person experiencing jaw symptoms may be more prone to seek treatment, when secondary unpleasantness dominates the picture, i.e., when the context in which the symptoms occur is negative or when the person has memories of similar symptoms getting worse in the past. In a qualitative study by Rollman et al., [73] it was shown that care seeking for TMD-pain complaints was associated with catastrophizing, i.e., interpreting the pain as alarming and too long lasting. It may be useful to further investigate the concept of secondary unpleasantness, its possible similarity as a construct with catastrophizing, and the relation with the development of orofacial symptoms and care-seeking behavior. It could be further speculated that some psychosocial factors, such as depression, somatization, and anxiety that are well-known risk factors for chronic TMD pain, [74] may be closely linked to the experience of secondary unpleasantness. Such psychosocial factors and their relation to non-painful symptoms have been investigated in other chronic pain disorders, such as irritable bowel symptoms. [75] Taking this information into consideration, it may be prudent to systematically assess non-painful musculoskeletal symptoms and their relationship to awake and sleep bruxism, while taking psychosocial factors into account. Moreover, future longitudinal studies should examine, whether an early intervention in patients with non-painful musculoskeletal symptoms may prevent the development of acute painful TMD, or transition of an acute painful state into a chronic one.

Pain

Pain as a symptom has much more consistently been evaluated as a possible consequence of awake or sleep bruxism. Overall, studies based solely on self-report of awake or sleep bruxism and pain are more indicative of a positive association than studies supporting bruxism assessment and pain diagnosis with validated clinical examinations and instrumental evaluations of muscle activity. Hence, increasing the validity of the assessment methods

seems to weaken the proposed associations, except when it comes to awake bruxism, where studies using EMA demonstrated that TMD patients have more tooth contact than healthy controls. [34] As mentioned previously, the validity of self-reported sleep bruxism has been questioned, and in a study using PSG as the gold standard, it was concluded that studies based on self-reports of sleep bruxism should, indeed, be interpreted with caution. [76] Importantly, also the use of PSG as a gold standard for sleep bruxism assessment is under current discussion, [2] because only frequency measures of EMG episodes or bursts are being considered and not taking into account the amplitude or intensity of such EMG activities. There is a need to reconsider the often-used gold standards of sleep bruxism assessment, with more refined measures of EMG activity over time being suggested valuable for examination of work-related musculoskeletal symptoms. [2]

Functional symptoms

Bruxism is commonly suggested to be a source of microtrauma of the TMJs and masticatory muscles, which, in turn, could lead to functional symptoms of the masticatory system. [77] However, the present review could not draw a robust conclusion on this proposed association. A variety of symptoms were evaluated in the reviewed studies, including TMJ clicking and crepitation sounds, disc-related disorders, and deviations in the movement of the mandible in adults [23–27,31,37,39] and children. [17,19,49–53,55–57] Although some studies used the RDC/TMD criteria for establishing their diagnoses (e.g., [35,53]), there generally was no uniform way of assessing these outcomes across studies, with some solely using self-report measures (e.g., [19,24,27]), and others including clinical examination in the assessment of participants (e.g., [26,39,52]). This made comparison of the studies difficult. Most importantly though, studies using more valid device-assisted methods for assessing sleep and awake bruxism were extremely sparse [23,34,39,57] and did not allow for the drawing of solid conclusions on the topic. Future studies should take advantage of available technologies in order to significantly contribute to the understanding of if and how sleep and awake bruxism are involved in the pathophysiology of functional symptoms of the masticatory system.

Additional suggestions for future studies

Masticatory muscle activity in terms of bruxism is most likely not enough to cause the onset or persistence of musculoskeletal pain and non-pain symptoms in the absence of other risk factors. [7,8] Therefore, it is preferable that future high-quality studies assess the multiple interactions between risk factors, such as, but not restricted to, psychological, lifestyle, sleep, and trauma/overloading variables, instead of solely focusing on the assessment of linear relations. [8,78] Prospective cohort studies using device-assisted bruxism diagnostic

methods may prove very valuable in this context. It is of course essential to carefully design and plan such studies by for example, cautiously selecting primary and secondary outcome parameters according to the study aim and plan and perform the statistical analyses using the highest standards to avoid "fishing expeditions". Also, more focus on effect sizes in addition to statistical significance is advocated.

Bruxism is considered to have two circadian manifestations, namely occurring during sleep and/or awake states. [2] There is still no evidence to prove that these two manifestations are two distinct conditions, or that they should be considered part of the same entity. [2] Until this topic is clarified, it is strongly advised that in future studies sleep and awake bruxism are assessed as separate variables. This may additionally contribute to the comparability of the outcomes of different studies. Furthermore, the distinction might make research results more directly applicable to clinical practice, were sleep and awake bruxism are often managed in a different manner. [79]

Furthermore, investigating different expressions of muscle activity may lead to new insights. Alongside with EMG frequency measures during sleep, such as number of episodes, bursts etc., it may be of value to investigate variables like background EMG activity, intensity, and amplitude of activity, variability of activity over time or the timing of activity during sleep, [20,48] and their relation to musculoskeletal symptoms. A similar approach can be suggested for awake bruxism studies. [34,35,37]

Regarding awake bruxism, it is suggested that more instrumental studies are conducted, especially including children and adolescent populations. It is imaginable that the implementation of instrumental awake bruxism studies in these populations is difficult, due to the possible lack of cooperation of young individuals. It may prove useful to design other diagnostic methods for these populations, for example, through direct or indirect (i.e., via video recordings or structured parental-reporting) observation of children in everyday situations, such as attending school, making homework etc.

Future experimental bruxism studies are encouraged to include not only healthy, symptom-free participants, but also individuals with preexisting musculoskeletal symptoms, since it might be speculated that their masticatory system reacts to mechanical loading in a different manner. Similarly to what is mentioned above, it is suggested that experimental studies also take into account other risk factors, such as somatization, depression, fear of movement, beliefs about the effect of bruxism on muscles, etc., as these factors may alter the

way that symptoms are experienced and the results of diagnostic test. [80]

As for functional musculoskeletal symptoms, the main suggestion of this review is that future studies use standardized and validated criteria for their assessment, such as instruments included in the DC/TMD. [9]

Importantly, the authors of this review suggest that in future studies non-painful musculoskeletal symptoms are assessed systematically and separately from pain symptoms. For this purpose, standardized criteria need to be developed. This will facilitate research on the importance of such symptoms as risk factors for 'more severe' symptoms, their interplay with other risk factors in orofacial pain processes, and their role in treatment-seeking behavior.

CONCLUSIONS

From the present review, it may be concluded that bruxism to some extent is associated with musculoskeletal symptoms. However, the evidence is conflicting and seems to be dependent on many factors such as for example age, whether the bruxism occurs during sleep or wakefulness, as well as diagnostic methodology regarding bruxism and musculoskeletal signs and symptoms. The literature does not sufficiently support a direct linear causal relationship between bruxism and such signs and symptoms, but points more in the direction of a multifaceted relationship dependent on the presence of other risk factors. Pain is by far the most commonly assessed symptom, whereas non-painful musculoskeletal symptoms have generally not been systematically evaluated. In light of recent findings indicating that non-painful symptoms may precede TMD pain, it is suggested to increase the scientific focus on non-painful musculoskeletal symptoms in future studies. Finally, it is strongly recommended that future studies do not rely solely on self-reports for assessment of bruxism status.

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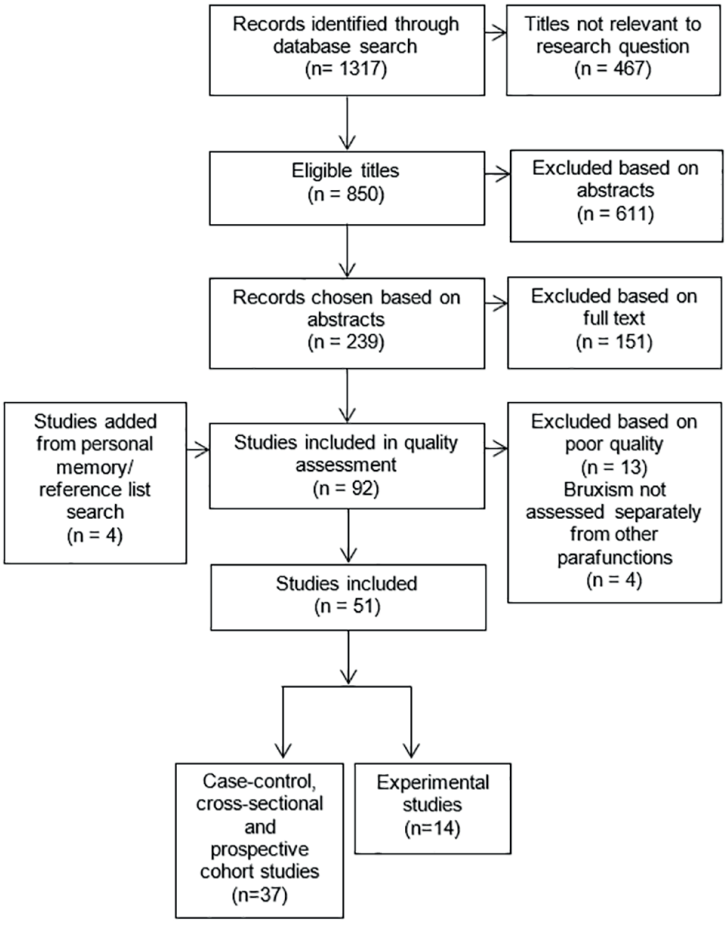

Figure 1. Flow chart of inclusion of articles in systematic review.

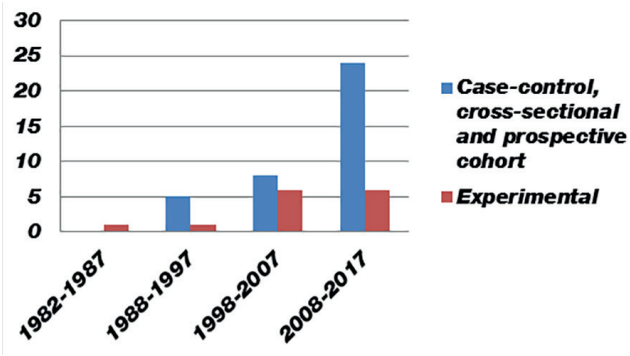

Figure 1. Overview of study designs and time of publication of included articles.

Table 1. Search string

("Bruxism"[Mesh] OR bruxer[text word] OR bruxers[text word] OR bruxing[text word] OR bruxist[text word] OR bruxists[text word] OR bruxofacets[text word] OR bruxomania[text word] OR clenching[text word] OR parafunction[text word])
AND
("Craniomandibular Disorders"[Mesh] OR "Pain"[Mesh] OR "Muscle Fatigue"[Mesh] OR "Muscle Weakness"[Mesh] OR "muscle hypertonia"[MeSH] OR temporomandibular disorders[text word] OR unpleasantness[text word] OR discomfort[text word] OR tenderness[text word] OR sensitivity[text word] OR hypersensitivity[text word] OR soreness[text word])

Table 2. Inclusion criteria for full text articles

The study is related to the research question
Contains original data and no double data
Study meets minimum quality criteria; see below
Reviews included for reading only and reference list checking
Bruxism is well-defined (e.g., ICHD, Glossary of Prosthodontics, Guidelines AAOP, Lobbezoo et al.)
Well-described bruxism assessment method (e.g., questionnaire, clinical examination, EMG, PSG)
Outcome parameters are well described and quantified (e.g., dichotomized, NRS, VAS)
Includes a control condition or control group
Full text in English is available

Table 3. Demographic characteristics and sample types of included studies.

#	First author, year, journal initials	n	Male	Female	Mean age (range)	Sample type
Case-Control, Cross-sectional						
1	Abe, 2013, JOP	81	34	47	25.8 (18-44)	Participants without TMD
2	Baba, 2005, JOP	93	47	46	24.7 M, 23.7 F (22-32)	Subjects selected at a Medical and Dental University
3	Blanco Aguilera, 2014, JOR	1220	190	1030	? (18-61 or more)	Subjects referred to specialized Orofacial Pain clinic
4	Camparis, 2006, AOB	40	8	32	36.1 (17-54)	Bruxing patients
5	Carra, 2011, EJOS	604	?	?	13 (7-17)	Patients of Orthodontic clinic
6	Chen, 2007, JOP	24	8	16	? (18-67)	Patients referred to Orofacial pain clinic and controls selected among friends and staff
7	Chun, 1990, JCD	96	42	54	12.6 (9-18)	Adolescents attending an Orthodontic and a Pedodontic University department
8	Duckro, 1990, Cranio	500	251	249	? (21-65 or more)	Residents of specific geographic area
9	Emodi-Perlman, 2012, JOR	244	61	183	? (5-12)	Pupils of selected school
10	Fernandes, 2012, JOR	272	34	238	? (21-65 or more)	Residents of specific geographic area
11	Fernandes, 2015, JOR	1307	712	595	? (12-14)	Adolescents attending schools in specific geographic area
12	Glaros, 2005, Cranio	96	26	70	Not provided for total sample, but for groups: [1] 35.4,[2] 39.5, [3] 44.9, [4] 39.2 (?/?)	General population and patients attending a Facial Pain Centre
13	Huhtela, 2016, JOPH	4403	1628	2775	Applied science: 24.4 (male), 23.7 (female), Academic: 25.2 (male), 24.7 (female) (19-35)	Academic and applied science university students
14	Kalaykova, 2011, JOP	260	124	136	14 (12-16)	Adolescents attending a Dental University student's clinic
15	Lavigne, 1997, EJOS	13	8	5	B with pain group: 25.3, B without pain group: 27.3 (?/?)	Sleep bruxers
16	Leketas, 2017, JCS	520	112	408	21.8 (18-64)	Patients visiting a University Clinic of Maxillofacial Surgery, persons recruited by announcements or from acquaintances

#	First author, year, journal initials	n	Male	Female	Mean age (range)	Sample type
17	Macfarlane, 2001, OD	327	56	271	Median, cases: 37, controls: 39	Patients referred to a Temporomandibular Disorder Clinic and patients attending general dental practitioners
18	Macfarlane, 2003, JD	2504	?	?	? (18-65)	Population attending a General Medical Practice
19	Manfredini, 2010, Cranio	276	83	193	32.2 (25-44)	Patients referred to a TMD clinic
20	Michelotti, 2010, JOR	668	182	486	Cases: 33.2, controls: 37.6 (8-79)	Patients referred to the Dental Clinic of a University and their accompanying persons
21	Moss, 1995, JOR	43	3	40	Cases: 42.8, controls: 47.7 (?/?)	General population at University medical centre and community
22	Mude, 2017, JPR	33	11	22	23.9 (?-?)	Students
23	Muzalev, 2017, Sleep	123	0	123	Cases: 37.8, controls: 34.7 (?-?)	Patients seeking treatment at a College of Dentistry
24	Nagamatsu-Sakaguchi, 2007, IJP	127	49	78	15.4 (?/?)	High school subjects of specific geographic area
25	Raphael, 2012, JADA	172	0	172	39.2 (19-78)	Patients attending a University College of Dentistry and their acquaintances
26	Restrepo, 2008, JOR	52	?	?	9.45 (8-11)	Students of school in specific geographical area
27	Rosseti, 2008, Cranio	26	12	14	Cases: 27.14, controls: 27.42 (17-40)	Unspecified population
28	Rosseti, 2008, JOP	60	48	12	Cases: 26.6, controls: 26.0 (19-42)	Unspecified population
29	Schiffman, 1992, JOR	250	0	250	Sophomore: 22, junior: 23, senior: 25 (?/?)	Sophomore, junior and senior nursing students
30	Şermet Elbay, 2017, IDJ	385	191	194	CLCPI group: 13.4 (?/?) , CLWP group: 13.5 (?/?)	Children attending public schools and child- protection institutions

#	First author, year, journal initials	n	Male	Female	Mean age (range)	Sample type
31	Shedden Mora, 2012, JPR	106	17	89	TMD cases: 27.4, pain free B cases: 25.7, controls: 24.3 (?/?)	Patients of a Department of Prosthetic Dentistry, an TMD outpatient clinic, university undergraduates and local community
32	Smith, 2009, Sleep	53	10	43	33.6	Patients of a Orofacial Pain Clinic and community
33	van Selms, 2013, CDOE	4208	?	?	14.5 (12-18)	Students attending secondary schools
34	Wei, 2017, JOR	24	0	24	Pain group: 37.4 (21-62), non-pain group: 31.1 (24-56)	Subjects recruited at a Dental University
35	Winocur, 2001, JOR	323	0	323	? (15-16)	Girls attending a high school
36	Yachida, 2012, JDR	115	39	76	Healthy men 25.3, healthy women 27.2, SB men 46.4, SB women 36.0, TTH men 41.1, TTH women 31.0 (?/?)	Students and staff of University, subjects responding to advertisements, patients attending a Headache Centre
Prospective Cohort						
1	Egermark, 2001, AOS	320	153	167	7, 11, 15 (-/-)	Random community sample
Experimental						
1	Arima, 1999, JOP	12	12	0	26.0 (21-42)	Healthy human subjects without history of TMD or bruxism
2	Arima, 2000, JOP	10	10	0	24 (20-30)	Healthy human subjects without history of TMD or bruxism
3	Christensen, 1982, TJPD	6	6	0	35 (?)	Dentist without clinicall discerbible diseases and dysfunctions of the manibular locomotor system
4	Dawson, 2013, Pain	30	14	16	Women: mean age 36; Men: mean age 41 (?)	Healthy human subjects
5	Farella, 2010, JDR	10	0	10	23.0 (?)	healthy dental students without report of bruxism, orofacial pain ot TMJ clicking in the preceding month
6	Glaros, 2004, JBM	14	8	6	? (21-35)	Healthy human subjects without history of TMD, chronic pain or headaches
7	Glaros, 1998, JOP	5	2	3	? (23-29)	Dental students without TMD or orofacial pain incl. headache

#	First author, year, journal initials	n	Male	Female	Mean age (range)	Sample type
8	Glaros, 2000, Cranio	20	0	20	26.5 (20-51)	Healthy human subjects without history of TMD, chronic pain or headaches
9	Koutris, 2013, CJP	40	20	20	27.7 (?)	healthy subjects without dental pain pathology or self-reported oral parafunctions
10	Takeuchi, 2015, Headache	18	9	9	Women: mean age 22.2; Men: mean age 25.8 (?)	Healthy university grad students without history of TMD
11	Turker, 2010, AOB	6	6	0	35.7 (?)	Healthy subjects without history of TMD
12	Svensson 1996, JOP	10	0	10	24.2 (?)	Healthy women without history of TMD
13	Svensson 2001, AOB	11	11	0	24.2 (23-27)	healthy young men without symptoms of TMD or orofacial pain
14	Suzuki, 2016, JOR	16	7	9	26.3 (21-40)	healthy participants without signs or symptoms of TMD
		n	Male	Female	Unknown gender	
	Total (%)	20176	4244 (21)	8564 (42.5)	7368 (36.5)	

Table 4. Overview of included case-control, cross-sectional, and prospective cohort studies.

	Dx	Self-report		Self-report plus clinical examination		Instrumental		
	B type	AB	SB	AB	SB	AB, EMA/EMG	SB, EMG	SB, PSG
Adults	1	Duckro, 1990*	Blanco Aguilera, 2014	No studies	Fernandes, 2012	Chen, 2007	Baba, 2005	Abe, 2013
	2	Macfarlane, 2001*	Duckro, 1990*		Manfredini, 2010	Glaros, 2005	Shedden Mora, 2012	Camparis, 2006
	3	Macfarlane, 2003*	Raphael, 2012*			Mude, 2017*	Yachida, 2012	Lavigne, 1997
	4	Michelotti, 2010	Macfarlane, 2001*				Mude, 2017	Raphael, 2012*
	5	Moss, 1995	Macfarlane, 2003*				Wei, 2017*	Rosseti, 2008*
	6	Rosseti, 2008*	Schiffman, 1992*					Rosseti, 2008
	7	Schiffman, 1992*	Huhtela, 2016*					Smith, 2009
	8	Huhtela, 2016*	Leketas, 2017*					Muzalev, 2017
	9	Leketas, 2017*						

Children	1	Carra, 2011*	Carra, 2011*	No studies	Emodi-Perlman, 2012	No studies	Nagamatsu-Sakaguchi, 2007	No studies
	2	Chun, 1990	Fernandes, 2015*		Kalaykova, 2011, JOP*			
	3	Fernandes, 2015*	van Selms, 2013*		Restrepo, 2008, JOR			
	4	Kalaykova, 2011*	Winocur, 2001*					
	5	van Selms, 2013*	Egermark, 2001*					
	6	Winocur, 2001*						
	7	Egermark, 2001*						
	8	Sermet Elbay, 2017						

Dx = Bruxism diagnostic method, B type= Bruxism circadian manifestation, AB= Awake bruxism, SB= Sleep bruxism. A study appears into more than one category when multiple types of bruxism were assessed. Such studies are marked with *.

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Chapter 3

Clinical jaw-muscle symptoms in a group of probable sleep bruxers

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ABSTRACT

Objectives

To investigate the presence and relationships between clinical jaw-muscle symptoms, and to test their associations with jaw-muscle electromyographic (EMG) activity during sleep in a sample of probable sleep bruxers with and without temporomandibular disorder (TMD) pain.

Methods

Pain, unpleasantness, tiredness, tension, soreness, and stiffness were scored on a 0-10 numerical rating scale (NRS) in 50 probable sleep bruxers, directly after a clinical TMD examination. The sample was subdivided into two groups, i.e., with and without TMD pain. Single-channel EMG recordings were performed for at least four nights. The mean number of EMG events/recording and of EMG events/hour, as well as the night-to-night variability in EMG events were evaluated. Descriptive data, correlations between the six symptoms, and correlations between symptoms and EMG measures were calculated.

Results

In the total sample, 90% of the participants reported at least one symptom. Tiredness and tension were the most prevalent symptoms (both 78%), and pain the least (30%). In the TMD pain group, pain remained the least reported symptom (57%). Based on the NRS scores, the intensity of symptoms was low to moderate, with tension presenting the highest median in the total sample (NRS 4), the TMD pain group (NRS 5), and non-TMD group (NRS 3). Significant correlations between all symptoms were found in the total sample, but not in the two subgroups. No significant associations between EMG measures and muscle symptoms emerged.

Conclusion

Jaw-muscle symptoms other than pain were highly prevalent in a sample of probable sleep bruxers. There were no associations between these symptoms and EMG measures of jaw-muscle activity during sleep. These findings challenge the concept of simple relationships between jaw-muscle activity during sleep and clinical muscle symptoms.

Key words

Sleep bruxism, electromyography, jaw muscle symptoms, orofacial pain, radar plot

INTRODUCTION

Persistent pain in the orofacial region is a bothersome condition for which treatment is often requested. [1] Non-painful symptoms, such as sensations of unpleasantness, tiredness, tension, soreness, and stiffness, have also been reported among individuals with TMD pain, [2] as well as in pain-free groups [2–4] and in general population studies. [5,6] Reporting three or more non-painful orofacial symptoms, i.e., jaw stiffness, cramping, fatigue, pressure, soreness, and/or ache, have found to be a strong predictor of the subsequent onset of TMD pain. [7] The nature of the association between jaw muscle pain and non-painful symptoms in individuals with and without a TMD-pain diagnosis is, however, not entirely clear. [7]

Sleep bruxism is a masticatory muscle activity during sleep that is characterized by rhythmic and non-rhythmic episodes, [8] and presumably involved in the onset and persistence of orofacial pain. [8–10] For decades, this topic has received ample attention from researchers. [11,12] Most likely, the relationship between orofacial pain and sleep bruxism is not a univariate, but rather a complex, and possibly bidirectional one, in which multiple factors (e.g., pain sensitivity, psychological, genetics, sleep, trauma/overloading) interact over time. [4,9,13] Several related studies, especially those focusing on TMD pain, have used instrumental methods, i.e., single-channel EMG or polysomnography (PSG), for the assessment of sleep bruxism. [2,14–19] Such diagnostic methods are recommended over self-report and/or clinical examination. [11,20] Single-channel EMG and PSG studies on the association between sleep bruxism and non-painful symptoms are extremely scarce, and have mainly focused on symptoms occurring in the morning. [2,21] A recent study by our group showed an association between jaw-muscle EMG measures and symptoms of muscle fatigue, tension, and soreness. [22] The relationship between sleep bruxism and jaw muscle sensations of unpleasantness, tiredness, tension, soreness, and stiffness remains, however, largely unknown.

The aims of this study were to investigate in a sample of probable sleep bruxers with and without a diagnosis of a painful TMD: a) the presence of, and relationships between clinical jaw-muscle symptoms, and b) the association between the frequency of jaw-muscle EMG activity during sleep and these symptoms.

MATERIALS AND METHODS

Study design

The data of this cross-sectional study were obtained at the baseline visit of a randomized placebo-controlled trial on the efficacy of contingent electrical stimulation (CES) using a single channel EMG device (Grindcare 4-DL) [22].

Participants

Participants were recruited between May 2015 and June 2016 from amongst patients attending the clinic of the Department of Dentistry and Oral Health, Aarhus University, Aarhus, Denmark, and through advertising via flyers on the Aarhus University Campus, via internet web pages of the Section of Orofacial Pain and Jaw Function (http://odont.au.dk/om-odontologi/sektioner/kof/), and internet volunteer recruiting systems (www.forsoegsperson.dk). Participants were eligible for the study when they fulfilled the following inclusion criteria: a diagnosis of "probable sleep bruxism", [20] i.e., presence of self-reported sleep bruxism and/or tooth-grinding noises reported by a sleep partner, plus at least one or more of the following clinical signs: tooth-wear facets, hypertrophy of the masseter muscles, evidence of wear on an oral appliance, hyperkeratosis of cheek mucosa (linea alba), teeth impressions on the tongue, lips, or cheeks, and/or tooth or tooth restoration fractures due to bite forces. Exclusion criteria were: age < 18 years, use of a pacemaker, reported allergies to nickel or rubber, and simultaneous participation in another clinical trial. In case the patients were wearing an oral appliance, they were asked to discontinue its use during their participation in the study. Signed informed consent was obtained by all participants.

Variables

Description of sample

Data on age and gender were collected. Examination of included participants according to the full Diagnostic Criteria for Temporomandibular Disorders (DC/TMD, Danish version) [23] was performed by a trained examiner (AS) in order to establish the presence and subtypes of TMD. Based on the DC/TMD diagnoses, the sample was further subdivided into two groups: probable bruxers with a painful TMD diagnosis, i.e., myalgia or myofascial pain and/or arthralgia, (TMD pain group), and probable bruxers without a painful TMD diagnosis (non-TMD group).

Pain and non-pain symptoms

Six symptoms, i.e., pain, unpleasantness, tiredness, tension, soreness, and stiffness in the

orofacial region were each scored separately on a 0-10 numerical rating scale (NRS), directly after the DC/TMD clinical examination. Questions were asked as follows: "How much of X, i.e., each symptom, do you have right now on a 0-10 scale, where 0 represents no X and 10 the worst X imaginable?". During the DC/TMD clinical tests, the masticatory system undergoes loading, for example during maximum opening, lateral and protrusive movements of the mandible, and as a result, pain might be elicited. [23] In this study, it was chosen to perform the clinical tests, and immediately after allow participants to score both pain and non-pain symptoms, as to create a homogenous baseline loading condition of the masticatory system of all participants.

A symptom was considered present when the NRS value was ≥ 1. The presence and number of reported symptoms were investigated, and the NRS value of each symptom was used as a measure of intensity. As an expression of the overall burden of these symptoms, the variable "symptom burden" was calculated as the sum of the NRS values.

Sleep bruxism

Sleep bruxism was assessed by performing EMG recordings of jaw-muscle activity with an ambulatory single-channel EMG-recorder (Grindcare®, version 4-DL, Delta Danish Electronics, Light & Acoustics, Denmark, hereafter referred to as GC). GC consists of an electrode, which connects through a wire to a sensor. The GC recording electrode attaches to the skin over the anterior part of the temporalis muscle, receives the EMG signal from the muscle, and transfers this to the device sensor. In the sensor, the EMG signal is amplified (x 800), filtered (250 Hz- 610 Hz), and stored on a microSD card until further analysis.

Participants received instruction and training by the examiner in the use of the GC, and written instructions were provided for consultation at home. Participants were free to choose the side of the face on which to place the device, i.e., left or right. They were instructed to use the device for at least 4 nights, during a one-week period, starting at the night following the baseline visit.

EMG data were analyzed with commercially available software (MATLAB and Statistics Toolbox Release 2015b, The MathWorks, Inc., Natick, Massachusetts, USA) by a technician not involved in other study procedures. All recordings were controlled for acceptable quality based on the following criteria: a complete recording had good impedance for at least 75% of the time, and the duration of the recording with good impedance is at least 4 hours. EMG events were scored using a 'moving average' (MA) algorithm, which uses a dynamic method

to score events when the EMG signal exceeds the amplitude of the background noise with 3 or more times, for a duration of ≥ 0.25 s. [24] The mean number of EMG events per recording, the number of EMG events per hour of recording, and night-to-night variability in EMG events were registered. EMG events per hour were calculated as follows: (events / hrecording1 + events / hrecording2 + … + events / hrecordingN) / N, where N = the number of recordings. Night-to-night variability in EMG events for each participant was expressed by calculation of the coefficient of variation (CV = SD / mean).

Analysis

For all variables, normality testing was performed using the Shapiro-Wilk test, and descriptive data were calculated. Age and gender differences between the TMD pain and non-TMD groups were tested with the Mann-Whitney U and Chi-square test, respectively. Differences in the number of accepted EMG recordings, mean duration of recordings, mean number of EMG events per recording, and night-to-night variability between the TMD and non-TMD groups were tested with the Mann-Whitney U test.

For the purpose of investigating the presence of, and testing the relationships between orofacial pain and non-pain symptoms (aim a), descriptive data on the prevalence and intensity of orofacial pain and non-pain symptoms were calculated. Six-sided radar plots, as means to visualize the overall symptom burden, were created. Spearman's correlation was run for testing the associations between symptoms. Differences in the prevalence and intensity of symptoms between the TMD and non-TMD groups were tested with the Mann-Whitney U, Chi-square, and Fisher's exact test, as appropriate.

Spearman's correlation was performed to test the associations between EMG measures, and the presence and intensity of symptoms (aim b). The significance level for all tests was set at p = .05. To account for multiple testing, all correlation analyses were corrected using the Bonferroni-Holm method. [25] Statistical analysis was performed using IBM SPSS Statistics 23 software (IBM Corp., Armonk, New York, USA).

RESULTS

Sample

During the recruitment period, 149 individuals were assessed and 60 were enrolled into the study based on the eligibility criteria. Sleep recordings of 10 participants were lost due to technical issues, i.e., recordings not stored on SD cards. These participants were excluded from further analyses; thus, the total sample size was 50 (29 females, 21 males), with a median (range) age of 28 (20-61) years. There was no significant difference between included and excluded participants for gender (Fisher's exact, P = .597) and age (Mann-Whitney U, P = .382).

For 21 (42%) participants, at least one painful TMD diagnosis was established according to the DC/TMD (TMD pain group). There was no significant difference between the TMD and non-TMD groups in gender (Chi square, P = .291) and age (Mann-Whitney U, P = .407). The distribution of DC/TMD diagnoses is presented in Table 1. Prevalence data on temporomandibular joint (TMJ) disorders are presented for descriptive purposes, and were not used in further analyses.

Presence of symptoms

Out of the 50 probable bruxers, 45 (90%) reported having at least one, and 37 (74%) having at least three orofacial symptoms (Table 2). Tiredness and tension were the most prevalent symptoms, closely followed by unpleasantness, soreness, and stiffness. Interestingly, pain was the least reported symptom. The most prevalent symptom in the TMD pain group was tiredness, while tension was the most reported symptom in the non-TMD pain group. In both groups, pain was the least reported symptom. The TMD pain group had a statistically significant higher number of reported symptoms compared to the non-TMD group (Mann-Whitney U, P = .001), as well as significantly more participants having at least three orofacial non-pain symptoms (Chi-square, P = .024). A significant difference between these groups was found for the number of participants reporting pain (Chi-square, P < .001), unpleasantness (Chi-square, P = .066), tiredness (Fisher's exact, P = .016), and soreness (Chi-square, P = .004), but not for those reporting tension (Fisher's exact, P = .092) and stiffness (Chi-square, P = .242) (Table 2).

In general, the intensity of symptoms was rated as low to moderate, with tension presenting the highest median in both the total sample, as well as the two subgroups (Table 2). In general, the intensity of symptoms was higher in the TMD pain group. The Mann-Whitney U test showed a statistically significant difference between the TMD and non-TMD groups for the intensity of pain (P = .001), unpleasantness (P = .006), tiredness (P = .002), tension (P =

.017), soreness (P = .016), and symptom burden (P = .001), but, albeit marginally, not for the intensity of stiffness (P = .054) (Table 2).

A radar plot with six axes was designed to visualize the total symptom burden. Each axis was labelled by one of the six orofacial symptoms. The 0-10 NRS value of each symptom was noted on the respective axis, which lead to the production of an area within the radar plot (Fig. 1). The symptom burden variable, i.e., the sum of all NRS values, correlates to the value of this area.

Relationships of symptoms

Table 3a shows the correlations between the intensity of orofacial pain and non-pain symptoms in the entire sample. Positive and statistically significant correlations were found between all symptoms. Pain was moderately correlated with unpleasantness and soreness, and to a lesser extent with tiredness, tension, and stiffness. The highest correlations, albeit of moderate size, [26] were found between tension on one hand, and stiffness, tiredness, and soreness on the other. Correlations between other pairs of symptoms were of low to moderate size.

Correlations between the intensity of pain and non-pain symptoms for the TMD and non-TMD groups are shown in Tables 3b and 3c, respectively. In the TMD pain group, a statistically significant, high positive correlation was found between pain and soreness. A significant correlation of moderate size was found between tension and stiffness. No significant correlations were found for the remaining pairs of symptoms.

In the non-TMD group, high and statistically significant correlations were found between tension and soreness and tension and stiffness. Significant correlations of moderate size were found between tiredness and stiffness, tiredness and tension, tiredness and unpleasantness, soreness and unpleasantness, and pain and unpleasantness. No significant correlations were found for the remaining pairs of symptoms.

EMG data and relationships with symptoms

In total, 604 recordings were stored in the SD cards, of which 453 (75%) fulfilled the quality criteria. The mean (s.d.) number of recordings per participant was 9.1 (2.8), with a mean (s.d.) duration of 7.2 (.8) hours (Table 4). The Mann-Whitney U test showed no significant difference between TMD and non-TMD groups for the number of recordings per participant (P = .411), mean recording duration (P = .311), mean number of events per recording (P = .562), events per hour (P = .914), and night-to-night variability (P = .716).

No significant associations were found in the entire sample of probable sleep bruxers between the mean number of events per recording, events per hour, and night-to-night variability, and the intensity or presence of orofacial pain and non-pain symptoms (Table 5a). Similarly, no significant associations between EMG measures and orofacial pain and non-pain symptoms were found, neither in the TMD pain group nor in the non-TMD group (Tables 5b and 5c).

DISCUSSION

This cross-sectional study investigated the presence of, and relationships between jaw-muscle symptoms of pain, unpleasantness, tiredness, tension, soreness, and stiffness, in a group of probable sleep bruxers with and without a TMD pain diagnosis. Furthermore, it investigated the association between these symptoms and frequency measures of jaw- muscle EMG activity during sleep.

Presence and relationships between symptoms

In the total sample of probable bruxers, jaw muscle symptoms were highly prevalent, with 90% of the participants reporting at least one, and 74% at least three symptoms. Tiredness and tension had the highest prevalence and intensity, while pain showed the lowest scores, pointing to the relevance of addressing non-painful symptoms when sleep bruxism is assessed in the clinic. Having at least three non-painful symptoms was reported by 90% of participants in the TMD pain group. A similar rate, i.e. 92.4%, of reporting three or more orofacial non-pain symptoms by clinically diagnosed TMD cases was found in the case-control study by Ohrbach et al. [27] On the other hand, in the same study, [27] only 4.8% of the non-TMD controls reported three or more non-pain symptoms, a rate which lies interestingly far from the present results, i.e., 62%. Certain differences in study design could explain this discrepancy. First, the studied non-pain symptoms were comparable, but not exactly the same. Moreover, symptoms were scored in a different manner, i.e., using an anamnestic checklist in the study of Ohrbach et al., vs. assessment by means of a NRS scale directly after a clinical examination in the current study. Furthermore, both studies recruited non-TMD controls from community populations, however, in the study of Ohrbach et al., non-TMD controls were sought irrespective of self-reported sleep bruxism status, [27,28] as opposed to the current study.

The issue of participant recruiting based on self-reported sleep bruxism deserves some further attention. The belief that jaw-muscle symptoms are attributed to sleep bruxism is quite common, and supported by popular online healthcare information sources. [29–31] The

experience of symptoms may lead an individual to believe they are bruxing during sleep. It is possible that the present high prevalence of symptoms in the non-TMD group reflects such beliefs, in the sense that individuals who experienced orofacial symptoms may have been motivated to participate, in an attempt to gain more insight into their presumably present sleep bruxism. Based on the above, it seems important that future sleep bruxism studies include a comprehensive assessment of not only pain, but also non-painful muscle symptoms, and take the matter of patient beliefs regarding perceived sleep bruxism status into consideration when selecting the study sample.

Paradoxically, in the TMD pain group, pain was the least reported symptom in terms of prevalence and intensity. It would be expected that this symptom would have been reported by all participants of a group that has just been diagnosed with a pain condition. In order to explain this finding, it might carefully be hypothesized that the presence of non-painful orofacial symptoms affects the outcomes of the DC/TMD diagnostic tests. Koutris et al. [32] have shown that comorbidity can influence the outcomes of diagnostic tests in the orofacial region. More specifically, they showed that the presence of widespread bodily pain was associated with the provocation of familiar pain by palpation of masticatory muscles and temporomandibular joints. [32] In the present investigation, jaw-muscle symptoms were scored directly after the DC/TMD diagnostic tests, thus assuming that the presence of symptoms had an influence on the results of the tests would not be valid. However, this hypothesis deserves further investigation with a more suitable study design. In addition to the above, the finding of pain being the least reported symptom in the TMD pain group may be suggestive of the TMD phenotype consisting of a variety of symptoms, that can be overlooked if the sole focus is on pain. The six-sided radar plot presented here gives an example of how the type and intensity of symptoms can be illustrated. Future research should investigate the different ways in which symptoms are expressed, and the extent to which they add to TMD-related suffering. For this purpose, qualitative study designs might be valuable. [33]

Furthermore, adequate evaluation of non-painful symptoms requires appropriate diagnostic instruments. In the present study, symptoms were assessed on a 0-10 NRS scale, after performance of the DC/TMD examination. The highly standardized DC/TMD are designed to diagnose pain in both clinical and research settings. [34] It would be practical if the same tests could be utilized to assess both pain and non-painful symptoms, and thus, investigating the validity of the DC/TMD diagnostic tests in this context is suggested.

Correlations between the intensity of jaw-muscle symptoms were found. In the total sample, all symptoms were found to be moderately correlated, indicating a possible phenotypic overlap. In the TMD pain group, however, only the couples of pain-soreness and tension-stiffness were correlated. This may reflect a common underlying pathophysiologic mechanism, [7] or imply a similar linguistic semantic of these words. [35] The correlation between tension and stiffness was also revealed in the non-TMD pain group, in which, however, correlations for other couples of symptoms were also found to be significant. Moderate R-values, as well as the large number of significant correlations, do not allow for overly strong interpretation of these results. Therefore, it is suggested that the topic is further examined, taking into account emotional and linguistic factors that may influence the words that individuals choose to describe their complaints. [35]

Relationship with EMG activity

Neither the presence, nor the intensity of jaw-muscle symptoms were found to be associated with jaw-muscle EMG measures. Furthermore, no differences were found in EMG measures between probable sleep bruxers with and without a TMD pain diagnosis.

With a few exceptions, these results are in line with those found elsewhere. A similar absence of association was reported in the EMG studies by Shedden Mora et al. [2] and Baba et al. [18] Yachida et al. [14]also did not find an association between craniofacial pain and EMG events per hour, but did find a positive association with the coefficient of variation from multiple-night EMG recordings. Similarly, Camparis et al. [16] did not find significant differences in PSG-assessed bruxism variables of self-reported sleep bruxers with and without painful TMD. Rossetti et al. [19] did find a significant association between PSG-based bruxism status and myofascial pain, however, there were no differences between myofascial pain patients and controls in phasic, tonic, and mixed bruxism episodes. Furthermore, Raphael et al. [17] did not find significant differences for PSG-based bruxism measures between myofascial pain cases and controls, with the exception of controls presenting at least two EMG episodes with grinding per recording compared to cases. Finally, Muzalev et al. [36] did not find a difference in PSG-assessed inter-episode intervals between myofascial pain patients and controls. Thus, a consistent association between sleep bruxism variables and a TMD-pain diagnosis is not supported by literature so far. From another point of view, a significantly elevated masticatory muscle background EMG activity in myofascial pain patients has been shown, [37] pointing to an alternative risk factor for explaining persistent pain, in addition to the commonly assessed frequency and duration of sleep bruxism variables.

Studies on the relationships of non-painful symptoms and EMG measures are scarce, and mainly focus on morning symptoms, thus, their results cannot directly be compared with the present findings. [2,21,37] Interestingly, results from the RCT from the same sample as the present investigation [22] showed that reducing the level of EMG activity of the jaw muscles by applying high intensity contingent electrical stimulation (CES) was associated with a decrease in NRS scores of symptoms of fatigue, tension, and soreness. Such decrease was also observed for tiredness and soreness in the low CES group, but not in the placebo group. These findings indicate an association between symptoms of fatigue, tension, and soreness with jaw-muscle EMG activity, as opposed to the findings of the present investigation. This discrepancy underlines the concept that relations between muscle symptoms and jaw-muscle EMG activity are not univariate, but multifaceted. A variety of factors, such as psychosocial and genetic variables, [9] may influence these relations, thus, it is suggested that future investigations on the relationship between sleep bruxism and muscle symptoms take those factors into account.

Limitations

Single-channel EMG recordings were performed, which might have influenced the results of this study to an extent, because the method tends to overestimate sleep bruxism outcomes. [38] Furthermore, assessment of symptoms was not performed taking into account the effect of other variables which are known to influence pain, such as psychosocial factors and oral parafunctions during wakefulness. [9] It is possible that such factors contribute to the presence and intensity of not only pain, but also non-painful symptoms, and influence their relationship with jaw-muscle activity during sleep.

The specific purpose of the present investigation was to study jaw-muscle symptoms in a group of probable sleep bruxers, i.e., individuals presenting with both clinical signs and a self-report of sleep bruxism, according to the diagnostic grading system of Lobbezoo et al., published in 2013. [20] This grading system has been updated in 2018, and currently a probable sleep bruxism diagnosis can be set based on a positive clinical inspection, with or without a positive self-report. [8] Thus, results of the present investigation cannot directly be compared with any future studies that utilized the 2018 grading system, which could be considered a limitation of this study.

CONCLUSION

Jaw-muscle symptoms were highly prevalent in a group of probable sleep bruxers. Tiredness and tension were the most frequent symptoms, while pain was the least. The general intensity of symptoms was low to moderate. Symptoms were both more prevalent and intense in probable sleep bruxers with a TMD pain diagnosis, compared to those without such a diagnosis. No association was found between any muscle symptom and frequency measures of jaw-muscle EMG activity during sleep. Overall, the present study results support the concept that simple relationships between jaw-muscle activity during sleep and muscle symptoms do not exist.

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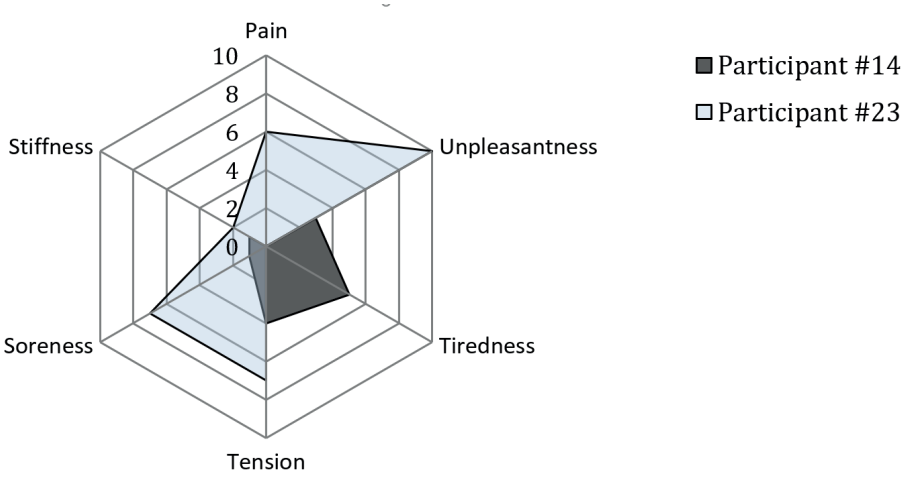

Figure 1. Example of symptom burden radar plots for two study participants

Table 1. Distribution of DC/TMD diagnoses (n=50)

Pain diagnoses	N (%)	TMJ Disorders	N (%)
None	29 (58)	None	31 (62)
Myalgia/MFP	19 (38)	DD with reduction	10 (20)
Arthralgia	11 (22)	DD with reduction with intermittent locking	3 (6)
Myalgia/MFP and Arthralgia	9 (18)	DD without reduction, with limited opening	0 (0)
Headache attributed to TMD	12 (24)	DD without reduction, without limited opening	5 (10)
		Degenerative joint disease	1 (2)
		Dislocation	0 (0)

DD= disc displacement, MFP= myofascial pain, TMJ= temporomandibular joint

Table 2. Prevalence and intensity of jaw-muscle symptoms

	All participants (n=50)		TMD group (n=21)		non-TMD group (n=29)	
	N *	Intensity #	N *	Intensity #	N *	Intensity #
Pain	15 (30)	0 (0-2.25)	12 (57) [a]	2 (0-4) [b]	3 (10) [a]	0 (0-0) [b]
Unpleasantness	36 (72)	2 (0-4.25)	18 (86) [a]	3 (2-5.5) [b]	18 (62) [a]	1 (0-2.5) [b]
Tiredness	39 (78)	3 (1-5)	20 (95) [a]	4 (3-5) [b]	19 (66) [a]	1 (0-3.5) [b]
Tension	39 (78)	4 (1-6)	19 (90)	5 (3.5-7.5) [b]	20 (69)	3 (3-5) [b]
Soreness	34 (68)	2 (0-5)	19 (90) [a]	4 (2-5) [b]	15 (52) [a]	2 (2-4.5) [b]
Stiffness	31 (62)	2 (0-4)	15 (71)	3 (0-4.5)	16 (55)	2 (0-3)
	All participants (n=50)		TMD group (n=21)		non-TMD group (n=29)	
Having ≥ 1 symptom *	45 (90)		21 (100)		24 (83)	
Having ≥ 3 symptoms *	37 (74)		19 (90) [a]		18 (62) [a]	
Having ≥ 3 non-pain symptoms *	37 (74)		19 (90) [a]		18 (62) [a]	
Symptom number #	4.5 (2-5)		5 [a] (4.5-6)		4 [a] (1.5-5)	
Symptom burden #	14.5 (5-24)		21 [a] (13.5-29)		11 [a] (2-17.5)	

* Number (%) of participants with symptom NRS ≥ 1

Median (25th- 75th quartile)

a, b within the same row indicate a significant difference between the TMD and non-TMD group

Symptom number = number of reported symptoms with NRS ≥ 1

Symptom burden = sum score of NRS values of all symptoms

Table 3a. Correlations between the intensity of jaw-muscle symptoms, entire sample (n=50) Spearman's correlation with Bonferroni-Holm correction, statistically significant correlations indicated in bold

	Unpleasantness		Tiredness		Tension		Soreness		Stiffness	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Pain	**.530**	**< .001**	**.434**	**.002**	**.491**	**< .001**	**.571**	**< .001**	**.401**	**.004**
Unpleasantness			**.557**	**< .001**	**.524**	**< .001**	**.505**	**< .001**	**.439**	**.001**
Tiredness					**.661**	**< .001**	**.509**	**< .001**	**.596**	**< .001**
Tension							**.645**	**< .001**	**.682**	**< .001**
Soreness									**.390**	**.005**

Table 3b. Correlations between the intensity of jaw-muscle symptoms, TMD group (n=21) Spearman's correlation with Bonferroni-Holm correction, statistically significant correlations indicated in bold

	Unpleasantness		Tiredness		Tension		Soreness		Stiffness	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Pain	.266	.244	.465	.034	.434	.050	**.719**	**< .001**	.512	.018
Unpleasantness			.468	.032	.523	.015	.225	.327	.495	.023
Tiredness					.584	.005	.336	.136	.499	.021
Tension							.329	.146	.623	.003
Soreness									.223	.331

Table 3c. Correlations between the intensity of jaw-muscle symptoms, non-TMD group (n=29) Spearman's correlation with Bonferroni-Holm correction, statistically significant correlations indicated in bold

	Unpleasantness		Tiredness		Tension		Soreness		Stiffness	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Pain	**.532**	**.003**	.167	.388	.375	.045	.359	.056	.129	.506
Unpleasantness			**.553**	**.002**	.469	.010	**.534**	**.003**	.333	.078
Tiredness					**.579**	**.001**	.484	.008	**.617**	**.001**
Tension							**.739**	**< .001**	**.732**	**< .001**
Soreness									.413	.026

Table 4. Descriptives of accepted EMG recordings

	All participants (N=50)	TMD group (n= 21)	Non-TMD group (n=29)
Recordings per participant *	9.1 (2.8)	8.5 (2.7)	9.5 (2.9)
Recording duration (hours)*	7.2 (.8)	7.3 (.8)	7.1 (.7)
Mean number of events per recording #	398.7 (254.6- 618.6)	424.4 (263.4- 649.3)	360.1 (247.5- 622.2)
Events per hour #	54.8 (36.1- 85.2)	58.1 (34.4- 81.8)	53.2 (37.1- 91.7)
Night-to-night variability #	.4 (.3- .6)	.4 (.3- .6)	.4 (.3- .7)
Total number of recordings	453	179	274

* Mean (s.d.)

Median (25^{th}- 75^{th} quartile)

Table 5a. Correlations between EMG measures and jaw-muscle symptoms, entire sample (n=50) Spearman's correlation with Bonferroni-Holm correction

	Mean number of events per recording		Events per hour		Night-to-night variability	
	r_s	p	r_s	p	r_s	P
Pain	.133	.358	.000	.998	.058	.689
Unpleasantness	.062	.667	-.023	.873	-.112	.439
Tiredness	-.023	.875	-.119	.411	-.018	.902
Tension	.010	.944	-.024	.869	.126	.383
Soreness	.049	.737	.096	.507	.101	.483
Stiffness	.205	.153	.192	.183	.154	.286
Number of reported symptoms	.118	.413	.021	.887	-.039	.786
Symptom burden	.081	.575	.019	.893	.082	.572

Table 5b. Correlations between EMG measures and jaw-muscle symptoms, TMD group (n=21) Spearman's correlation with Bonferroni-Holm correction

	Mean number of events per recording		Events per hour		Night-to-night variability	
	r_s	p	r_s	P	r_s	P
Pain	.396	.076	.200	.384	.393	.078
Unpleasantness	.159	.490	.142	.538	.209	.362
Tiredness	-.128	.580	-.250	.275	.141	.541
Tension	.035	.879	-.079	.734	.389	.081
Soreness	.298	.190	.320	.158	.471	.031
Stiffness	.104	.654	.153	.508	.255	.265
Number of reported symptoms	.161	.486	.018	.938	.089	.701
Symptom burden	.190	.409	.100	.666	.452	.040

Table 5c. Correlations between EMG measures and jaw-muscle symptoms, non-TMD group (n=29) Spearman's correlation with Bonferroni-Holm correction

	Mean number of events per recording		Events per hour		Night-to-night variability	
	r_s	p	r_s	p	r_s	P
Pain	-.179	.353	-.220	.253	-.208	.278
Unpleasantness	-.041	.831	-.082	.672	-.264	.166
Tiredness	.025	.896	.022	.911	-.131	.497
Tension	-.072	.710	.015	.940	-.016	.936
Soreness	-.101	.601	.003	.987	-.106	.585
Stiffness	.185	.336	.189	.327	.091	.638
Number of reported symptoms	.023	.905	.045	.815	-.134	.489
Symptom burden	.013	.947	.046	.811	-.105	.589

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Chapter 4

Experience with bruxism in the everyday oral implantology practice in The Netherlands: a qualitative study

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ABSTRACT

Objective

To explore how bruxism is dealt with by accredited oral implantologists within daily clinical practice.

Materials and methods

Nine semi-structured interviews of oral implantologists practicing in non-academic clinical practices in The Netherlands were performed, and thematic analysis was conducted using a framework-based approach.

Results

Oral implant treatments in bruxing patients were a generally well-accepted practice. Complications were often expected, with most being of minor impact. Contradictive attitudes emerged on the topic of bruxism being an etiologic factor for peri-implant bone loss and loss of osseointegration. Views on the ideal treatment plan varied, though the importance of the superstructure's occlusion and articulation features was repeatedly pointed at. Similarly, views on protective splints varied, regarding their necessity and material choice. Bruxism was diagnosed mainly by clinical examination, alongside with patient anamnesis and clinician's intuition. There was little attention for awake bruxism.

Discussion

Bruxism was generally not considered a contraindication for implantological treatments by accredited oral implantologists. Views on the interaction between bruxism and bone loss/loss of osseointegration varied, as did views on the ideal treatment plan.

Conclusions

There is a need for better understanding of the extent to which, and under which circumstances, sleep and/or awake bruxism can be seen as causal factors for the occurrence of oral implant complications.

Keywords

bruxism, dental implants, complications, experiences, qualitative

INTRODUCTION

Clenching and/or grinding of the teeth is a characteristic expression of bruxism and can occur while sleeping and/or while being awake. [1] In the field of restorative dentistry, bruxism is traditionally dealt with as "the bad guy", to be associated with various types of failures of dental restorations. [2] Regarding dental implants, it has been suggested that bruxism can lead to technical, and to a lesser extent to biological, complications even if, to date, no prospective evidence exists to prove this. [3] Alongside, but also as a consequence of this research paucity, no evidence-based gold standard exists about the optimal way to treat bruxers with dental implants. So far, clinical recommendations concerning occlusion and articulation as well as material choices are given in the form of expert opinions. [4,5] Consequently, a variability in treatment approaches of bruxing patients can be expected amongst dentists placing and/or restoring dental implants.

As for detecting the presence of sleep bruxism (SB), a polysomnographic study of sleep with audio-visual recordings (PSG-AV) is recommended to set a definite diagnosis. [2] This method is not suitable for the daily dental practice. [2] On the other hand, the much more feasible methods of self-report and clinical examination lack the validity of a PSG-AV, and can only indicate the presence of possible and probable SB. [1] Portable electromyographic (EMG) devices seem promising alternatives of PSG methods, although their widespread implementation in the dental practice is still in an initial phase. [2] Likewise, self-report and clinical examination can at best only lead to the diagnosis of probable awake bruxism (AB). [1] Therefore, accurately diagnosing both circadian manifestations of bruxism (i.e., SB and AB) is still a significant challenge faced in everyday clinical practice.

As a result of the above, the question arose of how bruxism is actually dealt with in the context of the clinical, non-academic reality of the oral implantology practice. It was hypothesized that experienced practitioners will have had to deal with all kinds of aspects of implant treatments in bruxing patients: from identifying the condition of bruxism, to the planning and outcome of their treatments, including possible complications related to the condition.

Furthermore, it was hypothesized that experiences with bruxism derived from daily practice could be a rich source of information for academia, meaning, investigating what works in real life, and what does not, can be a guide to defining future research questions and study protocols driven by clinical pragmatism. [6] In turn, as high quality research in the field of bruxism and implant complications will undoubtedly emerge in the future, it is important to gain

insight into the present status of clinical practice, as an aid to the design of reality-motivated implementation policies of research results. [6] Therefore, the aim of this study was to explore and critically analyze the attitudes and experiences acquired by experienced oral implantologists when dealing with bruxing patients in a non-academic setting.

METHODS

Study design

An effective way to gather a broad spectrum of information related to personal attitudes and experiences is the use of semi-structured interviews, which are a form of qualitative research. [7] Thereby the researcher/interviewer can acquire in-depth information from the interviewee on pre-conceived topics, while new, unthought-of ideas are allowed to emerge and be explored. [7]

Interviewee sampling

Purposive sampling, i.e., sampling based on a specific criterion was used to select interviewees. [8,9] The criterion was that implantologists should have considerable experience in performing oral implant treatments. Therefore, only dentists accredited to perform such treatments by the Dutch Association of Oral Implantology (Nederlandse Vereniging voor Orale Implantologie, NVOI), were selected for inclusion, since this group comprises of profoundly experienced professionals in the field of oral implantology in The Netherlands. Alongside, it was aimed to recruit implantologists from geographically spread areas of The Netherlands in order to account for possible socio-geographical influences. [10] After permission of the NVOI, the accredited implantologists were alphabetically invited to participate by an e-mail with a short, standardized text, accompanied by a brochure describing the purpose and methods of the study. Implantologists were informed about the interviewer's professional background and the motives to perform this study. When an implantologist agreed to participate, no other implantologists practicing in the same area were contacted.

Interview conduct and data analysis

Semi-structured interviews of approximately 30 minutes with dentists-implantologists who run a practice focused on the placement and restoration of dental implants in The Netherlands were conducted by MT. MT is a dentist, trained and clinically active in the field of orofacial pain, oral movement disorders, tooth wear, and dental sleep medicine, and a PhD student at the Academic Centre for Dentistry Amsterdam (ACTA). MT does not perform oral implant

treatments. Training for the conduct of the study included self-study and the performance of three pilot interviews, under supervision of a researcher (AR) with training and experience in the field of qualitative research. AR furthermore is a physical therapist, active as a clinician and academic in the field of orofacial pain and oral movement disorders. The interviewer had no personal or professional affiliation with the participants. All interviewed implantologists were informed about the purpose and methods of the study and the professional background of the interviewer, and gave a written informed consent. The study was reviewed and approved by the Ethics Committee of ACTA (reference number 2016016).

Prior to the first interview a number of relevant domains were defined, and subsequently, an interview topic guide was designed. [9] The goal of the topic guide was to function as an agenda and memory aid for the interviewer, in order to ensure systematic collection of information on the predefined domains. [9] These domains were defined based on the available literature, the feedback from the three pilot interviewees, and the professional experience of an expert panel consisting of the co-authors of this paper (MT, AR, CV, DW, FL). CV is a physical therapist, active as a clinician and academic in the field of orofacial pain and oral movement disorders. FL is a dentist, active as a clinician and academic in the field of orofacial pain, oral movement disorders, tooth wear, and dental sleep medicine. DW is a dentist, active as a clinician and academic in the field of oral implantology. AR, CV, FL and DW are also actively involved in undergraduate and postgraduate education of dentists in The Netherlands. The domains covered were: feasibility of, and experiences with implant dentistry in bruxing patients; attitudes regarding the features of an implant treatment plan in bruxing patients; attitudes regarding the diagnosis of bruxism in the clinic, and attitudes related to scientific research in the field of implant dentistry and bruxism (Table 1).

These four domains were explored during the interviews using open-ended questions, and interviewees were encouraged to bring up relevant items during the conversation, even if they were not included in the topic guide. [7,9] Data collection and analysis occurred concurrently, allowing for new themes to be fused into the topic guide as the study progressed. [9] The interviews took place at a location of the interviewee's choice, which in all cases was their dental practice. Only the interviewer and interviewee were present during the interview. At the start of each interview, interviewees completed a questionnaire on demographic data, and data related to their education (year of birth, year of graduation, place of studies, year of registration as an oral implantologist in the Netherlands, postgraduate education in oral implantology and/or bruxism, and the approximate number of implant-borne superstructures placed per year, i.e. 10 to 50, or ≥50).

Each interview was audio-recorded and thereafter, a verbatim transcription was made, with any information revealing the identity of the interviewee removed. The transcriptions were not returned to the interviewees for comments or corrections, and no interviews were repeated. Thematic analysis of each transcript was performed by MT shortly after its acquisition, using a framework-based approach. [9,11] This analytic method was carried out in successive steps. [9] First, each transcription was investigated line-by-line for the identification of initial themes. Initial themes were given short, descriptive titles. Their identification was based on published literature, the data acquired from the pilot interviews, and the professional judgement of the investigator (MT). Next, conceptually related initial themes from the available interviews were grouped into main themes, each of which consisted of sub-themes. This process was done by hand, without the aid of data-analysis software. The analysis was reviewed by AR, and any disagreements in the interpretation of the data were resolved by discussion. Stepping backwards in the analytic process was allowed, when newly occurring initial themes from subsequent interviews required separate main or sub-themes, or when deeper familiarization of the researchers with the data led to new insights for their grouping. Interviews continued to be performed until saturation, i.e., until no new main or sub-theme emerged out of the data. After this, two more interviews were performed, in order to confirm saturation. Once saturation was achieved, the main and sub-themes were given numerical codes. These codes were used to label the transcribed data, i.e. to assign the interview texts to the proper main and sub-theme. Next, a thematic chart was created in Microsoft Excel 2010 software, in which the top row represented the main themes, under which each sub-theme was given a column. These columns served for clustering of all textual data that were related to the respective sub-theme. The textual data in this step were summarized, i.e. their essence was extracted with care not to lose the context or language in which they were expressed. This allowed for the synthesis of data and formulation of conclusions per sub-theme, and subsequently per main theme. [9]

RESULTS

Participants

In August 2016, 348 professionals were registered as NVOI-accredited oral implantologists. This number includes 100 oral and maxillofacial surgeons, who were excluded from our selection procedure, since they are mainly involved with the surgical, but not the prosthetic part of implant treatments (Fig. 1). Between the 26th of August and the 22nd of September 2016, 169 dentists (19 females, 150 males) were approached for participation. The other 79 dentists were not approached for the following reasons: personal or professional affiliations with the interviewer (17), inability to retrieve the email address (35), not practicing in The Netherlands or inclusion of a dentist practicing in the nearby area (27). After this recruitment round, 5 dentists agreed to participate. Three implantologists reported not being able to participate to the study due to lack of time, while the remaining 161 did not provide a reason for non-participation. Since saturation was not achieved after these five interviews, a second round of recruitment was performed between the 29th of September and 11th of November 2016. During this period, an e-mail reminder was sent to a selection of 26 implantologists practicing in areas of the country from where no one had been interviewed before. As a result of this recruitment round, two more interviews were performed, after which saturation of data was achieved. From the same recruitment round, two more interviews were performed, confirming the saturation of data. Thus, in total, nine implantologists were interviewed in this study, between August and December 2016.

All interviewees were male, with a mean (range) age of 49 (33-59) years (Table 2). The nine interviewees were established in five out of the 11 provinces of The Netherlands, in various distances from academic dental institutions. The mean (range) number of years of practicing dentistry was 23 (10-31). Interviewees had acquired their dental degree in The Netherlands. All interviewees reported having followed postgraduate education in the field of oral implantology in the past five years, in the form of courses, lectures, congresses, and/or reading professional literature. Six interviewees reported having followed postgraduate education related to bruxism.

Thematic analysis

Out of the thematic analysis, four main themes emerged, which coincided with the four domains that were described by the expert panel prior to the interviews: 1) bruxism and implant treatment outcomes; 2) treatment aspects of implantological interventions; 3) diagnosis of bruxism; and 4) improvement of care in the future. Each theme consists of

several sub-themes. The themes and sub-themes are described below and translated quotes from the original transcripts in Italics [interview number] are provided when useful. Within the quotes, text within parentheses (…) is inserted when needed to provide the reader with contextual information. A comprehensive overview of the results is provided in Table 3, with the most important findings described in the text below.

Theme 1: Bruxism and implant treatment outcomes.

1. General attitude about impact of bruxism on oral health.

Interviewees considered bruxism damaging for the dentition, as it can cause tooth wear, fractures of teeth and restorations, endodontic pathology, loss of teeth, pain, and limitation of mandibular movement. Occlusion and articulation were viewed as important mediators of the damaging effects of bruxism. *"I think that bruxism, that it is important that people do not do this, it just damages your dentition"* [3]. On the other hand, it was also mentioned that in the absence of pain, adequate oral function is not limited by bruxism.

2. Feasibility of implant dentistry in bruxers

There were two opposite attitudes regarding the feasibility of implant dentistry in bruxing patients, a stronger, positive attitude as opposed to a less prominent, negative one. The first advocates that bruxism is generally not a contraindication for implant dentistry. Some precautions need to be taken though, for example, interviewees argued that the patient should be without orofacial pain prior to the start of implant treatment, and the condition should be taken into account during treatment planning. From the interviews, the image arose that implant-related interventions could even be helpful for the bruxer with multiple tooth loss, since the exerted forces would be better distributed over the dentition. *"With implants you can of course help distribute the forces better, when you have many lost teeth and you have an occlusion on 4 or 5 teeth… this is also not helpful for the (intraoral) situation"* [4]. On the other hand, some expressed negativity and an uncomfortable feeling about implant treatments in bruxers, especially when it came to clenching activity.

3. Encounters with complications

There was a wide variation in the experiences and attitudes regarding the occurrence and type of implant complications related to bruxism. One interviewee had never experienced any complication directly related to bruxism. In general, though, complications were expected by the interviewees, either sometimes or, for the "real bruxers", always. *"Sometimes you will experience some things, yes, and I have to say that, in implantology, it is not that bad, but if it goes wrong then it is often very annoying"* [6]. Chipping of porcelain was mentioned

as the most common complication. Other types of complications were: wear or fracture of a full removable prosthesis (RP), wear or fracture of a mesostructure, wear of antagonists or problems with antagonistic porcelain, fractures or loosening of screws, and fractures of implants. Divergent experiences and visions emerged regarding bone loss and loss of osseointegration as a consequence of bruxism. A similar lack of consensus was found for loss of osseointegration due to bruxism, with some having experienced it, while others arguing it is not possible (see paragraph below). *"An implant that loosens due to overload I do not believe in, that is an implant that was never well integrated"* [9].

4. Mechanism of complications

Factors mentioned as being related to complications of implant treatments are the inattentiveness of the restoring dentist (e.g., insufficient tightening of screws or control of occlusion), material/implant properties, tooth wear and subsequent change of occlusion over time (leading to more contact of the superstructure with the antagonists), having a bad starting point (e.g., bruxing on an implant construction with a high crown-to-root ratio), and skills of the technician. Various views on how bruxism could be related to bone loss, periimplantitis, and loss of osseointegration were expressed:

- Excessive loading can lead to bone loss, which can be followed by bacterial invasion, ultimately leading to periimplantitis. *"More and more voices are raised to support that periimplantitis has at its origin a mechanical component, tension, then you get bone loss, and after that you get the bacterial invasion and everybody starts calling it periimplantitis, because it is inflamed"* [2];
- Inflammation pre-exists and subsequent overload can lead to more profound bone loss. *"I do not believe that overloading can cause bone loss, but overloading can cause bone loss when there is an underlying infection"* [3];
- Load can cause micro movements of the implant in the bone, which can lead to loss of osseointegration;
- Load can cause loss of osseointegration, only if this was poor already;
- Periimplantitis is mainly caused by other factors, e.g., cements remnants;
- Uncertainty about possible relationship between bruxism and periimplant bone loss

5. Consequences and treatment of complications

Porcelain fractures were generally not considered as troublesome complications. Smoothing out the edges was usually sufficient, though in more severe cases the superstructure may need to be replaced. When such fractures occur, it is a good moment to pause and investigate the cause of it, and think of preventive measures. *"Is it (chipping of porcelain) a disaster? Oh well,*

*you fix it, but then it is a moment to check with attention, maybe should I, for example, build up the canines?" [*4]. Material-wise, it was argued that a cheaper material, such as composite, may cause less financial pain when needing to be replaced, than a more costly ceramic material. Also, it was mentioned that when using harder materials for the superstructure, such as zirconia for fixed dental prostheses (FDPs) or metal parts in RPs, the occlusal forces may be led to more distant components of the implant, and other, "deeper" problems may occur. *"The solution to use full zirconia is nice, I always say, but you should realize that when you make the crown constantly harder, in the end either way something will break, and then it will break deeper"* [5]. Complications in general could have a negative emotional impact on patients, who could become frustrated for having to visit the implantologist too often, and put blames on the implantologist. Some implantologists were not fond of the issue of complications in bruxers, but in general this did not appear to be a significant problem, neither emotionally, nor financially.

Theme 2: Treatment aspects of implantological interventions

1. Assessment of patients

In the context of treatment planning, implantologists found it generally important to pay close attention to intraoral signs of heavy mandibular function from the start of the therapeutic trajectory. Taking time to observe signs of function, such as wear facets, was important, and implantologists should similarly try to understand why certain teeth may have fractured in the past. Making intraoral photographs and discussing them with the patients was considered as extremely helpful. Knowing the patient for a long time, but also sensing that something is going wrong in the mouth was also mentioned as a source of information. *"There is no strict protocol, that one is (a bruxer), that one not…you sense things, you think something here is not going well"* [7].

2. Treatment features

Implantologists gave ample attention to the topic of the features that their implantological treatments should have in (presumable) bruxers. Their views were concentrated around aspects of occlusion, articulation, protection, materials, and other technical issues.

Paying attention to occlusion on FDPs was considered as very important, and the matter was approached in several ways: a) superstructure occluding with the antagonists only when biting hard in maximal occlusion, b) superstructure completely out of contact, and c) superstructure allowed to stay in regular occlusion. Opinions regarding articulation were pointing more towards one direction: interviewees generally agreed that superstructures

should be free from contact with antagonists during lateral movements of the mandible. If the superstructure does participate in a lateral movement, then support from neighboring teeth in the form of group guidance is preferred. Besides adjusting the superstructure itself, a common way to achieve these goals is by building in canine guidance on non-implant borne superstructures with, for example, direct composite restorations. Occlusion and articulation should be controlled during the preventive check-up visits at the general dentist, because, interviewees agreed, the dentition not only wears, but is also in slight movement during the course of years. Consequently, over time a superstructure may acquire undesirable contacts with its antagonists.

Various views were expressed about the need for protection of the final restoration(s). Making an occlusal splint to wear during sleep was always advised by some interviewees, while others argued that a protective splint in necessary in some, but not all cases of suspected bruxism. No specific criteria were given as guides for deciding in which cases a splint should be made. As for the material, some preferred a hard and others a soft one, for reasons of patient's comfort. *"I don't really feel it makes such a difference, to be honest (in protective effectiveness of a soft or hard splint), I find it important that they wear it, that is why I choose a soft one"* [4]. Less attention was paid to awake bruxism, with only one brief mentioning of giving advices and making the patient more aware of it.

There were plenty of views on the characteristics of materials that can or cannot be used when bruxism was expected. Interviewees preferred wide implants, and if necessary, a bone augmentation should be performed for creating space for a wider implant. A longer waiting period should be kept before loading an implant in an augmented site. As many as possible implants should be placed and neighboring implants should be blocked. The skills of the dental technician were important for the longevity of restorations. Interviewees had different preferences for FDP materials, such as metal occlusal surfaces, monolithic zirconia, lithiumdisilicate, or composite. On the other hand, some argued that in terms of material choice, treatment is the same, regardless of whether or not someone bruxes.

When a RP is made, this should be taken out during sleep. Two interviewees mentioned following a specific pattern when making full RPs in bruxing patients. One strives for a prosthesis design that as much as possible is mucosally supported, so that people will feel pain when bruxing. *"We go as resilient and mucosal supported as possible, so that people will really have pain at the moment they start to grind"* [2]. Another interviewee chose for a prosthesis supported by rigid metal parts and provided with soft artificial teeth. Due to its

metal support the prosthesis will not break, but the teeth are allowed to wear. When worn, the teeth are to be replaced.

3. Communication with patients

Bruxism and its consequences for implant treatments were discussed with patients. Prior to the start of the treatment, patients were informed about the risks for the course of treatment (e.g., superstructures may wear fast), and expectations regarding future needs (e.g., worn denture teeth that may need to be replaced periodically). Patients were also informed that their future dentures need to be taken out during sleep, or on the need to wear a protective splint. By some, all this information was put in a written informed consent.

In order to increase the awareness of patients on their bruxing behavior, interviewees took time for discussion, used intraoral photographs, and had the patients feel the fremitus of their teeth (i.e., the movement of teeth when subjected to functional occlusal forces [12]). By raising awareness, patients might be more inclined to accept possible future complications, not put the blame of their occurrence on the implantologist, and be more compliant with preventive advice given. Some patients are already aware of their bruxism, others are not, but do recognize it after discussion, while some remain reluctant to accept they might be bruxing. *"The art is to make the problem very clear to the patient…there are people that (say) 'I do not grind', but when you show them the (dental wear) facets, then of course they start to see it themselves"* [4].

4. Role of general practitioners

General dentists were the main professionals that refer patients to the interviewed implantologists. Often, they place the superstructure after the implant has been placed by the implantologist. Some interviewees reported that general dentists should pay more attention to proper occlusion and articulation of the superstructure they place, a matter which is often overlooked. Interviewees communicated with the referring dentists, and advised them on matters such as the need for creating canine guidance, the need for protection in the form of a splint, or on material choices. These advices are not always followed, either due to reluctance of the general dentist, or of the patients themselves. *"Then I put in the letter to the dentist to consider placing a splint for the night, which dentists never make, because they think this is nonsense, they say that the patients will not wear it anyhow"* [3]. Furthermore, the general practitioners could play an important role after the implant treatment is complete, by signaling changes in occlusion and articulation during the regular check-ups. What also emerged from the interviews is that general dentists' improper handling of implant

components might, in some cases, be an important source of complications, irrespective of bruxism (e.g., when abutment screws are not tightened properly).

5. Sources of information

Information on which decision-making is based in practice was collected from various sources. Interviewees mentioned postgraduate courses, reading literature, but also their own experience and intuition. Undergraduate education was not referred to as an important source of knowledge. *"Everything that has to do with cantilevers (I do not make)…that is based on my feeling, on nothing else"* [2].

Theme 3: Diagnosis of bruxism

1. Importance of diagnosing bruxism

Opinions about the importance of diagnosing bruxism in the implantologist's practice diverged. At one end, it was mentioned that knowing whether or not the patient bruxes is very important and should be investigated routinely. *"One (dentist) pays more attention to it (bruxism) than the other, and the other pays more attention to other things…I think that it is a part of… you look at several issues: the condition of the dentition, how is it restoratively, caries sensitivity, periodontally, and this is also how you should look functionally, what is someone doing with their dentition"* [7]. At the other end, it was mentioned that bruxism occurs in virtually everyone, and it is not important per se to know if someone is active, but instead to make an effort to understand the multiple reasons of why things (restorations, teeth, etc.) fracture or otherwise fail in the mouth.

2. Diagnostic approaches

It was not a topic of controversy that interviewees used intraoral and extraoral examination, and to a lesser extent patient anamnesis, in order to collect signs and symptoms that indicate the presence of bruxism. There was, however, variability in the signs and symptoms examined. Extraoral examination involved observing the shape of the face and size of visible masticatory muscles, the activity of muscles while talking, and the overall impression that the patient gives, in terms of their temperament. *"The character of people, how they come across, a couple…how they dress, how they present themselves, you can see if they are controlling biters or relaxed people…so that gives me a suspicion"* [2]. Intraoral examination commonly involved looking for tooth wear. Current, or history of, fractured teeth or restorations is important, as well as the presence of many, otherwise unexplained, endodontic treatments and lost teeth. *"Then you look at wear facets and also the teeth that were lost, because the history often tells a whole story, if at one side I have many endodontic treatments and the*

other side not…possibly because the forces on that side were higher" [4]. Teeth may show an increased mobility or fremitus, molars could have furcation problems that are not explained by an overall periodontal disease, and hyperkeratotic cheek lines may be present. A deep anterior bite mentioned being associated with clenching, and a more open bite with grinding. The anamnestic part, where patients are asked whether they recognize bruxism, was not considered trustful, as it was mentioned that many are unaware of their activity, though their bed partners may sometimes be. Temporomandibular joint complaints were sometimes also used as indicators of bruxism. Additionally, some also used their experience and a intuition as aids to detect bruxers.

3. Challenges

Interviewees struggled with some issues when attempting to diagnose bruxism. Intraoral signs and self-report were not considered watertight diagnostic methods. Acquiring a partner-reported diagnosis brought some dentists in an uncomfortable position, since it involved asking patients questions that might intervene into their private life. Another issue that emerged is related to the mere definition of a bruxer, i.e., when is one defined a bruxer and how is the time-variant nature of bruxism dealt with? *"Then the first question is, of course, what is a bruxer, where is the limit, it is a very big grey area, this is the difficult thing about it"* [5].

Theme 4: Improvement of care in the future

1. Role of education

As for which component in the education of dentists could help improve the care for bruxing patients, there was a focus on the importance of proper occlusion and articulation, since it may prevent future complications. Furthermore, general dentists should learn to at least see the signs of bruxism, and to take this into account when planning their treatments. *"I don't know if you can stop bruxing, but I think there should be more attention to in the education, to learn how to see it…if you think that someone is bruxing that you build in a situation in the mouth, that you protect many things a bit more, there has to be more attention for this, it does need some time, but it is the neglected child in the undergraduate dental training"* [4].

2. Role of diagnostic approaches of bruxism

For some, improvement of bruxism diagnostic methods was important, since now some treatment plans are based on a suspicion, rather than a solid diagnosis of bruxism. Having, however, a solid diagnosis should be the basis on which a subsequent treatment plan is built. Also, if bruxism could be objectified, patient compliance with wearing a splint during sleep

could increase. On the other hand, it was also argued that improving the diagnostic methods is not necessary. This was either because the complication rates in bruxers are already very low, or because implant constructions are made as strong as possible, regardless of whether or not someone might be bruxing.

If diagnostic methods were to be improved, their main feature should be simplicity in use. The example of a chair-side screening tool was given, allowing the dentist to track changes of the oral situation indicative of bruxism during the periodic preventive check-up, and guide the decision to use a more thorough diagnostic method. Also, a device that patients could easily use at home, while sleeping, and which could objectify bruxism activity was suggested. *"There should be an objective test indeed (to know) if someone is a bruxer or not, but then you have the very severe ones and the lesser, and the others that do it once per month, and that one every night, it is, I do find it difficult"* [3].

3. Role of treatment approaches of bruxism

There was little focus of implantologists on the topic of actually treating bruxism. Using botulinum toxin for this purpose was considered.

4. Other issues

A number of other ideas regarding improvement of care in the future emerged from the interviews. Though seemingly not closely related, they are grouped together in this last section of the results, since they were not fit for any of the sub-themes above. There was an opinion that future research on the topic is unnecessary. Also, it was argued that good research in this domain will only be possible if there is a clear definition and consensus about who is considered a bruxer. More research about the properties of splints would be welcome, so that their use becomes more evidence-based, rather than experience-based. *"Purely those splints, their shape, what is comfortable for the patient, what is optimal for the patient in terms of protection, because now I do something in an empiric way"* [9]. Finally, it was expressed that if patients were more informed and more understanding and accepting of the fact that bruxism may lead to a number of problems, the dentist's job would become more pleasant.

DISCUSSION

The interviews showed that implantologists had a generally open attitude for performing implant-related treatments in patients with bruxism activity, and even though some complications might be expected, their extent is not such that bruxism is considered a contraindication. A number of studies have shown that bruxism (as diagnosed based on self-report and/or clinical examination, i.e., "possible and probable bruxism") is associated with implant technical and, to some extent, biological complications. [3,13,14]To our knowledge, there is no literature suggesting that bruxism is an absolute contraindication for dental implant treatments. Thus, it seems that both in daily practice and in research, implant complications can be expected in bruxers, and bruxism is not considered a contraindication for implant treatments per se.

Most implantologists had experienced technical complications of the implant-superstructure system, mainly porcelain fractures. This finding is consistent with bruxism-implant literature, [13] and implant technical complication rates in general. [15] Technical complications related to bruxism did not appear to be a largescale burden for the implantologists in emotional and financial terms, but for the individual patient it was reported that this might be the case. In a small scale prospective study, Spies et al. [16] found patient satisfaction with function, esthetics, sense, speech, and self-esteem not to be affected by the occurrence of technical complications. Also, Brägger et al. [17] found that taking care of biological and technical complications was related to low patient costs and visits in single tooth replacements. However, Klinge et al. [18] report that the matter of patient-related implant outcomes is "underexposed in research", with the exception of mandibular overdentures. Taking also into account that bruxing individuals might have had multiple experiences with burdening dental complications prior to the start of the implant treatment, it is suggested that in this population, patient-related outcomes are further investigated.

Prominent controversy appeared to exist on the topic of bone loss and loss of osseointegration, with some implantologists arguing these can be etiologically related to bruxism, while others arguing against such a relation. Controversy on this topic was also found in other studies. Mattheos et al. [19] investigated the attitudes of registered periodontists in Australia and the United Kingdom regarding the etiology of mucositis and periimplantitis. The authors found that 15% of the Australian and 36% of the UK periodontists thought of adverse loading as an etiological factor. The difference between countries was significant. [19] A similar study was carried out by Papasthanasiou et al. [20] in the United States. Here, 71.8% of periodontists

pointed adverse loading as an etiologic factor for periimplant diseases. [20] Though these studies were not specifically attributing adverse loading to bruxism, we can assume that bruxism can be a source of adverse biomechanical loading, therefore the outcomes of these studies are relevant for the bruxism-implant literature. Clearly, a wide diversity of opinions seems to exist not only within, but also between countries. Periimplantitis is most probably the result of the interaction of many risk factors, with the importance of biomechanical overload still being controversial, and in need of further investigation. [18] The abovementioned variety of specialists' opinions within and between countries most likely reflects the lack of unequivocal evidence on the relation between biomechanical loading and bone loss and/or loss of osseointegration, and a possible diversity in dental educational programs. [19] From a patient's perspective, it is not unimaginable that these diverging opinions may create confusion and subsequent distrust for the dental profession.

There were ample, diverging views on which features will lead to better treatment outcomes in bruxers. These included patient information and consent procedures, implant/superstructure material properties, occlusion and articulation patterns, skills of (general) dentists and technicians, post-treatment protection by splint, and post-treatment maintenance. Although variability of views was apparent, there was a general trend to focus on meticulous control of occlusion and articulation of the implant-supported superstructure. Views on the properties of correct occlusion of the implant fixed superstructure with its antagonist(s) varied from no contact at all, to contact only during biting hard in maximal occlusion, to no difference with contacts found in the natural dentition. To our knowledge, no literature exists that provides an evidence-based guideline for superstructure occlusion features, an observation that is not new. [21] Occlusion and articulation can clinically be evaluated, are issues familiar to dentists, and can be modified at low costs, therefore their significance in implantology practice should be further clarified.

As for implant-supported RPs, the general opinion of the interviewed implantologists was that these should not be worn during sleep. This reflects a protective measurement against sleep bruxism, and requires patient compliance. If the prosthesis is not worn during sleep, wear of the mesostructure may occur, though the extent of this issue is not known. There was barely any mentioning of measurements that aimed to protect specifically from awake bruxism. Two interviewees described their approach for bruxist RP wearers. One preferred making the RP as mucosally supported as possible, so that pain will be felt when bruxing, an approach that may be helpful in cases of awake bruxism. This follows the rationale of 'aversive conditioning', i.e. "the process in which an unwanted behaviour is paired with a noxious or unpleasant

stimulus, with the intention to reduce the undesired behavior". [22] The aversive conditioning approach has been discussed in bruxism literature, in the form of biofeedback techniques for the management for both awake and sleep bruxism. [23] To our knowledge, there is no evidence to support the effectiveness of this approach in implant dentistry. Mucosal pain was provoked in both conventional as implant-supported RPs during maximum bite force in the study of Fontijn-Tekamp et al., [24] though the conventional RP group presented significantly more pain than the implant-supported group. We were not able to obtain literature on the relation between bruxism and mucosal pain in implant-supported RP wearers. However, pain in the underlying soft tissue of conventional denture wearers was related to awake bruxism in the study of Piquero and Sakurai. [25] The authors selected suspected awake bruxists based on soft tissue pain complaints, especially in the afternoon. They found that this group presented significantly more masseter muscle EMG activity that the control group (i.e., denture wearers without pain) during rest, and suggested that identifying awake bruxism is of great importance for the success of subsequent treatment of denture wearers. [25] Similarly, Kumagai et al. [26]showed that awake bruxism, as well as other factors (such as age, number of missing teeth, mucosal condition, mucosal damage, bone prominence) is an independent predictor of intensity and frequency of mucosal pain in the denture-bearing area of patients with partial removable dental prostheses. It would be of interest to investigate whether awake bruxism is related to mucosal pain in implant-supported RP wearers, and if so, if this mechanism can be used in treatment planning following the aversive conditioning paradigm. Meanwhile, we suggest that the clinician keeps an open eye for the possibility that otherwise unexplained mucosal pain complaints might be related to (undetected) awake bruxism, and/or sleep bruxism, if the RP is worn during sleep.

In cases of a full upper RP against a fixed dentition in the lower jaw, another implantologist argued for making a rigid, metal reinforced base with soft artificial teeth. This way, the RP will not break under occlusal loading, but will rather be subject to wear and subsequent replacement of the artificial teeth. The implantologist mentioned high patient satisfaction with this approach. Clinical cases of protecting an implant-supported RP with metal parts from fractures have been published. [27,28] In a 5-year prospective case series study, Boven et al. [29] found acceptable/good outcomes in terms of implant survival, peri-implant bone level, probing depths, and peri-implant plaque, calculus, and bleeding indices for maxillary implant-supported overdentures opposed by (partial) natural dentitions, with the overdentures fabricated in a similar way as the implantologist described above. The authors also report good patient satisfaction at the end of the follow-up period. [29] Thus, it is plausible that this is an effective treatment concept for the edentulous maxilla vs. (partially) dentate

mandible, but the matter has not been researched in bruxing samples. We suggest that this be a topic of future research.

Skills of the dentist (e.g., in handling of implant components, such as tightening of screws) and of the dental technician (e.g., in designing the anatomical features of superstructures) involved in the treatment of the bruxer were repeatedly mentioned in the interviews as factors contributing to the success and complication rates. These factors have also emerged in other literature. In the study of Papathanasiou et al., [20] improper design of implant-supported restorations (i.e. a dentist and/or dental technician responsibility) was, among others, reported by registered periodontists in the United States as a possible etiological factor of periimplantitis. Similarly, on the topic of periimplantitis, Dawood et al. [30] report that "peri-implantitis may be more frequently encountered when planning is poor, restorations are poorly designed and manufactured, implants and implant components are poorly engineered, and surgery poorly executed". Heitz-Mayfield et al. [31]report that, for the prevention of implant technical complications, careful treatment planning and handling of implant components is recommended . Spies et al. [16] suggest that the more severe fractures of veneering ceramic of zirconia-based implant FDPs observed in their study "might be considered manual errors and not directly correlated with the composition of the veneering ceramic or the layering technique" which, according to the authors, points to the importance of even the smallest omissions of the dentist or dental technician. [16]

Post-treatment protection of the implant-superstructure complex during sleep by an occlusal splint was a standard advice by some, but not all interviewed implantologists. It makes logical sense that if the occlusal forces exerted when bruxing directly on the superstructure, and through this to the underlying implant, are responsible for subsequent complications, then placing a device on top of the superstructure that works as a wave breaker should solve many problems. This approach is commonly advised by expert opinions. [4,32,33] However, the concept of the protective splint is not only not scientifically proven, but is seriously under-researched. [34] As for the risks of wearing an occlusal splint, some precaution may be justified in patients suffering for obstructive sleep apnea (OSA), since it has been reported to aggravate their OSA condition. [35] In other cases, though, having a patient wear a properly designed occlusal splint is not known to be able to cause any irreversible health damage. Therefore, the "better safe than sorry" approach currently followed is not to be blamed. However, if a splint in reality has no preventive value, then patients are confronted with unnecessary costs and the burden of having to be compliant with wearing it. Scientific evidence not only on the effectiveness of this intervention, but also on the features the ideal protective splint should have (in terms of

material, thickness etc.) is therefore necessary.

Several of the implantologists interviewed in this study mentioned the need for control of the occlusion and articulation features during the regular preventive check-ups at the general dentist (in the Netherlands, it is common practice that these check-ups take place every 6-12 months). This recommendation is driven by the thought that the occlusion changes over time, due to tooth wear and/or slight movements of the teeth. The implant borne prosthesis will not move and is likely not to wear in exactly the same manner as the rest of the dentition, therefore might come in the position of unwanted occlusion and articulation. The same recommendation is also found in literature. Maintenance appointments with monitoring of the occlusion are suggested by Heitz-Mayfield et al. [31] and Dawood et al. [30]

In our sample, bruxism is mainly diagnosed by clinical extra- and intraoral examination, and to a lesser extent by patient anamnesis. Literature suggests starting with patient anamnesis (i.e. self- and/or partner report) in order to assess the likelihood of a patient bruxing, [2] i.e., set the diagnosis of possible sleep bruxism. [1] It seems that in everyday practice implantologists tend to rely more on their clinical examination and tend to give little weight to what literature suggests should be the first diagnostic step in bruxism diagnosis. This may be explained by the fact that in everyday practice, experience has taught dentists that self-reported bruxism is of little validity, which is widely accepted in literature too. [2] The relation between anamnestic bruxism and a diagnosis based on anamnesis plus clinical examination has been subject of investigation, [36] and the concept of a graded bruxism diagnosis is already under revision since it was first published. [37] The results of our study indicate that clinical examination for signs of bruxism may be more accepted and recognized by dentists for use in everyday practice. This also highlights a difference between the research and clinical practice world: if studies would use more clinical signs to diagnose bruxism instead of self-report, their results might be more translatable for everyday practitioners.

No uniform way to clinically diagnose bruxism evolved from the interviews. This might be related to the fact that even though standardized questionnaires do exist for assessing self-reported bruxism (e.g., Oral Behaviors Checklist; [38] the BRUX scale [39]), this is not the case for a clinical diagnosis. Meaning, recommendations are given to look for clinical signs (such as impressions in lips, cheeks, tongue, tooth wear etc.) [1,2,40], but no standardized form or index exists in which dentists can score these signs (e.g., modified bleeding index [41]). This allows for subjective interpretations of which clinical signs to look for. Furthermore, an intuition-assisted diagnosis was not uncommon among the interviewed implantologists.

Intuition is considered a key characteristic of clinical expertise, acquired by extensive learning. [42] However, an intuitive diagnosis may not directly be considered valid. [42] Such a diagnosis will rely on clinical suspicion, which arises when the clinician recognizes certain illness patterns. [42] In low back pain literature, a "strong clinical suspicion" has recently been reported as having acceptably high diagnostic accuracy as a red flag for malignancy. [43] We were not able to retrieve literature mentioning such a specific manner to diagnose bruxism. Therefore, we suggest that the extent of using this approach in bruxism diagnostics, and its validity be further researched.

Implantologists faced challenges related to the vagueness of the label of "who do we consider a sleep bruxer". The issue of not everyone bruxing every night and not in the same intensity, i.e., the time-variant nature of bruxism, was acknowledged. This has also been a topic of scientific research. [44,45] Sleep bruxism diagnostic criteria have been established for PSG studies. [46] These criteria are, however, not quite useful for daily practice, not only because PSG is unavailable in such a setting, but also due to the above-mentioned fluctuation in sleep bruxism activity over time. We suggest that practitioners might be more helped if a diagnostic method existed that could identify the intensity of bruxism in a simpler manner, such as portable, user-friendly, single-channel EMG devices.

As for the mere importance of diagnosing bruxism, even though it was generally considered valuable to look for signs of bruxism, the significance of such diagnosis was questioned by the argument that there are more, and maybe more important, reasons why implantological complications occur, and dentists ought to learn and be aware of them. Thus, practitioners seem not to attribute most of implant complications to bruxism. Literature suggests that the presence of bruxism may increase both implant failure rates, as the rates of implant technical complications, though other factors (e.g., material-related) may also play a role. [47] In their retrospective study, Chrcanovic et al. [48] included 1406 patients who had received 3 or more implants in the course of 34 years (a total of 8337 implants), and investigated cluster behavior in implant failure (i.e., a patient having at least three dental implant failures) and related risk factors. Based on their analysis, the authors suggest that a cluster pattern among patients with implant failure is highly probable. Possible/probable bruxism emerged as an important risk factor for cluster failures, both at the patient (OR 6.376) and the implant level (OR 5.2). Other potential risk factors also emerged from this study (shorter implants, turned implants, poor bone quality, age of the patient, intake of antidepressants and of medicaments to reduce gastric acid production, and smoking). [48] Taking the observations of the interviewed implantologists and the abovementioned literature into account, the picture

arises that in daily clinical practice, bruxism is considered less of a problem than in published data. The nature of our study, i.e., qualitative and not quantitative, allows for documentation of the opinions and attitudes of practitioners, but not for quantification of the extent in which they have actually dealt with, for example, bruxism-related complications. Therefore, our results are not directly comparable with those of other bruxism-implants literature. When attempting to use published literature as a basis, and the experiences of our interviewees as inspiration, we consider it plausible that: a) bruxism is related to mechanical complications and implant failures, but b) other risk factors do exist and an interaction with bruxism is likely, and c) there may be a "high risk" group of patients, in which bruxism, with or without the presence of other risk factors can be expected to cause more complications.

Additionally to what has been mentioned so far, we would suggest that in future research:

- the generic term of "bruxism" is avoided and the circadian manifestations, i.e., awake and sleep bruxism are considered separately,
- a simple, chair-side, standardized tool is designed to diagnose sleep and awake bruxism at the possible/probable level in both research and clinical settings, as to make future research comparable and facilitate homogenous clinical practice,
- efforts are made for the design of user-friendly, and valid devices that will allow for a definite level of sleep and awake bruxism diagnosis in large scale cohorts. The focus should not only be on the question if there is bruxism activity, but also on other aspects, such as type, intensity, and time-intervals of activity, [49]
- the interaction between known risk factors for implant-superstructure complications is further investigated, as well as the possibility that risk profiles may exist both at the implant and the patient level, and
- special attention is given to the investigation of the effect of bruxism on bone loss and loss of osseointegration, since opinions in this field are highly divergent.

Several limitations of this study, and the measures taken to counter them, should be discussed. The prior development of domains, though on one hand valuable for the conduct of the study, [9] may on the other have been a source of bias, in terms of luring the interviewer to pay more attention to the discussion of these domains with interviewees, and not allowing for sufficient elaboration of new topics. Also, it could be possible that, to some extent, the interviewer's own professional attitudes and experiences with the management of bruxism shaped not only the acquisition, but also the interpretation of data. [50] In order to eliminate these undesirable influences, several measures were taken. There was a strong preference for open-ended questions, as to avoid guiding interviewees' answers. However, in some

instances this was not possible. For example, when the use of occlusal splints was discussed, the question "What sort of splint do you prefer?" was often asked. Though seemingly open-ended, the answer to this question would be either "hard" or "soft", since these are the two types of occlusal splints mainly used in The Netherlands. Thus, this should be considered a closed-ended question. Furthermore, the interviewer made a careful effort to retain the role of a 'curious listener', by being alert for newly occurring concepts or ideas, and by exploring them further by asking appropriate probing questions. Interview questions were formulated in a neutral way, avoiding criticism on interviewee professional attitudes. In this aspect, though experienced in the field of bruxism, the interviewer is not clinically active in the field of oral implantology, a fact that was discussed with all interviewers prior to the start of the interviews. Thus, between interviewer and interviewees, there was no issue of comparing, nor judging of implantological treatment choices. As for issues related to bruxism, e.g. the diagnosis, the professional background of both the interviewer (MT), as the second investigator analyzing the data (AR), might have had some influence in the interpretation of the data. In order to minimize this influence, a systematic, line-by-line analytic approach was maintained, and care was taken not to over- or underemphasize any topic emerging from the interviews.

Certain issues regarding the sample characteristics should be mentioned. First, the all-male sample of this study was interviewed by a female investigator. It is unknown if this gender difference might have influenced the conduct of the interviews, or the interpretation of the data. [7] Second, only nine, out of 169 initially approached, oral implantologists were included in this study. There was a very high number of invited oral implantologists who did not respond to the call for participation, possibly due to limited available time for participating in an interview. It is unknown if the oral implantologists that were eventually included in this study are different from their peers, in terms of professional experiences and attitudes. Sampling in this qualitative study continued until saturation of data was achieved, i.e. until no new topics emerged from the interviews. Two extra interviews were conducted as to confirm this saturation, and thematic analysis provided a rich pallet of themes. If further investigation of the experiences and attitudes of oral implantologists is desired, the themes that emerged from this study could form a basis for the design of a quantitative study. An example hereof would be an online, questionnaire-based study, which could be less time-consuming for practicing oral implantologists, and may therefore acquire a larger sample size.

Finally, in this sample of nine oral implantologists, three reported not having followed any postgraduate education in the field of bruxism, in the five years prior to the conduct of the interview. The type and extent of continuing education might influence the attitudes and

treatment choices of practitioners. [19] Concepts about the nature of bruxism, i.e. it being or not a pathological condition, as well as it's diagnosis, are evolving. [37] Therefore, it is suggested that ongoing education on this topic would be utterly beneficial for helping oral implantologists in handling based on state-of-the-art knowledge, and should be included in postgraduate educational resources.

CONCLUSION

The findings of this study suggest that treating bruxing patients with dental implants in the practices of accredited oral implantology specialists in The Netherlands is generally well-accepted. Complications can occur, and treatment planning should be careful, but bruxism is not considered a contraindication for implant treatment. Variability appears to exist in attitudes and opinions regarding bruxism diagnosis, the mechanism of biological complications and treatment planning approaches. The most divergent attitudes and opinions are those related to the associations between bruxism, bone loss, and loss of osseointegration.

DECLARATION OF INTERESTS

F. Lobbezoo is a member of the Academic Advisory Board of Sunstar Suisse SA and has no financial interest in this company. The other authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. Sunstar Suisse SA provided financial support for this study via a research grand to ACTA. M. Thymi is a PhD student at ACTA, whose salary is being provided through the abovementioned research grant. All other authors receive their salaries from their country's government. Sunstar Suisse SA is not involved in the design of this study, nor in the collection, analysis, and interpretation of data, and writing of this manuscript.

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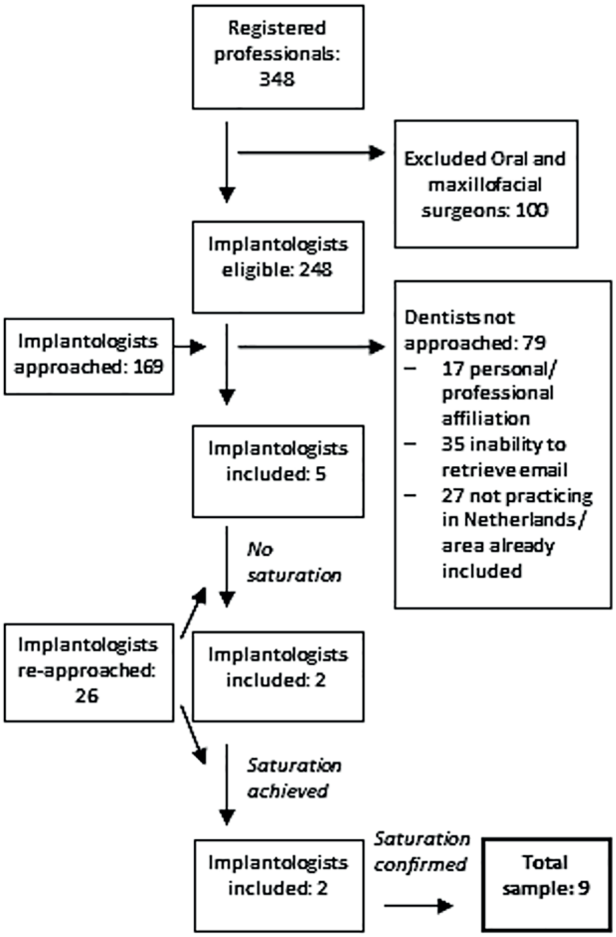

Figure 1. Inclusion flowchart

Table 1. Main domains included in topic guide

1	Feasibility of, and experiences with implant dentistry in bruxing patients
2	Attitudes regarding the features of an implant treatment plan in bruxing patients
3	Attitudes regarding the diagnosis of bruxism in the clinic
4	Attitudes related to scientific research in the field of implant dentistry and bruxism

Table 2 Sample characteristics

Total sample size	9
Male/female	9/0
Mean (range) years of practicing dentistry	23 (10-31)
Mean (range) years of being an accredited oral implantologist	10 (2-18)
Approximate number of implant borne superstructures placed per year	10-50: 1 participant ≥ 50: 8 participants
Number of participants having followed postgraduate education in the field of oral implantology in the past 5 years	9
Number of participants having followed postgraduate education in the field of bruxism in the past 5 years	6

Table 3. Main themes, subthemes and summary of experiences and attitudes

1. Bruxism and implant treatment outcomes
1. General attitude about impact of bruxism on oral health
Bruxism is damaging (wear, endodontic treatments, tooth loss, fractures, pain or limitation of movement) Without pain function is not impaired Occlusion/articulation are important mediators for damaging effects
2. Feasibility of implant dentistry in bruxers
Positive attitude: implants are possible, bruxism is not a contraindication (unless there is pain, some precautions needed, it can even help distribute forces better, better than conventional porcelain) Negative attitude: clenching can be dangerous, possible, but with uncomfortable feeling for dentist
3. Encounters with complications
Variation in attitudes: Occurrence of complications: never, there is always something, real bruxers will break everything, no control over when it goes well/sometimes miraculously well, no complications until occlusion changes over time due to wear of all teeth except the implant-borne restoration Type of complications: usually chipping of porcelain, wear or fracture of FP, wear or fracture of mesostructure, wear of antagonists or problems with antagonistic porcelain, fractures of screws, fractures of implants, bone loss Bone loss: not possible, only after infection, independent of infection Loss of osseointegration: possible, impossible
4. Mechanism of complications
Bone loss/loss of osseointegration: a) Excessive loading can lead to bone loss, which can be followed by bacterial invasion, ultimately leading to periimplantitis b) Inflammation pre-exists and subsequent overload can lead to more profound bone loss c) Load can cause micro-movements of the implant in the bone, which can lead to loss of osseointegration, d) Load can cause loss of osseointegration, only if this was poor already e) Peri-implantitis occurs mainly due to other reasons (e.g. wrong placement of implant, cement remnants) f) Uncertainty about form of relation Other complications: inattentiveness of dentist (tightening of screws, occlusion, etc.), materials, wear and subsequent change of occlusion over time, bad starting point (e.g., after periimplantitis treatment), technician
5. Consequences and treatment of complications
Chippings: usually not very troublesome, investigate cause Finances: reparation under warranty, pain less with cheaper materials, burden for practice is low Emotional: irritation for patients, blame on dentist, burden not high for dentist Practical issues: immediately new implant after removal of fractured one, harder suprastructure materials may lead to other, deeper problems, time investment

2. Treatment aspects of implantological interventions
1. Assessment of patients
Thorough investigation of signs of function in every patient from start of therapeutic trajectory Understand why fractures occurred in the past History/knowing the patient/intuition helps Make intraoral pictures and discuss them with patient
2. Treatment features
Occlusion, various views: only when biting hard in maximal occlusion, out of occlusion, can make contact, maybe out of contact, check at preventive check-ups Articulation: no contact if lateral forces are anticipated, strive for front- and canine guidance, maybe out of articulation, check at preventive check-ups Protection: a) Splint: is important, not so much b) Splint material: soft splint gives more compliance, hard splint is less comfortable, hard splint is comfortable, c) Splint design: should allow freedom of movement, thin d) Advices and awareness regarding bruxism during the day Materials/technical issues, variety of views: diameter, strength, number of implants, implants blocked, bone augmentation, occlusal pattern, material of crowns, technician skills, informed consent, advices to referring dentist Removable prosthesis: a) Concept A: as much as possible mucosally supported so that pain is felt when bruxing, bite not too high, lingualized bilaterally balanced occlusion b) Concept B: strong basis with soft teeth, teeth wear and are replaced, basis does not break c) Taken out during sleep
3. Communication with patients
Discuss beforehand: risks/expectations, protection, FP out during sleep, written informed consent Awareness of problem: pictures, feel the fremitus, discussion in order to increase acceptance, so that blame will not be put on dentist, increase compliance with advices, some are already aware Discussion may come across with denial or intervention with private issues.
4. Role of general practitioners
Important for longevity of implant-supported restorations Should pay more attention to occlusion and articulation when placing suprastructure Role of preventive check-ups for early detection in occlusion and articulation changes Communication about materials/protection/advices for canine guidance Complications due to improper implant component handling
5. Sources of information
Literature, courses, undergraduate education Experience, intuition

3. Diagnosis of bruxism
1. Importance of diagnosing bruxism
Very important, should be part of routine
It would be nice to know
Not per se recognizing bruxism, but in general being able to discover the cause of failures is important
2. Diagnostic approaches
Extraoral examination: shape of face/muscles, activity of jaw, general appearance/temper
Intraoral examination: tooth wear, presence or history of fractures, endodontic treatments, mobility, furcation problems, cheek lines, lost teeth, type of bite (deep/open)
Anamnesis: self-report, partner report, temporomandibular joint complaints
Other: “a feeling”, knowing the patient, experience
3. Challenges
Uncertainty about diagnosis:
Importance of intraoral and extraoral signs? (validity)
Importance of self-report? (patients not aware, denial for the sake of not taking responsibility/financial aspects, privacy issues)
What is the definition of a bruxer, how do you know if someone is currently active
4. Improvement of care in the future
1. Role of education
Attention of general practitioners for occlusion and articulation, learn how to see signs of bruxism and take it into account during treatment planning
2. Role of diagnostic approaches of bruxism
It is important: treatment should be based on good diagnosis, improve compliance of wearing protective splint, difficult since bruxism can fluctuate, simple chair side tool, device for home, referral clinic for extreme cases
Not important: complications mainly due to infection, constructions already strong enough for everyone (bruxers and non-bruxers)
3. Role of treatment approaches of bruxism
Does not seem to be an important issue for implantologists, but maybe for dentistry in general
Use of botulinum toxin
4. Other issues
Define who is a bruxer
Information brochures regarding bruxism/more understanding from patients
Other/improved materials
No reason for further research
Splint features

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Chapter 5

Associations between sleep-bruxism and (peri-) implant complications: a prospective cohort study

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ABSTRACT

Objectives

To describe the protocol of a prospective cohort study designed to answer the question: 'Is sleep bruxism a risk factor for (peri-)implant complications?'.

Methods

Our study is a single-centre, double-blind, prospective cohort study with a follow-up time of 2 years. Ninety-eight participants fulfilling inclusion criteria (planned treatment with implant-supported fixed suprastructure(s) and age 18 years or older) will be included. Sleep bruxism will be monitored at several time points as masticatory muscle activity during sleep by means of a portable single-channel electromyographic device. Our main outcomes are biological complications (i.e., related to peri-implant bleeding, probing depth, marginal bone height, quality of submucosal biofilm and loss of osseointegration) and technical complications (i.e., suprastructure, abutment, implant body or other).

Results

The study is currently ongoing, and data are being gathered.

Discussion

The results of this prospective cohort study will provide important information for clinicians treating bruxing patients with dental implants. Furthermore, it will contribute to the body of evidence related to the behaviour of dental implants and their complications under conditions of high mechanical loadings that result from sleep bruxism activity.

Conclusion

The protocol of a prospective cohort study designed to investigate possible associations between sleep bruxism and (peri-) implant complications was presented.

INTRODUCTION

Implant treatment complications

Treatment with dental implants is one of the important options for patients with a partially or completely edentulous jaw. Dental implants are installed in the jawbone, and a firm, intimate, and lasting connection between implant and bone can be created (i.e., osseointegration). [1] A systematic review with meta-analysis showed high 5- and 10- year survival rates of implant-supported fixed prostheses (95.2% and 86.7%, resp., for fixed dental prostheses; 94.5% and 89.4%, resp., for single crowns). [2] However, despite these high survival rates, the same systematic review also reported a frequent occurrence of various types of implant treatment complications (up to 38.7% 5-year complication rate for fixed dental prostheses). [2]

Complications of the implant-suprastructure complex can be biological or technical. [3] Biological complications affect the peri-implant soft tissues and bone and are defined by pocket-probing depths, bleeding and/or suppuration on probing, and marginal bone loss over time. [2] Technical complications affect the mechanical integrity of the implant and suprastructure components and can be defined into major, such as implant fracture or loss of the prosthesis; intermediate, such as abutment fracture, abutment screw loosening, or veneer fractures; or minor, such as loss of retention of the prosthesis, loss of screw hole sealing, or chipping of veneering material. [4]

Reporting implant complications is valuable when assessing success of the implant-suprastructure complex as a whole, because, unlike single outcomes such as marginal bone loss or soft tissue parameters, it provides a more comprehensive picture of the total treatment outcome. [5] Clinical and radiographical evaluations of implants and their suprastructures are generally considered to be important for detection of early signs of these implant complications. [6]

Sleep bruxism

Sleep bruxism has recently been defined as a repetitive jaw-muscle activity characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible during sleep. [7] It is suggested that jaw-muscle contractions are a natural activity during sleep, and that sleep bruxism episodes are observed in most individuals. [8] Up to 37% variability in sleep bruxism outcome measures has been reported in sleep bruxers, [9] suggesting that sleep bruxism has a time-variant nature.

Polysomnography with audio-visual recordings (PSG-AV) is necessary in order to achieve a definite diagnosis of sleep bruxism, [7] according to established cut-off criteria. [10] However, this technique is costly and often impractical to perform, leading to the use of less accurate methods for diagnosing sleep bruxism. In clinical practice and research settings, this involves self-report instruments, clinical examinations, and electromyographic (EMG) recordings of masticatory muscle activity during sleep. [7,11]

Epidemiological studies based on self-reports have found that approximately 12.8 % of the adult population reports "frequent" sleep bruxism. [12] To date, only a single study assessed the prevalence of sleep bruxism based on PSG recordings and the above mentioned cut-off criteria in a large population sample. [13] Based on single-night PSG recordings, the prevalence of sleep bruxism in an adult population was 7.4%, regardless of self-reported bruxism complaints. [13] In the future, studies implementing diagnostic methods capable of capturing the time-variant nature of sleep bruxism should lead to more accurate figures about the prevalence of sleep bruxism. [9] Prevalence data based on sound criteria are important. However, the clinician interested in the consequences of sleep bruxism should be aware that, even individuals who, after one or several PSG recordings, would not officially be characterized as sleep bruxers, can present (mild) bruxism activity during sleep. [14]

Sleep bruxism and implant treatment complications

Sleep bruxism is considered an important source of loading applied to implants and their suprastructures, and it is a longstanding concept that sleep bruxism can lead to biological and technical complications. [3] Two recent systematic literature reviews point towards the notion that bruxism can contribute to the occurrence of mainly technical failures of implant treatments, [15,16] while there is no sound evidence that bruxism is related to biological implant complications. [15]

However, a causal relationship between sleep bruxism and (peri-)implant complications has not yet been demonstrated. [15,16] This lack of sound evidence is the consequence of mainly two factors. First, up to the present time, there is no study with the specific design to assess the effect of bruxism on dental implants. Studies that have included bruxism as one of the factors contributing to complications show a large variation in terms of both the technical and the biological outcomes of implant treatments, so that their comparability is compromised. [15,16] Second, there are issues regarding the internal validity of those studies, such as an inadequate distinction between sleep and awake bruxism, and insufficient diagnostic approaches of sleep bruxism. [3,15,16] Based on the assumption that sleep bruxism can lead to complications,

clinicians are so far instructed to be cautious, and are guided by expert opinions regarding practical aspects of implant treatments in patients with (suspected) bruxing behavior. [15] These guidelines include advices on implant and suprastructure characteristics, such as the number, length, and diameter of implants, the material of the suprastructure, and the occlusion and articulation patterns. [3] Expert opinions represent the lowest grade of evidence and cannot, therefore, fulfill modern clinicians' needs for evidence-based decision making.

The lack of high-level evidence also affects researchers, since suspected bruxism is often – but not always – an exclusion criterion in studies concerning the outcomes of dental implant treatments. [3] Consequently, the populations in such studies may significantly differ from each other, which undermines the ability to compare their outcomes in an unequivocal way. Furthermore, if sleep bruxism proves indeed to have detrimental consequences for the success of implant treatments, it is an important factor to be considered when designing relevant studies.

Mechanical loading and biological parameters

Clinical studies, literature reviews, and expert consensus papers [17–19] report that formation and maturation of a microbial biofilm around an implant is an important etiologic factor in the pathogenesis of the peri-implant infectious diseases "mucositis" (i.e., inflammatory process in the mucosal tissue) and "peri-implantitis" (i.e., inflammatory process additionally characterized by marginal bone loss). Submucosal biofilm associated with these diseases has been reported to present low species diversity, with fewer numbers of bacterial species found around diseased implants, compared to the biofilm found around healthy implants. [20] Other factors related to the occurrence of peri-implant disease include smoking and a history of periodontitis. [21]

Based on current literature, it is not fully known whether and how mechanical implant loading contributes to peri-implant tissue complications (i.e., inflammation and bone loss). Several clinical studies [22,23] suggest that high mechanical stress, exceeding the biological load-bearing capacity of an osseointegrated oral implant, [24] is associated with loss of marginal bone or even loss of the osseointegration around the implant. More recently, a review on animal studies found differences in the histological features between plaque- and overload-induced peri-implant bone loss. [25] However, as yet, causative relationships between mechanical loading and peri-implant biological complications have not been established, due to a general lack of clinical studies with an appropriate design to assess the effect of excessive loading on dental implants, [26] and poor definitions of the loading conditions (e.g., poor approaches to diagnose parafunctions such as sleep bruxism). [15]

It remains unclear if, and to what extent, loading and microbial factors interact in the process of peri-implant tissue destruction. [24] Animal experimental data suggest that high loading of clinically stable dental implants is associated with marginal bone loss in the case of inadequate plaque removal, while when plaque control is sufficient, this loading might lead to an increase of bone density around the implant. [27] Additionally, data revealing unique and unsuspected microbial communities around failing implants have recently been presented, [20] while sparse human clinical data suggest a possible different microbial profile between implants failing due to mechanical overload, as compared to implants failing due to peri-implant infection. [28,29] However, thus far, research supporting these suggestions is not conclusive. [30] Investigating the time-dependent associations between mechanical forces (such as those attributed to sleep bruxism), the composition of microbial communities, and host response will enhance our insight into the pathogenesis of peri-implant disease.

Objective of the present study

To contribute to the understanding of the time-dependent associations between sleep bruxism and complications of dental implant treatments, we aim to perform a prospective cohort study. Our main aim is to answer the research question: "Is sleep bruxism a risk factor for (peri-)implant complications?". Sleep bruxism will be monitored by measuring masticatory muscle activity during sleep. The investigation will have two main outcomes, namely technical complications and biological complications. As to avoid variation in the outcomes caused by failing retention of removable suprastructures, we will confine our study population to patients treated with fixed suprastructures.

The following null hypotheses are formulated: 1) Sleep bruxism is not associated with the occurrence of technical complications. Outcomes of interest are: suprastructure complications, abutment complications, implant fractures, or other technical failures (see "Variables" paragraphs for a more comprehensive description of all variables), and 2) Sleep bruxism is not associated with the occurrence of biological complications. Main outcomes related to this hypothesis are: differences in marginal bone height, peri-implant bleeding on probing, pocket depths, and loss of osseointegration.

Our secondary aim is to examine whether there is an association between sleep bruxism activity and the composition of peri-implant submucosal biofilm. For this purpose, the null hypothesis is: Sleep bruxism is not associated with species diversity of peri-implant submucosal biofilm. The main outcome will be peri-implant submucosal microbiome diversity.

Study design

The study has a prospective, double-blind design and will be performed in the Academic Centre for Dentistry Amsterdam (ACTA), in The Netherlands. Aimed duration of the study is 3 years: one year sampling period and two years of follow-up. Participants of the study will receive one or more dental implants, which will be loaded with a fixed dental prosthesis for replacement of one or more lost teeth. Baseline assessment (T_1) of each participant will take place after the healing period of the implant(s), at the appointment of taking the impressions for the prosthesis. Afterwards, assessments will take place within a follow-up period of two years at pre-fixed time intervals (two weeks; T_2, six weeks; T_3, three months; T_4, twelve months; T_5, and 24 months after baseline; T_6, see Table 1). These assessment intervals match those of the regular clinical procedures at ACTA, with the exception of T_3, which represents an additional examination. Recurrent ambulatory EMG recordings for the diagnosis of sleep bruxism will be performed by the participants in their home environment at T_1, T_3, and T_5. Clinical measurements will be performed by one examiner (MT) at ACTA. This examiner, as well as the participants, will be blinded for the main predictor of the study, i.e., sleep bruxism diagnosis based on EMG recordings.

MATERIALS AND METHODS

Ethical considerations and registration of study

All study procedures are performed according to the guidelines issued in the Declaration of Helsinki. Approval of the research protocol by the Medical Ethical Committee of the Vrije Universiteit Amsterdam was obtained (METC – VUmc ref.: 2011-245). The Dutch Healthcare Inspectorate (DHCI) acknowledged that the obligation for notification of the DHCI prior to the start of the clinical investigation was fulfilled. The research is included in the Netherlands Trial Register (Trialregister.nl, ref. no.: 4930) and is registered at the US National Institutes of Health (ClinicalTrials.gov Identifier: NCT02410681). Extensive documentation of all standard operating procedures is performed, following ISO 14155.2011 criteria. Collected data will be digitally stored using ALEA® Data Management- version 4 (ALEA® Data Management, FormsVision, The Netherlands). ALEA® provides online data management tools for use in clinical trials and enables tracking of all changes made to previously inserted data.

Participants

Participants will be enrolled in the study if they fulfil the inclusion and exclusion criteria, agree to participate, and sign the informed consent form. Participants will be recruited from

the clinic of the department of Oral Implantology and Prosthetic Dentistry of the ACTA. This department treats patients situated in the greater Amsterdam area. Inclusion criteria are: a planned treatment with implant-supported fixed suprastructure(s) and age 18 years or older. Exclusion criteria are: opposing teeth of implant-supported fixed suprastructure(s) are restored with removable artificial teeth; patients categorized in the classes 3 or higher according to the American Society of Anesthesiologists (ASA) system for classification of physical status; [31] use of an occlusal splint, mandibular repositioning appliance, or any other bruxism mitigating device during sleep; active periodontitis at the time of implant placement; known allergy to the EMG device electrode material; usage of a pacemaker; and swollen, infected, or inflamed tissues or skin eruptions, e.g. phlebitis, varicose veins etc. in the placement area of the EMG device electrode. Pregnant women will not be treated with dental implants. Pregnancy after placement of implants will not be a reason to stop participation of the subject in the study.

All patients of the clinic of Oral Implantology and Prosthetic Dentistry for which one or more implants are planned will be screened for fulfilment of the inclusion and exclusion criteria and willingness to participate in a clinical study. Eligible patients will be thoroughly informed about the study, upon which they will be given one week time to consider participation. Written informed consent will be obtained prior to enrolment of a patient in the study. Participation is voluntary and can be withdrawn at any time, without consequences for the course of treatment.

Sample size

To analyze the association between predictors and outcome variables for both our main aim and our secondary aim, multilevel regression analyses will be used. [32] Therefore, we will use the suggested formula '50 + 8k (k; number of predictors)' for calculation of our sample size. [33] Based on that formula, this study (with 6 predictors) will need a minimum sample size of '50 + 48 = 98' participants.

Variables

An overview of the time points at which each variable is assessed is provided in Table 1.

Main predictor

Sleep bruxism (SB)

Sleep laboratory polysomnographic recordings with simultaneous audio-visual recordings (PSG-AV) together with self-report and clinical examination are currently considered to lead to a definite diagnosis of sleep bruxism. [7] PSG-AV recordings enable quantification of

SB-specific muscle activity, i.e., rhythmic masticatory muscle activity of masseter and/or temporal jaw muscles, as well as exclusion of non-SB-specific muscle activity, e.g., swallowing and scratching. [34] However, it is difficult to use the PSG-AV for large sample studies due to feasibility and financial considerations. [35]

As alternatives to PSG-AV, various types of ambulatory recorders of masticatory muscle activity have been developed. Those have the obvious benefits of a natural home setting and low costs, and have been used in clinical studies, although specificity of the SB-specific muscle activity assessment remains a limitation. [35] Therefore, muscle activity assessed with ambulatory recorders is considered a proxy for a SB diagnosis.

In our study, SB is assessed by measuring the electromyographic (EMG) activity of the right temporal muscle during sleep with an ambulatory EMG-recorder (Grindcare®, version 3+ DL, Delta Danish Electronics, Light & Acoustics, Denmark), at the home setting of the individual. [35] Grindcare® is a device designed for the management of sleep bruxism and consists of a sensor (the portable unit which registers EMG activity and can be attached to the individual's clothing) and the electrode (which attaches to the skin over the temporal muscle and is connected with the recording device by a wire). It can detect and record muscle EMG activity and issue a weak electrical stimulus on the skin, aimed at eliminating bruxism activity. For the purposes of this study, the issue of electrical stimuli is turned off and the device is used in its diagnostic mode. Within the Grindcare® 3+ DL device, the EMG signal is amplified 808 times and band-pass filtered between 200 and 650 Hz. The signal is then converted by an analog-to-digital converter within a range of 0 to 1,5 Volt and stored on a microSD card, from which it can be transferred and stored on a personal computer for further analysis. There are three sessions of sleep recordings (T_1, T_3, and T_5), each consisting of three consecutive nights. The first session will start at the day of the baseline measurements. The second session takes place at six weeks from baseline, and the third session at 12 months from baseline. During their presence in the clinic, participants will be thoroughly trained on the function of the Grindcare® device and placement of the electrode on the area of greatest distension of the right temporalis muscle by one examiner (MT). Additionally, they will be provided with a clearly written and illustrated instruction manual to aid in the proper use of the device. At the start of each recording, participants are instructed to perform three maximum voluntary clenches (MVC) in maximum intercuspation, each lasting for at least 3s, with 10s of rest between them. Within two weeks after each recording session, the device is returned to the examiner (MT), who will transfer the raw EMG data to a personal computer. The EMG signal will be assessed for the presence of an acceptable signal-to-noise ratio (i.e., >10), during

a sufficient length of the recording (i.e., at least 75% of the length of the recording), and absence of artefacts, such as loss of the electrode, by custom-made software, designed for this purpose by the software engineer of the department of Oral Kinesiology of ACTA. If one or more recordings fail they will be repeated as soon as possible, and no longer that two weeks after the first raw EMG data have been evaluated.

The raw EMG data will be analysed for calculation of SB outcomes upon completion of the entire follow-up period of the study, using a stepwise analysis tool incorporated in the BruxismDetector software. This software has been developed at the department of Oral Kinesiology of ACTA. The beginning of the sleep period will be defined as 30 minutes after electrode placement, and the end at moment when the EMG signal starts to exhibit an unstable pattern prior to electrode removal. During total sleep time (TST), EMG amplitudes >20% of the highest MVC will be selected for SB episode scoring, according to the Lavigne et al. 1996 criteria. Type of SB episodes will be scored as follows: phasic (at least 3 suprathreshold EMG bursts lasting ≥0.25 sec and <2.00 sec and separated by two interburst intervals of <2.00 sec), tonic (one EMG burst lasting ≥ 2.00 sec), or mixed (both phasic and tonic types of bursts). When the time interval between two bursts is ≥ 2.00 sec, a new episode is considered to start. [10] Per recording, two SB outcome variables will be derived, viz., the number of bruxism episodes per hour of sleep (Epi h^{-1}), and the bruxism time index (BTI; i.e., the total time spent bruxing divided by the total sleep time, times 100%). [9,36]

Outcomes

Biological complications

Biological complications will be assessed by examining cardinal features of peri-implant health, i.e., bleeding on probing, probing depths, and marginal bone height. [37] Also, loss of osseointegration will be registered.

Peri-implant bleeding on probing will be scored per implant according to the Modified Gingival Index (mGI) [38] as follows:

- Score 0; No bleeding when a periodontal probe is passed along the gingival margin adjacent the implant;
- Score 1; Isolated bleeding spots visible;
- Score 2; Blood forms a confluent red line on margin;
- Score 3; Heavy or profuse bleeding.

Peri-implant probing depths will be scored using a standardized periodontal probe

(Click-Probe® 3/5/7/10 blue, KerrHave, Switzerland) with pressure of 0.2-0.25N. Clinical probing depth will be measured in mm as the distance from the mucosal margin to the bottom of the deepest clinical probing site on each side of the examined implant (mesial, distal, buccal and lingual). Per implant, the mean value of those sides is calculated.

Marginal bone height will be assessed radiographically. Vertical bitewing radiographs will be taken using the parallel cone technique and phosphor plates (VistaScan® Image Plate, Dürr Dental, Germany), with the assistance of individually modified plate positioning devices. Modification of the positioning devices will aim at acquiring geometric reproducibility of the radiographs during the successive examinations of the participants. More specifically, reproducing the intraoral position of the device will be achieved by using a silicone (Provil® Novo, Putty regular set, Heraeus Kulzer, Germany) mold, made just after the suprastructure is placed. A reproducible position of the X-ray tube with respect to the plate positioning device will be acquired by the use of a customized hard plastic aiming block. Radiographs are taken with a dental x-ray generator operated at 63kV DC, 8mA, and exposure time of 0.32s. The obtained images will be imported in a commercial dental image archiving program (Emago®, Oral Diagnostic Systems, the Netherlands). Marginal bone height will be measured on each radiograph using the appropriate tool of the program as the vertical distance [mm] from a fixed landmark point on an implant (implant shoulder) to the superior border of the marginal bone at each of the mesial and distal sides of the implant. The Subtraction technique of the Emago® software will be used to detect differences in marginal bone between subsequent radiographs. Measurements will be performed by two independent examiners. Per implant, the mean value of both sides is calculated.

Mobility of the implants or their suprastructures will be assessed manually by clinical investigation using the back part of the handles of two hand instruments (e.g., mouth mirror and probe). Mobility will be scored as either present, or not. When mobility is present the examiner will investigate and note the cause of mobility, i.e., technical complication(s) or loss of osseointegration.

Throughout the course of the study, if any of the aforementioned conditions require treatment, usual care will be provided.

Technical complications

Implant technical complications will be assessed by clinical and radiographical examination. The following complications will be registered:

1. Suprastructure complications (complete or incomplete fracture of veneer, fracture of framework, loosening of occlusal screw or fracture of luting cement, fracture of occlusal screw);
2. Abutment complications (loosening or fracture of abutment screw, fracture of abutment);
3. Implant fracture; and
4. Other complications (e.g., loss of occlusal screw seal).

In case any of these complications occur, the treating dentist will be informed and appropriate treatment will take place.

Composition of peri-implant submucosal biofilm

The Shannon diversity index will be used for expressing microbiome diversity. [20] Composition of peri-implant submucosal biofilm will be analysed by means of genome analysis of bacterial samples, using an open-ended sequencing technique. [39] Per implant, biofilm will be collected after supramucosal plaque has been removed by means of polishing paste (Proxyt® fine paste, Ivoclar Vivadent) and a polishing cup, and the clinical crown has been rinsed with water and dried with air. Sterile paper points (Henry Schein® Absorbent Points #504 medium, Henry Schein, USA) and sterile dental tweezers will be used to collect intrasulcular peri-implant biofilm from four sites of each implant (mesial, distal, lingual, and buccal). Samples will be transferred to tubes (Axygen® Self-standing, clear, sterile Scientific Screw Cap Tubes, 2.0ml , Axygen, USA) and stored in the laboratory of ACTA at-80^{o}C until further analysis.

Covariates and confounders

The association between SB and the outcome variables described will be controlled for possible interacting and/or confounding effects from a series of other variables. These include smoking status, self-reported awake bruxism, peri-implant plaque accumulation, and periodontal parameters. These variables have been chosen based on literature supporting either their purported modifying influence on the main outcomes (i.e., covariates), or their association with both our main predictor and main outcomes (i.e., confounders), and are described below.

Smoking has been shown to be associated with sleep bruxism, [40] peri-implant and periodontal inflammation, and bone loss. [21] Also, it has been shown to affect both the composition of subgingival [41] and submucosal [42] biofilm. Smoking will be evaluated by four categories (never, occasional, former, current), using the questionnaire developed by Hukkinen et al. [43] Participants reporting smoking less than 5-10 packs are categorized as never-smokers.

Participants having smoked more than 5-10 packs, but never on a regular basis, that is, daily or almost daily, are categorized as occasional smokers. Regular smoking in the past defines a participant as former smoker, whereas regular present smoking represents current smoker. Other forms of tobacco use (cigars, cigarillos, or pipe tobacco) are dichotomized and defined as someone never having smoked any of these forms of tobacco (classified as never smoker), or having ever smoked at least 50 cigars, 75 cigarillos and/or more than 3-5 packages of pipe tobacco (classified as current smoker).

Clenching and/or grinding of the teeth while awake are manifestations of awake bruxism [7] and may form an important source of mechanical loading of implants and their suprastructures. Awake bruxism will be evaluated by a self-report 5-pointscale (0=never, 1=rarely, 2=sometimes, 3=often and 4=always), using a single item derived from the Dutch translation of the Oral Behaviors Checklist. [44] Subjects will be asked: "Could you indicate how often you have performed the following activities during the last month: Clench or grind your teeth while you are awake?".

Peri-implant supramucosal biofilm has reported to be crucial for the development of peri-implant disease. [6] Per implant, plaque accumulation is scored according to the modified Plaque Index (mPI) [38] as follows:

- Score 0: No detection of plaque;
- Score 1: Plaque only recognized by running a periodontal probe across the smooth marginal surface of the implant. Implants covered by titanium spray in this area always score 1;
- Score 2: Plaque can be seen by the naked eye;
- Score 3: Abundance of soft matter.

Periodontal parameters of all present natural elements and implants, with the exception of the implants being studied, will be recorded, since periodontal disease has been reported to favour the occurrence of pathology around dental implants. [45] These parameters include the number of clinical pockets with probing depths of ≥5mm and Bleeding Index (BI). Probing depths are measured as the distance from the gingival (or mucosal) margin to the bottom of the deepest clinical pocket on six sides of the examined tooth or implant (mesio-buccal, mesio-lingual, disto- buccal, disto-lingual, buccal, and lingual), using a standardized periodontal probe (Click-Probe® 3/5/7/10 blue, KerrHave, Switzerland) with pressure of 0.2-0.25N. Pockets with depths of ≥5mm are scored as either present or absent. Bleeding on probing is assessed on the same sides described above, using a standardized periodontal

probe (Click-Probe® 3/5/7/10 blue, KerrHave, Switzerland) with gentle pressure of 0.2-0.25N as either present or absent within 30 sec after probing. The BI (%) is calculated using the formula: (number of sites with bleeding/total number of sites examined) x 100.

Morphological and restorative aspects of the implant treatments are registered in the dental record of each subject as part of regular clinical practices of ACTA, and will serve for the description of the baseline characteristics of our subjects' implants. These include the number of occluding pairs of natural teeth, geometrical characteristics of the implants, factors related to loading of the implants, prosthetic characteristics of the implant-supported suprastructures, and the status of their antagonists.

The number of occluding pairs of natural teeth is defined as the number of pairs between upper and lower equivalent natural teeth, by oral assessment. Implant characteristics recorded are the type of implant (manufacturer and system) and implant size (diameter and length, in mm). Characteristics related to loading of the implants and loadability of the receiving bone site include time of loading the implant with the definitive prosthesis (immediate, i.e., within one week after implant placement; early, i.e., between one week and two months; or late, i.e., after two months), bone or soft tissue augmentation procedures, bone quality (according to the criteria proposed by Lekholm and Zarb, 1985), [46] and position of implant (within arch, lower or upper jaw). Prosthetic characteristics of the implant-supported suprastructures are noted. Type of abutment (material, fabrication method), type of implant-supported suprastructure (single crown, fixed partial denture with or without cantilever), retention type (cemented or screw-retained), and material of the suprastructure are registered. Regarding the antagonists of the studied implants, the structure of opposing occlusal contact(s) (natural tooth, implant or none), type of restorative material present on opposing supporting cusp(s), and occlusal contact of implant-supported restoration with antagonists during maximum intercuspation protrusion and/or laterotrusions are registered after oral assessment, with the aid of a 12µm occlusal foil (Hanel occlusion foil 12 µm, Coltene ®, Germany).

REPORTING OF DATA AND STATISTICAL ANALYSIS

Descriptive statistics

Descriptive statistics for categorical variables will be presented using frequency tables, and continuous variables will be presented as each mean and standard deviation. [47] The incidence of biological and technical complications will be reported. [47]

Single/multiple analysis

Our hypotheses will be tested using multilevel regression analyses. [32] As for the main aim of the study, hypotheses about associations between sleep bruxism and the occurrence of technical complications or loss of osseointegration will be tested by using a Cox proportional hazards regression model. [48] Possible associations between sleep bruxism and bleeding on probing, pocket depths, and marginal bone height will be tested by means of linear regression analysis. Likewise, for our secondary aim, possible associations between sleep bruxism and microbiome diversity will be tested by means of linear regression analysis. The regression models will be expanded to examine the effects of confounders and covariates on the associations between main predictor and main outcomes. We aim to adjust our analysis for dependency of data, which arises from the fact that multiple implants can be placed in one subject, thus violating the assumption of independent observations. [48]

DISCUSSION

To our knowledge, this is the first clinical prospective cohort study to investigate the associations between sleep bruxism and dental implant treatment complications.

Certain strong points of this investigation should be recognized. Firstly, the study aims to answer a clinically relevant question, for which the literature so far is inconclusive. A strength of our design is the clear distinction between sleep and awake bruxism that is made. Given the possibility that the different types of bruxism may be differently associated with implant failure, together with the fact that these two conditions require different management approaches, [49] employs that this distinction will enhance the clinical applicability of our results. SB will be diagnosed by means of EMG recordings. Though less valid than the gold standard, i.e., PSG recordings with audio-visual recordings, this feasible diagnostic method is a good proxy, and by performing repeated measurements it enables capturing the time-variant nature of SB. What is more, by extensively documenting our study procedures and the careful

data management, we aim to contribute to the performance of transparent and reproducible research.

On the other hand, certain limitations should be acknowledged. For one, no patient-related outcomes, such as satisfaction with the prosthesis, esthetics, or function will be assessed. Also, no outcomes related to complications-associated costs of treatment will be studied. Though it would be of interest to investigate these parameters, they were not included in our protocol for the sake of avoiding a too complex study design. Future investigations should address these outcomes. Also, our patient sample is derived from a dental school, thus it could be hypothesized that it differs from the population attending other dental care facilities. However, no data are available today to describe if and how these populations might differ from each other.

DECLARATION OF INTERESTS

F. Lobbezoo is a member of the Academic Advisory Board of Sunstar Suisse SA and has no financial interest in this company. The other authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. Sunstar Suisse SA provided financial support for this study via a research grand to ACTA. M. Thymi is a PhD student at ACTA, whose salary is being provided through the abovementioned research grant. All other authors receive their salaries from their country's government. Grindcare® is a trademark of Sunstar Suisse SA, which provided the EMG devices for the duration of the study. Sunstar Suisse SA is not involved in the design of this study, nor in the collection, analysis, and interpretation of data, and writing of this manuscript.

Table 1 Overview of examination time points and variables collected.

Time point (time from baseline)	Variables collected
T_0 (0)	Sleep bruxism, modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, modified plaque index, submucosal biofilm samples, awake bruxism, smoking status, periodontal parameters
T_1 (2 weeks)	Modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, modified plaque index, periodontal parameters
T_3 (6 weeks)	Sleep bruxism, modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, technical complications
T_4 (3 months)	Modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, technical complications, submucosal biofilm samples
T_5 (12 months)	Sleep bruxism, modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, technical complications, modified plaque index, submucosal biofilm samples, awake bruxism, smoking status, periodontal parameters
T_6 (24 months)	Modified gingival index, peri-implant probing depth, marginal bone height, loss of osseointegration, technical complications

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Chapter 6

Associations between sleep bruxism and (peri-) implant complications: lessons learned from a clinical study

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ABSTRACT

Objective

To report and discuss the lessons learned from the conduct of a clinical study on the associations between sleep bruxism and (peri-)implant complications, the protocol of which has been pre-published.

Materials and methods

A single-center, double-blind, prospective cohort study with a two year follow-up was performed in the Academic Centre for Dentistry Amsterdam (ACTA), The Netherlands. Eleven adult participants were included, where an inclusion of 98 was planned. Sleep bruxism was assessed by multiple single-channel electromyographic (EMG) recordings. Main outcomes were biological and technical complications. Results of the study are presented alongside with comments on encountered difficulties.

Results

Insufficient participant recruitment and failed EMG recordings were encountered. The small sample size did not allow answering the study's main aim, and was mainly attributed to the study's protocol complexity. EMG recording failures were attributed to insufficient quality of the EMG signal and detachments of the electrode.

Discussion

The lessons learned from the conduct of this study can be used to design successful future clinical studies.

Conclusion

Adequate participant recruitment, effective EMG recordings, and a careful selection of predictor variables are important ingredients for the successful conduct of a longitudinal clinical study on the association between sleep bruxism and (peri-)implant complications.

INTRODUCTION

Bruxism, either sleep or awake, can be a significant source of overload for dental implants. As such, its association with (peri-)implant complications is already hypothesized for a long period of time. [1] The body of literature on this topic has been growing steadily in the past few years. Systematic reviews have shown a positive association between bruxism and implant failures. [2-4] However, as pointed out in these reviews, the results need to be taken with great caution, since the reviewed studies suffer from poor bruxism definitions and a lack of objective methods to diagnose bruxism. [2-4] More recently, a prospective cohort study using an objective diagnostic method for sleep bruxism, i.e., single-night portable electromyography (EMG), found no relationship between high intensity of sleep bruxism and a higher risk of complications in patients with implant-supported fixed complete dentures. [5]

To our knowledge, no other prospective studies designed to address bruxism as a risk factor for dental implant complications have been published, nor are there any studies on this topic registered in major public trial registries, i.e., clinicaltrials.org and clinicaltrialsregister.eu (search terms bruxism AND implant, date of search 28-08-2019). Ideally, studies on the topic should comply with the following:

Appropriate case definition. This includes a clear reference to which bruxism definition has been used, and a distinction between sleep and awake bruxism. Assessment of sleep bruxism should at least include an objective instrumental assessment such as (ambulatory) polysomnography (PSG) or EMG recordings. Variability in sleep bruxism should be taken into account, and this would correspond to the need for multiple overnight recordings. Awake bruxism should ideally be addressed by instrumental means, [6] and in the absence of those, a standardized questionnaire can be used. [7]

Appropriate outcome definition. Clearly defined biological and technical complications [8], and inclusion of patient-reported outcome measures (PROMs), i.e., aesthetic outcomes and measures that reflect the patients' perception of their implant treatment success. [9]

Adequate sample size. Sufficient size to allow for sound statistical analyses, even in the case of rare outcomes, e.g., implant fractures. Analyses should take collinearity into account that arises from the fact that multiple implants can be present in the mouth of a single participant. [10]

In 2017, our research group published the protocol of a study that complies with nearly all these features. [11] The primary aim of this study was to investigate whether sleep bruxism is a risk factor for dental implant biological and technical complications. The secondary aim was to investigate whether there is an association between sleep bruxism and the composition of periimplant submucosal biofilm. The study was approved by the local Medical Ethical Committee (Vrije Universiteit Amsterdam, ref.: 2011-245) in December 2014, and was registered in the Netherlands Trial Register (Trialregister.nl, ref.:4930) as well as by the US National Institutes of Health (ClinicalTrials.gov identifier: NCT02410681). Implementation of the study protocol took place between February 2015 and May 2019.

There were several important obstacles which hampered the conduct of the study when following the published protocol. As a result, our primary and secondary aims could not be answered. However, through the failure of adhering to the original study protocol, important lessons were learned. These can be used to promote the design of future, more successful research, with optimal utilization of human and financial resources. [12] Taking this into account, reporting on the execution of the current study is of value to the scientific community. [12-14] We are aware of the fact that this is not common in our field therefore, the purpose of this paper is to report and discuss the lessons learned from the conduct of a clinical study on the associations between sleep bruxism and (peri-)implant complications and not, in this case, the clinical results.

MATERIALS AND METHODS

A comprehensive description of the study protocol is presented elsewhere. [11] In short, a single-center, double-blind, prospective cohort study with a 2-year follow-up period was designed. The follow-up period initially consisted of eight visits, i.e., at baseline, two weeks, six weeks, three months, six months, one year, 18 months, and two years. Due to low participation rates, two visits were omitted eight months after the study was initiated, viz., the ones at 6 months and 18 months, in order to make the study protocol less burdening (see results section) for the participants. Thus, the final study protocol consisted of six visits. Participants were recruited from the clinic of the Department of Oral Implantology and Prosthetic Dentistry of ACTA. Inclusion criteria were: planned treatment with implant-supported fixed suprastructure(s) and age ≥ 18 years. Exclusion criteria were: opposing teeth of implant-supported fixed suprastructure(s) are restored with removable artificial teeth; patients categorized in the classes 3 or higher according to the American

Society of Anesthesiologists (ASA) system for classification of physical status; [15] use of an occlusal splint, mandibular repositioning appliance, or any other bruxism-mitigating device during sleep; active periodontitis at the time of implant placement; known allergy to the EMG device electrode material; usage of a pacemaker; and swollen, infected, or inflamed tissues or skin eruptions in the placement area of the EMG device electrode. Pregnancy after the placement of implants was not a reason to stop participation in the study. The aimed sample size was 98, as calculated by the formula: n = 50 + 8k; where k= the number of predictors, which was set at 6. [16] Aimed duration of the study was 3 years: one year for sampling and two years for follow-up. Participants were compensated for their time at the amount of 60 euro upon completion of the follow-up period.

The primary predictor of the study was sleep bruxism, as assessed by the EMG activity of the right temporal muscle during sleep, measured with an ambulatory, single-channel EMG device (GrindCare, version 3+ DL, Delta Danish Electronics, Light & Acoustics, Hørsholm, Denmark). Besides recording EMG activity, the device can issue electrical impulses to lower the EMG activity. This feature was turned off before the device was given to the participants. Three sessions of overnight recordings, each consisting of three consecutive nights, were performed at baseline, six weeks, and one year follow-up. Quality of raw EMG data was assessed based on the following criteria: the presence of an acceptable signal-to-noise ratio (SNR), i.e., maximum voluntary contraction (MVC) amplitude > 10 times the noise amplitude, during a sufficient length of the recording, i.e., at least 75% of the length of the recording, and absence of artefacts, such as detachment of the electrode. Participants were required to perform three MVCs in the first 30 mins. of each recording in order to enable subsequent scoring of bruxism episodes. A sticker reminding participants of this necessity was placed on all EMG devices. Scoring of bruxism events was performed according to published criteria, based on a 20% MVC threshold. [17] The number of bruxism episodes per hour of sleep (Epi/h) and the bruxism time index (BTI, i.e., the total time spent bruxing divided by the total sleep time, times 100%) were derived per recording.

The main outcomes were biological and technical complications, and composition of peri-implant submucosal biofilm. Data on confounding and/or interacting variables were collected, i.e., smoking status, awake bruxism, peri-implant plaque accumulation, and periodontal parameters (i.e., number of clinical pockets with probing depths of $\geqslant$5 mm and Bleeding Index). Furthermore, for the complete description of our sample, data on morphological and restorative aspects of participants' implant treatments were collected. A comprehensive overview of all collected data is provided in Table 1.

RESULTS

In order to serve the 'lessons learned' purpose of the current article, results on the topics of participant recruitment, sample characteristics, and sleep bruxism recordings are presented together with comments on encountered difficulties. Apart from the above-mentioned issues, the measures taken to deal with these difficulties are discussed, giving this results section a mixed results-discussion format. Furthermore, descriptives for the main outcome variables are provided. A general discussion of the results will be presented in the last section of this article.

Participant recruitment

Participants were recruited between February 2015 and August 2016. Thirty-nine individuals fulfilled the inclusion and exclusion criteria. Of those, 28 (72%) were not included in the study due to the following reasons: participation in another study (n=1), not willing to participate (n=16), unable to contact after initial screening (n=6), and planned future use of an occlusal splint after initial screening, as proposed in the final prosthetic treatment plan (n=5). Thus, 11 participants were included in the study.

Comment: There was a low number of individuals fulfilling the inclusion and exclusion criteria, and from among those, very few agreed to participate in the study. Those who declined participation (n=16) were not required to provide a reason, however, some voluntarily did. Verbally reported reasons were: not having enough time for extra visits, not willing to sleep with a device in fear of receiving radiation, and, most importantly, not willing to commit to a lengthy obligation after having gone through an intensive implantological treatment trajectory. In order to tackle the issue of low participation, it was decided, eight months after recruitment was started, to decrease the participant burden of the study protocol by omitting two study visits. Furthermore, the recruitment period was, within the limits of the study's budget, extended by seven months. The omission of two study visits did not have a positive effect on the inclusion rate, thus, after this period, it was decided to terminate recruitment. Upon approval of the local medical ethics committee, the study continued to complete the follow-up of already included participants, as to provide pilot data for the design of future studies. All participants were informed about this decision and were free to continue or terminate their participation in the study. No participants terminated their participation on these grounds.

Sample characteristics

Eleven participants (3 females), with a mean (s.d.; range) age of 54.8 (9.8; 32-66) were included in the study. The total number of implants was 19. Eight participants (2 females, 13 implants) completed the one-year follow-up period, and six of them (1 female, 9 implants) completed the entire study. Reasons for dropping out were: not willing to perform more EMG recordings (n=1), suprastructure not placed (n=1), planning of occlusal splint due to suspected parafunction after inclusion (n=1), and unable to contact for future appointments (n=2). Descriptives of the sample that completed at least the one-year follow-up are presented in Table 2.

Sleep bruxism recordings

In the total sample (n=11), 94 overnight recordings were performed. Of those, 44 (47%) fulfilled the pre-established quality criteria. The remaining 50 recordings that could not be used presented the following issues: no MVC in the first 30 min of the recording (n=22), low SNR (n=8), electrical pulses accidentally turned on (n=5), detachment of the electrode (n=12), and recording performed but not stored on the SD card (n=3). In the sample that completed the 1-year follow-up (n=8), a total of 79 recordings were performed, of which 40 (51%) fulfilled the quality criteria. Issues in the insufficient 39 recordings were: no MVC in the first 30 min of the recording (n=18), low SNR (n=8), detachment of the electrode (n=10), and recording performed but not stored on the SD card (n=3). The characteristics of accepted recordings are presented in Table 3. There was no significant difference between different time-points for either episodes/h or BTI (repeated measures ANOVA, F=.554, p= .512, and F= .249, p= .787, respectively).

Comment: As seen from these data, the absence of MVCs, low SNR, and detachment of the electrode were the most important reasons for recording failures according to our quality criteria. Detachment of the electrode is a complication that will render an unusable recording, especially if it occurs early on in the recording. The issues of absent MVCs and low SNR might be tackled by alternatively scoring the EMG signal based on the times-noise-level (TNL) method, [18] i.e., by using the multiplication (e.g., 2 or 3 times) of the background EMG noise level as the event threshold. However, thus far, there is no consensus regarding the ideal scoring criteria of EMG signals acquired from ambulatory EMG devices [19], and deciding to adopt any alternative scoring method might thus be premature.

Main outcomes

Biological complications

Profuse bleeding on probing, i.e., modified gingival index (mGI) = 3, was scored in two implants of a single participant on 3-months follow-up. All other bleeding on probing scores were low, with a median mGI of 0 at T1, T2, T4, and T6, and 1 at T3 and T5. Probing depths were small, and not indicative of clinical attachment loss. There were no clinically significant changes in marginal bone height. None of the implants showed mobility or were lost (Tables 4a and 4b). Furthermore, at T6, 2 participants (3 implants) reported sensitivity in the region of the implant.

Comment: No significant issues related to the collection of biological data were encountered, with the minor exception of radiographic data acquisition in the anterior region. Though modified, the vertical bitewing positioning devices did not fit in this region. Alternatively, periapical plate positioning devices were used.

Technical complications

During the 1-year follow-up period, 4 technical complications were observed in 4 participants. At T4, a loosened occlusal screw occurred in 2 out of 10 implants, in 2 participants. The appearance of wear facets was the most frequent complication. At T5, wear facets appeared in 2 out of 8 implants, in 2 participants. At T6, wear facets appeared in 4 out of 9 implants, in 3 participants. There were no issues related to the collection of technical complications data.

Biofilm composition

Analysis of collected biofilm data would not serve any meaningful purpose due to the small sample size, thus, it was not performed.

DISCUSSION

The purpose of this paper is to report and discuss the lessons learned from a clinical study on the associations between sleep bruxism and (peri-)implant complications. The execution of the pre-published study protocol was hampered by a number of issues, the most important of which were related to participant recruitment and the performance of sleep bruxism recordings.

It was not possible to achieve the predefined sample size (n=98). Instead, in the 19 months that were available for participant recruitment, only 11 individuals enrolled in the study. Reasons for the low inclusion were a low number of individuals fulfilling the inclusion and exclusion criteria (n=39), and, among those eligible individuals, a high non-inclusion rate (n=28, 72%). Not willing to participate was the most common reason for not including an otherwise eligible person (57% of non-inclusions), and this issue was not adequately tackled when extra study visits were omitted from the protocol. Due to medical ethical considerations, it was not possible to demand and record a reason for non-participation. However, a number of individuals declining participation spontaneously provided this reason, and the matter was additionally discussed with the clinicians who were active in the clinic where the recruitment took place. From this, it could be concluded that deciding to commit to a longitudinal observational study that included multiple sleep registrations was felt as a burdening obligation, after a lengthy implant-related treatment. Individuals receiving dental implants often have gone through a long period of dental treatment of teeth that were eventually lost, before getting into implant treatment trajectories. However, prospective cohort studies are not uncommon in the field of oral implantology (e.g., see [8, 20]). Therefore, the tremendous difficulty in finding individuals willing to participate was not anticipated. In contrast to other prospective studies, though, the current study required active participant engagement, viz., multiple overnight recordings, which may have set the threshold for participation too high. It might also be hypothesized that this threshold could lead to selection bias. We could possibly attract participants who were already aware of sleep bruxism activity, and interested in objectifying this, and/or attract highly motivated individuals who wished to keep their implants healthy. These participants would be interested in participating in a study with a strict follow-up regimen, with close monitoring of their implants. Furthermore, in this study, no differences were found for the sleep bruxism variables, i.e., Epi/h and BTI, between different time-points in the course of one year, which could suggest that multiple recordings are not necessary. However, this finding should be taken with great caution, since the study sample was too small to draw any robust conclusion on the course of sleep bruxism over time. Variability in sleep bruxism activity in short [21] and longer [22] periods of time has been shown in other studies. More research on the natural course of sleep bruxism in needed, [7] and in the meantime, addressing the time-variant nature of sleep bruxism through multiple sleep recordings at different time-point is of importance in future studies.

Furthermore, even if all eligible individuals (n= 39) had agreed to enroll in the study, the sample size calculated would still have not been achieved in the amount of time permitted by the study budget. Based on the capacity of the Clinic of Oral Implantology and Prosthetic

Dentistry of ACTA, no issues were expected related to the number of individuals fulfilling the inclusion and exclusion criteria. However, reality showed a high number of ineligible individuals due to removable prostheses in the opposite jaw, and/or (planned) wearing of occlusal splints after the implant/prosthetic treatment. The issue of low participation in a prospective cohort study with multiple overnight recordings and a lengthy follow-up period could be addressed by designing a multicenter study, with a longer recruitment period. This, of course, has extensive financial and practical implications.

The use of occlusal splints raises another issue that affects participant inclusion and can lead to selection bias. Occlusal splints are recommended by clinicians in the case that sleep bruxism is suspected, for example due to a history of severe dental attrition or repeated fractures of dental restorations. [23] Thus, by using this as an exclusion criterion, it is possible that a high-risk group of bruxers is filtered out from the study sample, consequently biasing study outcomes. As shown in the retrospective study by Chrcanovic et al., 'possible' and 'probable' sleep and/or awake bruxism may be associated with an increased risk of dental implant failure. [24] It would be very interesting to prospectively study such groups of bruxers with instrumental diagnostic devices. However, from a medical ethical point of view, it is not done not to provide these patients with a protective occlusal splint. Alternatively, patients wearing occlusal splints can be included in relevant studies, when the variable of wearing a splint would be taken into account in the statistical analysis.

EMG recording failures were mostly attributed to the absence of MVCs, low SNR, and detachment of the electrode. Detachment of the EMG device's electrode from the skin and subsequent failure of the EMG recording has also been reported in other studies using the same device (e.g., [25-27]) as well as for other ambulatory EMG devices (e.g., [28]). Reasons for detachment might include insufficient cleaning of the skin prior to electrode placement, secretions of sweat and sebaceous glands during sleep, improper placement of the electrode, accidental pulling of the electrode wire, and electrode adhesive properties. To some extent, these factors can be addressed by using wireless electrodes, by improving electrode adhesive properties, and by providing participants with skin cleansing products for use prior to electrode placement.

A 20 % MVC threshold was used in this study to score EMG events. [17] Subsequently, the presence of at least one MVC was required in each recording, as well as a sufficient signal-to-noise ratio. To this end, a 'MVC amplitude > 10 times the noise amplitude' criterion was used. Unfortunately, MVCs were absent in 18 out of 79 (23%) recordings, despite

thorough instruction of participants and reminders placed on the devices. A similar problem is not frequently reported in literature. Failure of obtaining a MVC was reported for only 1 out of 108 participants in the study by Takaoka et al.. [27] Although compliance issues, such as forgetting, or not being able to use the device have been reported elsewhere (e.g., [25], it is not clear why participants in the present study did not comply with the instruction to perform MVCs. In order to avoid such compliance-related recording failures, a more prominent reminder, such as an audio alarm signal, could be used to stimulate participants to perform the MVCs. Moreover, an EMG scoring method that is independent of the presence of a MVC can be considered, provided, as discussed above, its validity has been established.

A final comment should be made regarding the choice of predictor variables in future studies assessing the effect of sleep bruxism on dental implants. The influence of confounding variables when interpreting the results of such studies has also been reported by Chrcanovic et al.. [2] In the current study, four variables were chosen as possible confounders, i.e., smoking status, awake bruxism, peri-implant plaque accumulation, and periodontal parameters, based on available literature. [11] Other variables, such as implant geometrical characteristics and antagonist status were collected, but only for the purposes of a complete description of the sample. It may be argued that these parameters should also be considered as confounders. However, doing so would have significant implications for the final sample size [16]. Moreover, careful selection of variables is also important considering that a large number of such variables can increase the risk for type I error. Given the significant number of variables that can be assessed in a bruxism-dental implant complication study (e.g., [24]), it is suggested that future studies in the field include at least a set of 'classic' confounders/covariates, i.e., smoking and periodontal parameters, variables emerging from clinical studies (e.g., [24]), and variables emerging from the experience of dentists in daily practice (e.g., [23]).

CONCLUSION

The conduct of a prospective clinical cohort study on the associations between sleep bruxism and (peri-)implant complications should take the following factors into account:

- participant recruitment: rates can be low; a multicenter approach with an extensive recruitment period should be considered,
- sleep bruxism recordings: failures can occur as a result of low participant compliance and device detachments; EMG devices should be simple and minimally burdening in their use, and it is suggested that the quality of the raw EMG signal is evaluated, and

- the choice of predictor variables is important in terms of sample size and statistical considerations; it is suggested that it is based on the results of clinical studies.

COMPETING INTERESTS

FL is a member of the Academic Advisory Board of Sunstar Suisse SA and has no financial interest in this company. Sunstar Suisse SA provided financial support for this study via a research grant to ACTA. MT is a PhD student at ACTA, whose salary is being provided through the above-mentioned research grant. All other authors report no conflict of interests.

DISCLAIMER

GrindCare is a trademark of Sunstar Suisse SA, which provided the EMG devices for the duration of the study. Sunstar Suisse SA is not involved in the design of this study, nor in the collection, analysis and interpretation of data, and writing of this manuscript.

Table 1. Overview of study variables and data collection methods

Type of variable		Scale	Instrument	Time point
Outcomes Biological complications	Bleeding on probing	Modified Gingival Index (REF) (0: no bleeding when a periodontal probe is passed along the gingival margin adjacent the implant; 1: isolated bleeding spots visible; 2: blood forms a confluent red line on margin; 3: heavy or profuse bleeding)	Periodontal probe (Click-Probe 3/5/7/10 blue, KerrHave, Bioggio, Switzerland)	T1, T2, T3, T4, T5, T6
	Probing depth	Distance (mm) from the mucosal margin to the bottom of the deepest clinical probing site on the mesial, distal, buccal and lingual sides of the implant. Per implant, the mean value of those sides is calculated		
	Marginal bone height	Vertical distance (mm) from implant shoulder to superior border of marginal bone in mesial and distal sides; the difference in marginal bone height between subsequent radiographs is calculated	Image acquisition: Vertical bitewing radiographs, parallel cone technique, phosphor plates (VistaScan Image Plate, Dürr Dental, Bietigheim-Bissingen, Germany), individually putty-modified plate positioning devices Image processing: Emago software (version 6.0), Oral Diagnostic Systems, Amsterdam, The Netherlands	
	Loss of osseointegration	Presence/absence	Clinical and radiographic evaluation	

Type of variable			Scale	Instrument	Time point
Outcomes	Technical complications	Suprastructure	Complete or incomplete fracture of veneer, fracture of framework, loosening of occlusal screw or fracture of luting cement, fracture of occlusal screw	Clinical and radiographic evaluation	T3, T4, T5, T6
		Abutment	Loosening or fracture of abutment screw, fracture of abutment		
		Implant body	Fracture		
		Other	E.g., appearance of wear facets, loss of occlusal screw seal, etc.		
		Biofilm composition	Shannon diversity index of peri-implant submucosal biofilm, collected from the mesial, distal, lingual and buccal sides of each implant	Biofilm collection and storage: Sterile paper points (Henry Schein Absorbent Points #504 medium, Henry Schein, Melville, NY, USA), tubes (Axygen Self-standing, clear, sterile Scientific Screw Cap Tubes, 2.0 ml, Axygen, Union City, CA, USA) and stored in the laboratory of ACTA at −80 °C Biofilm analysis: genome analysis of bacterial samples, open-ended sequencing technique	T1, T4, T5
	Covariates/ confounders	Smoking status	Never, occasional, former, current	Questionnaire (Hukkinen et al. REF)	T1, T5
		Awake bruxism	Never, rarely, sometimes, often, always	Questionnaire (Oral behaviors Checklist REF)	

Type of variable			Scale	Instrument	Time point
Outcomes	Covariates/ confounders	Plaque accumulation	Modified Plaque Index (REF) (0: no detection of plaque; 1: plaque only recognized by running a periodontal probe across the smooth marginal surface of the implant. Implants covered by titanium spray in this area always score 1; 2: plaque can be seen by the naked eye; 3: abundance of soft matter)	Clinical examination	T1, T2, T5
		Periodontal parameters	Number of clinical pockets with probing depths of ⩾5 mm and Bleeding Index of all present natural elements and implants (except implants under study)	Periodontal probe (Click-Probe 3/5/7/10 blue, KerrHave, Bioggio, Switzerland)	
	Sample descriptive variables	Occluding pairs of natural teeth	Number of pairs between upper and lower equivalent natural teeth	Clinical examination	T1, T5
		Implant geometrical characteristics	Type of implant (manufacturer and system), implant size (diameter and length, in mm)	Electronic health record	T1
		Implant loading characteristics	Time of loading with the definitive suprastructure (immediate, i.e., within 1 week after implant placement; early, i.e., between 1 week and 2 months; or late, i.e., after 2 months), bone or soft tissue augmentation procedures, bone quality (REF), and position of implant (within arch, lower or upper jaw)	Electronic health record	T1
		Prosthetic characteristics	Type of abutment (material, fabrication method), type of implant-supported suprastructure (single crown, fixed partial denture with or without cantilever), retention type (cemented or screw-retained)	Electronic health record	T2

Type of variable	Scale	Instrument	Time point
Antagonist status	Structure of opposing occlusal contact(s) (natural tooth, implant or none), type of restorative material present on opposing supporting cusp(s), and occlusal contact of implant-supported restoration with antagonists during maximum intercuspation, protrusion and/or laterotrusions	Electronic health record and clinical examination with a 12 µm occlusal foil (Hanel occlusion foil 12 µm, Coltene, Langenau, Germany)	T2, T5

T1: baseline (impression appointment), T2: 2 weeks (suprastructure placement), T3: 6 weeks, T4: 3 months, T5: one year, T6: two years

Table 2. Sample characteristics (n = 8 participants, who completed at least 1 year follow-up)

	T1; Baseline (n= 8 participants; 13 implants)		T2; 2 weeks (n= 7 participants; 11 implants)	T5; 1 year (n=8 participants; 13 implants)	
Smoking status	Never: 2	Current: 0	-	Never: 3	Current: 0
	Occasional: 1	Former: 5		Occasional: 1	Former: 4
Awake bruxism	Never: 4	Often: 0	-	Never: 1	Often: 0
	Rarely: 1	Always: 0		Rarely: 5	Always: 0
	Sometimes: 3			Sometimes: 2	
modified Plaque Index*	0 (0-0)		0 (0-2)	0 (0-0)	
No. of pockets ⩾5 mm	< 2: 7		< 2: 6	< 2: 8	
	⩾ 2: 1		⩾ 2: 0	⩾ 2: 0	
Bleeding Index (%)*	10 (7-16.25)		6 (3.75-13.75)	5 (3.5-7.75)	
Occluding pairs of natural teeth*	9.5 (7.25-11.5)		-	8 (7.25-9.75)	
Implant manufacturer and system	Straumann SP RN Roxold SLActive: 4		-	-	
	Straumann BL NC Roxolid SLActive: 5				
	Straumann BL RC Roxolid SLActive: 4				
Implant size*	Diameter: 4.1 (3.3-4.1)		-	-	
	Length: 10 (10-12)				
Time of loading	Late: 13		-	-	
Augmentation (soft and/or hard tissues)	No: 5		-	-	
	Yes: 8				
Implant position	Upper: 10	Anterior: 6	-	-	
	Lower: 3	Posterior: 7			
Type of suprastructure	Single crown: 9		-	-	
	Fixed partial denture (no cantilever): 4				
Type of abutment	Titanium prefabricated: 5		-	-	
	Titanium custom made: 8				

	T1; Baseline (n= 8 participants; 13 implants)	T2; 2 weeks (n= 7 participants; 11 implants)		T5; 1 year (n=8 participants; 13 implants)	
Type of retention	Cemented: 4 Screwed: 9	-		-	
Suprastructure material	Metal: 1 Full ceramic: 10 Metal-ceramic: 2	-		-	
Opposing occlusal contact	-	Natural tooth: 11 Implant: 2		Natural tooth: 11 Implant: 2	
Contact in maximum intercuspation	-	No: 7	Yes: 6	No: 8	Yes: 5
Contact during latero-/protrusion	-	No: 10	Yes: 3	No: 8	Yes: 5
* median (25^{th}-75^{th} percentile)					

Table 3. Characteristics of accepted recordings for participants that completed 1 year follow-up

	T1	T3	T5
Duration (hours)*	6.07 (1.55)	6.61 (1.48)	6.05 (1.13)
Episodes/h*	2.17 (1.4)	2.81 (2.31)	3.86 (2.56)
BTI*	.95 (1.15)	.46 (.32)	.59 (.38)

* mean (s.d.), T1: baseline; 8 participants/15 recordings, T3: 6 weeks; 5 participants/12 recordings, T5: 1 year; 6 participants/13 recordings, BTI: bruxism time index

Table 4a. Biological and technical implant complications in the 2-year follow-up period (participant level)

	T1; Baseline (n=8)	T2; 2 weeks (n=7)	T3; 6 weeks (n=6)	T4; 3 months (n=5)	T5; 1 year (n=8)	T6; 2 years (n=6)
Modified Gingival Index^	0 (0-2)	0 (0-2)	1 (0-2)	0 (0-3)	1 (0-2)	0 (0-2)
Probing depth#	1.8 (1-2.3)	1.3 (1-2.8)	1.5 (1.2-2.3)	2.8 (1.1-3.3)	1.4 (1-2)	1.8 (1.4-2.5))
Marginal bone height#	.7 (.4-1.4)	.7 (.5-1.5)	.8 (.4-1.6)	.7 (.6-1.8)	.8 (.2-1.4)	.4 (-.2-1)
Technical complications	-	-	0	2 (loosening of occlusal screw)	2 (occlusal wear)	3 (loosening of occlusal screw [1], occlusal wear [3])
Loss of osseointegration	0	0	0	0	0	0

^ median (min-max), # median (25th-75thq)

Table 4b. Biological and technical implant complications in the 2-year follow-up period (implant level)

	T1; Baseline (n=13)	T2; 2 weeks (n=11)	T3; 6 weeks (n=9)	T4; 3 months (n=10)	T5; 1 year (n=13)	T6; 2 years (n=9)
Modified Gingival Index^	0 (0-2)	0 (0-2)	1 (0-2)	0 (0-3)	1 (0-2)	0 (0-2)
Probing depth#	2 (1.3-2.3)	1 (1-1.8)	1.5 (1.1-2.3)	2.4 (1.3-3.3)	1.8 (1-2.1)	1.8 (1.3-2.5)
Marginal bone height#	.7 (.4-1.7)	.9 (.2-2)	1 (.3-1.7)	.9 (.4-2)	.9 (.3-1.9)	.3 (1-1.5)
Technical complications	-	-	0	2 (loosening of occlusal screw)	2 (occlusal wear)	5 (loosening of occlusal screw [1], occlusal wear [4])
Loss of osseointegration	0	0	0	0	0	0

^ median (min-max), # median (25th-75thq)

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Chapter 7

Patient-based experiences with the use of an ambulatory electromyographic device for the assessment of masticatory muscle activity during sleep

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ABSTRACT

Background

Further development of ambulatory electromyographic (EMG) devices is useful for future sleep bruxism research. Participant burden by the use of such devices has not been addressed.

Objective

To explore the experience of individuals who use a portable EMG device that pairs with a smartphone app, in order to detect factors that could facilitate and/or hamper its utilization in future scientific research.

Methods:

Fifteen adults were recruited in the Orofacial Pain and Dysfunction clinic of the Academic Centre for Dentistry Amsterdam (ACTA). Overnight recordings were performed in the home setting during one week. Time investment, feelings and thoughts, encountered difficulties, and reasons for not using the device were assessed in a diary through open-ended questions and 5-point Likert scales. Content analysis of textual data was performed and descriptives of quantitative data were calculated.

Results:

Time investment was low (mean 10.2 min in the clinic, and 1.9 min per recording at home). Quantitative data showed an overall good experience (median of 4). Qualitative diary data showed that the desire to gain insight into one's masticatory muscle activity formed the main motivation to use the device. Detachment of the device, and difficulty in using the app were the most prominent negative experiences.

Conclusion

The EMG device was well accepted for multiple overnight recordings. Curiosity for gaining insight into muscle activity was the most important factor that facilitated its use, and the app addressed this need. Device detachment and difficulties in using the app were the main factors that hampered its use.

Keywords

Sleep bruxism, electromyography, ambulatory, smartphone, experience, mixed methods

BACKGROUND

Sleep bruxism is a masticatory muscle activity during sleep with rhythmic and non-rhythmic features 1 with potential negative oral health consequences, such as musculoskeletal symptoms, tooth wear, and complications of restorative dental treatments. 2 The activity occurs in most people, 2 and, to some extent, its frequency and intensity vary over time. 3 The development of an ideal assessment tool remains of high priority in the sleep bruxism research agenda. 1 Patient self-report and/or clinical examination are extensively used. 4 These methods are simple, low-cost, and readily available, but unfortunately lack validity. 1 Instrumental methods that provide electromyographic (EMG) data of masticatory muscle activity are currently suggested for accurate sleep bruxism assessments. 1 Polysomnography (PSG), preferably with audio-video (AV) recordings, has long been considered the gold standard for a definitive sleep bruxism diagnosis. 5 PSG is a multiple-channel sleep study, which requires set-up, analysis, and interpretation by trained professionals. 6 This procedure has substantial financial and feasibility implications, and makes multiple consecutive recordings a burdening task. Therefore, PSG is not suitable for the clinician seeking a simple diagnostic method for daily practice, 7 and it poses significant challenges for the research setting in terms of study budgets and participant recruitment.

Portable EMG devices can produce masticatory EMG data and have the potential to overcome PSG-related issues of feasibility and cost-effectiveness. [8] They can be self-administered at the home setting, for single or multiple-night recordings. [8] On the other hand, they may overestimate sleep bruxism activity, compared to PSG. [7] Validity of a diagnostic device is obviously one of its most important features. However, even the most valid device will not be suitable for widespread use if it causes significant burden to the user, especially when it is aimed for use during sleep. [9] The absence of wires and the possibility for self-administration at home make the burden of portable EMG devices lower compared to PSG. However, this burden may still be significant, especially in the case of multiple night recordings. It may be hypothesized that burden arising from sleeping with a portable EMG device for several nights may affect the outcomes of sleep bruxism research, manly by being a reason for participants to not fully adhere to study protocols.

Portable EMG devices have been used in sleep bruxism studies (e.g. [10–15]), and their further development may prove extremely useful for future research. To our knowledge, however, no studies have addressed the issue of participant burden by the use of such devices. Therefore, the aim of this study is to explore the experience of individuals with the use of a portable

EMG device (BUTLER® GrindCare®, Sunstar Suisse S.A., Etoy, Switzerland) for the assessment of masticatory muscle activity during sleep, in order to detect factors that could facilitate and/or hamper its utilization in future scientific research

METHODS

Study design

A mixed methods cohort study was designed. During one week, participants performed overnight EMG recordings in their home setting and completed a diary. Ethical approval was acquired by the local medical ethics committee (Medical Ethics Review Committee of VU University Medical Center, reference 2017.354).

Study population

Participants were recruited among the patients attending the clinic of Orofacial Pain and Dysfunction of the Academic Centre for Dentistry Amsterdam (ACTA). This clinic receives referrals from primary care related to temporomandibular dysfunction, orofacial pain, tooth wear, dental sleep disorders and bruxism. Inclusion criteria were: age 18 years or older, diagnosis of probable sleep bruxism, [5] and sufficient understanding of the Dutch language in reading and writing. The following exclusion criteria were applied: patient categorized as class 3 or higher according to the American Society of Anesthesiologists (ASA) system for classification of physical status, [16] presence of a pacemaker, known allergy to the EMG gel pad material, pregnancy, and presence of orofacial pain that is triggered by touch of the facial skin. Patients fulfilling these criteria were informed by the investigator about the study and were given a week time to consider participation. The investigator consulted with the clinician before approaching patients, to discuss whether study participation might interfere with regular care. The latter involves counseling and one or more of the following: physical therapy, psychological therapy, occlusal splint therapy, pharmacological treatment and, in cases of severe tooth wear, restorative treatment. When a patient was interested in participation, an appointment with the investigator was made, adjacent to the next regular clinic visit, during which informed consent was signed and the device was handed out. An appointment was made for returning the device, for which participants were free to choose the location and time, in order to keep the burden of the study low. If regular care involved placement of a new occlusal splint, the device was given after the splint habituation period (i.e., after 2 weeks) as to avoid interference of any discomfort by the new splint with the study outcomes. Participants were asked to use the device for at least one night, and were

encouraged to use it for as many nights as possible, with a maximum of seven. Compensation for study-related travelling costs was given, and participants received an oral hygiene "goodie bag" at the time of enrollment, which was provided to ACTA by Sunstar Suisse SA.

EMG device

The BUTLER® GrindCare® is a commercially available, CE-marked, wireless, single-channel EMG device with dual utility, i.e., to monitor masticatory muscle activity, and issue contingent electrical impulses aimed to lower this activity. [17] It consists of a galvanic tripolar electrode that attaches to the skin over the anterior part of the temporalis muscle with a gelpad (Figure 1). The electrode carries a sensor which registers EMG activity and can issue the electrical impulses. A built-in algorithm analyzes the EMG signal and scores events based on EMG background noise level. [17] Event data are stored within the sensor. The device's charger is embedded in a separate docking station. Once the sensor is placed in the docking station, data are transferred and stored in the docking station, and deleted from the sensor. [17] The user can install a smartphone app which pairs with the docking station through Bluetooth technology. Subsequently, event data are transferred to, and directly visible on the user's smartphone [17] (Figure 2). The language of the app is in English.

Outcomes

Time in the clinic for providing instructions was assessed with a stopwatch. Instructions were given by one investigator (MT), and included an explanation of all device components, instructions for skin cleaning, basic features of the app, and transferring data from the sensor to the app. Electrode placement was practiced in front of a mirror.

The diary consisted of two sections, that covered 11 domains of interest (Table 1). These domains were chosen based on experience of our research group with the use of a previous research prototype version of the device. [18] The first section consisted of two parts, one for each evening prior to using the device, and one for each morning after usage. The second section included questions on the overall experience, and was filled in at the end of the follow-up period.

In section 1, open-ended questions invited participants to express their feelings and thoughts on the use of the device before sleep, and, afterwards, their experience with sleeping with it. Additionally, several topics were assessed through 5-point Likert scales, i.e., ease or difficulty in placing the device on the skin (0 = extremely difficult, 5 = as easy as can be), feeling of comfort in the prospect of sleeping with the device (0 = extremely uncomfortable, 5 = as

comfortable as can be), and the degree to which the device was disturbing during sleep (0= extremely disturbing, 5 = not disturbing at all). Furthermore, participants were asked to record the time it took placing device, from the moment of unpacking the gelpad, until the device was placed on the skin. Participants were asked to record any reason for not using the device.

In section 2, open-ended questions were used to address any encountered troubles, reasons for using or not using the app, and complaints and/or suggestions regarding the use of the device and app. Five-point Likert scales were used to assess how pleasant or annoying it was to sleep with the device, how easy or difficult it was to use the various components, such as gelpads, docking station, etc., and if the participant would recommend the use of the device to others for diagnostic purposes.

Data analysis and final sample size

For section 1 of the diary deductive content analysis of qualitative data was performed in successive steps, which were adapted from the framework-based approach, as described by Ritchie and Lewis, [19] and Pope. [20] The analysis focused on detecting factors that would facilitate and/or hamper device utilization, and, to this end, positive and negative experiences prior to, and after sleeping with the device were identified. First, a chart was created in Microsoft Excel 2010 software. Original textual data on each domain (as described in Table 1) were inserted in the first column by one investigator (MT). They were investigated for initial themes, which were inserted in the second column of the chart. From there, per domain, initial themes were grouped based on conceptual relevance. Extraction and grouping of initial themes was repeated by a second investigator (MV) independently of the first. The two analyses were compared, and the final content of each main theme was based on consensus between both investigators. Inclusion of participants continued until no new themes arose from the diaries, that is, until saturation of data. [19,20] Saturation was confirmed by including one more participant. Consequently, the final sample consisted of 15 participants. Frequencies of reasons for not using the device were calculated. Textual data of the diary's section 2 were grouped according to relevance. For quantitative variables, descriptive data were calculated using Microsoft Excel 2010 software.

RESULTS

Sample and recordings

Thirty potential participants were approached between April 2018 and March 2019, and 15 were included (10 female, mean age (s.d.): 46.7 (16.3)). Reasons for non-inclusion were: could not be reached after initial screening (n=3), time limitation/distance from residence (n=2), no further appointments at ACTA (n=3), ASA score changed to 3 after initial screening (n=1), and termination of inclusion due to saturation of data (n=6). The 15 participants were given the device for a maximum of 7 nights, thus, in total, 105 recordings could have been performed. The actual number of performed recordings was 63 (median (25th-75th quartile): 5 (3-5.5), range 0-7). Reasons for not performing a recording are presented below.

Time investment

The mean (s.d.) time for providing instructions in the clinic was 10.2 (3.2) min. The mean (s.d.) time spent for placement of the device at home was 1.89 (1.3) min per recording.

Experiences prior to sleeping with the device

Feelings and thoughts

A median (25th-75th quartile) of 4 (4-5) was found for the question on ease or difficulty in placing the device, and 4 (3.75-4) for the question on how comfortable it feels to go to sleep with the device (Table 2).

Analysis of free text data showed that all participants reported a mixture of positive and negative experiences. Most prominent positive experiences included feelings of curiosity and enthusiasm about using the device. These feelings arose from the desire for gaining an insight into one's muscle activity. Satisfaction and surprise about the device's ease of use were reported, as did a sense of comfort after attaching it to the skin. Furthermore, a relaxed, neutral, 'neither positive nor negative' attitude was reported, as well as a sense of familiarity after the first day of usage.

Negative experiences included feelings of frustration, disappointment, uncertainty, anxiousness, and reluctance. Most prominent negative experiences involved frustration and disappointment regarding detachment of the device during sleep and failure to establish a connection between the docking station and the app. Frustration was also reported about encountered skin irritation, headache, dizziness, and the physical interference of the device with wearing glasses. Uncertainty was expressed about whether the device is used in

the correct way, whether it will work properly, and whether it will stay attached all night. Furthermore, worrying that the skin will get irritated, sleep quality will be affected, and that it will take too much time to take the device off in the morning were reported. These worries were expressed together with a reluctance in using the device.

It was clear from the diary data that when difficulties in the use of the device were encountered, e.g., detachments during sleep, skin irritation or failure to connect the docking station with the app, negative experiences were more prominently expressed.

Reasons for not using the device

Reasons for not using the device were reported for 31 out of 42 unperformed recordings (Table 2). Most frequent reasons reported amongst participants were not feeling like using the device, malfunction of the device, and not sleeping at home. Only one participant did not perform any recordings, and this was due to a general dissatisfaction with the regular clinical care she received (indicated as 'don't feel like it').

Experiences after sleeping with the device

A median (25th-75th quartile) of 4 (3-5) was found for the question on the degree to which the device was disturbing during sleep (Table 2).

Analysis of free text data showed both positive and negative experiences. One participant expressed only a positive experience, plainly describing it as 'fine'. Another participant expressed only a negative experience, due to the occurrence of skin irritation. All other participants described a mixture of positive and negative experiences. Overall, these participants reported no, or minimal bother by the device during sleep. The most important reason for sleep disturbance was detachment of the device (8 participants/13 recordings). Other sources of disturbance were sleeping on the side of the device, skin irritation, awareness of the device's presence on the skin, and electrical pulses. The latter occurred in a single participant, who had voluntarily turned them on without proper instruction for this function, due to curiosity.

General experience

Difficulties encountered while using the device

A median (25th-75th quartile) of 4 (3.25-5) was found on both the questions of how pleasant or annoying it was to sleep with the device, as well as how easy or difficult it was to use the various components (Table 2).

In this section of the diary participants largely repeated the issues they had reported in section 1. In addition to what has been described above, one participant reported not being able to place the device in the docking station, one reported annoyance due to hair getting stuck between the device and the skin, and two participants reported that the device had broken. This was confirmed by the investigator (MT). In the first case, the electrode was torn into two pieces when the participant attempted to remove the gelpad. In the second, the device failed to turn on, for unknown reason. Moreover, two participants reported difficulty in using the gelpads. One found that removing them was too time consuming in the morning, and difficult in the evening, due to increased stiffness when they dry out. The other reported placing the gelpads wrongly, thus having to repeat the procedure. Furthermore, difficulty in establishing a connection between the app and docking station, and subsequent failure to gain insight into collected data was reported. This matter was verbally discussed between participants and the investigator when the device was returned. One participant indicated having difficulty with the language of the app being English, and not the native, i.e. Dutch. The other participants did not report any language issues. Upon receiving the devices an attempt was made to pair the participants' smartphones to the docking station together with the investigator (MT). These attempts were all successful.

Reasons for (not) using the app

All but one participants attempted to use the app. The participant who did not use the app used the device for a single night and did not report a reason for not using the app. Insight into the amount of muscle activity was the most prominent reason for using the app. Two other reasons were reported, i.e., to check whether the device is working correctly and for contributing to the success of the study.

Suggestions and/or complaints regarding the use of the device

A median (25th-75th quartile) of 4 (4-4) was found for the question on whether the participant would recommend the use of the device to others for diagnostic purposes (Table 2).

Some improvement suggestions were made. Alternating between sides of the face, as to avoid irritation of the same spot, was proposed for preventing skin irritation. Recommendations for the app were given: it should show if the stimulation mode is accidentally turned on, if the device is working properly, it should be translated in the native language, and have an effective troubleshooting section. Regarding the other device components, it was suggested to provide the docking station with a switch that can disconnect it from the electricity network, since leaving it connected all day felt unsafe. Finally, it was suggested providing the

gelpads with grip tabs for easy removal, and that the device should be made compatible with wearing glasses.

DISCUSSION

Main findings

This study explored the experience of individuals with the use of a portable EMG device (BUTLER® GrindCare®) for the assessment of masticatory muscle activity during sleep, in order to detect factors that could facilitate and/or hamper its utilization.

The median (25th-75th quartile) number of overnight recordings was 5 (3-5.5). This shows a good compliance, given that participants were encouraged, but not obliged, to use the device for as many nights as possible during one week. Mean (s.d.) time investment was low, i.e. 10.2 (3.2) min for providing instructions in the clinic, and 1.89 (1.3) min per recording at the home setting.

An overall good experience, with a median of 4 (on a 5-point Likert scale) was found for the domains of ease or difficulty in placing the device, feeling of comfort in the prospect of sleeping with the device, degree to which the device was disturbing during sleep, degree to which sleeping with the device is pleasant or annoying, ease or difficulty in using the device components, and willingness to recommend use of the device for diagnostic purposes.

Qualitative diary data gave more in-depth information on participant experiences. The desire to gain insight into one's masticatory muscle activity came with feelings of curiosity and enthusiasm, and formed the main motivation to use the device and app. Moreover, satisfaction and surprise about the device's ease of use were reported. These positive experiences were counteracted by negative ones, the most prominent being frustration and disappointment following detachment of the device during sleep, and failure to connect the docking station with the app. Furthermore, negative experiences arose from skin irritation and occurrence of headache in a limited number of participants.

Factors that hamper device utilization

Detachment of the device during sleep occurred in 13 out of 63 (20.6%) recordings. Detachments have been reported in other studies (10, 12, 13, 15, 21). Takaoka et al. [10] encountered lack of adhesiveness of the EMG device (GrindCare 3.0, Medotech A/S) in one

out of 106 (.9%) participants performing three recordings. Shedden Mora et al. [15] reported loosened electrodes and failure to charge batteries of the EMG devices (basic PTA device, Haynl Elektronik GmbH, Schönebeck, Germany, with silver-silver-chloride electrodes; T3402 Triodes, Thought Technology Ltd, Montreal, Quebec, Canada) in nine out of 117 (7.7%) participants performing three overnight recordings. Conti et al. [21] and Yachida et al. [12] reported lost electrodes (GrindCare 3.0, Medotech A/S) without providing exact prevalence figures. In all studies, this led to loss of data. Karakoulaki et al. [13] reported loss of connectivity between the EMG device (BiteStrip, Scientific Laboratory Products) and the skin for three out of 45 (6.7%) participants performing single-night recordings, which were subsequently repeated. Interestingly, the prevalence of electrode detachments in abovementioned studies is quite lower than in the present, a finding that could be explained by the device's design. The electrode used presently carries the EMG sensor. In the studies of Shedden Mora et al. [15] and Takaoka et al. [10] the sensor was attached to the electrode through a wire. It is thus possible that the weight and/or volume of the sensor in the current study contributed to detachment from the skin. On the other hand, it might be argued that accidental pulling of the wire might contribute to loosening of an electrode. Karakoulaki et al. [13] used an electrode which carried the sensor as well, however, compared to the present study, the sensor was less voluminous, though differences in weight are unknown. Moreover, differences in skin preparation and electrode adhesion, i.e. with gelpad or pre-gelled type, might have contributed to the variation in the prevalence of detachments. Overall, these considerations should be taken into account in future developments of the EMG device, e.g. by investigating which features contribute to good skin adherence, as well as in future scientific studies, e.g. by standardizing skin preparation and estimating sample sizes that take possible data loss into account.

Furthermore, despite careful verbal and written instruction, participants encountered difficulties in establishing a connection between the docking station and the app. The app not being in the native language contributed to this difficulty for one participant. All attempts to establish the connection were successful when the investigator, i.e. a more experienced user, assisted the procedure at the end of the study. This implies that the cause of the issue could lay at the level of the app's functionality, i.e. the feature that is related to its performance, ease of use, etc. [22] Therefore, further development and adequate quality testing of this feature is suggested. [22]

For a limited number of participants skin irritation (n=2) and headache (n=1) decreased the tolerability of the device. Assessments of skin irritation and sensitization have been performed for regulatory clearance of the device by relevant authorities, [17] and instructions

to discontinue use if skin irritation occurs are included in the user manual. We were not able to retrieve reports of skin irritation in other studies with EMG recordings of masticatory muscle activity during sleep, however, this has been used as an exclusion criterion in one study. [23] Skin irritation has been reported to limit the use of gel electrodes to short periods of time, [24] and it might be hypothesized that the sensitive facial skin might be particularly prone for irritation if gelpads are used for longer time periods. It is suggested that skin conditions that render the skin prone for irritation are considered as exclusion criteria for future use of the device. Furthermore, headache lasting for several hours was experienced by one participant. This participant had voluntarily turned on the electrical pulses for the recording after which the headache occurred and it is plausible that the headache was related to this feature, and not to the diagnostic mode of the device. No similar incident could be retrieved from literature. Experiencing headache was included in the informed consent procedure of the current study, based on incidental reports of increased morning headache related to commercial use of previous versions of the device. Out of precaution, it is suggested that this information be included in informed consent procedures.

Other hampering factors were reported, such as difficulty in removing the gelpad from the electrode, and difficulty in simultaneously wearing glasses. It is suggested that these factors are taken into account by the manufacturer when designing future versions of the device.

Factors that facilitate device utilization

Curiosity for gaining insight into one's masticatory muscle activity during sleep was the most important factor that facilitated the use of the device, and the smartphone app was the means by which this need was met. To our knowledge, no studies have utilized ambulatory EMG devices that pair with apps which are available for participants for the investigation of masticatory muscle activity during sleep. A recent study by Prasad et al. used comparable technology for assessing muscle activity during waking hours and concluded that this is a promising tool in the field of awake bruxism research. [25] In line with this conclusion, the results of the current study suggest that visualizing masticatory muscle activity on a smartphone app can be beneficial in the field of sleep bruxism, through engaging and motivating the user to comply with multiple overnight recordings. Moreover, the app may be further developed to indicate proper function of the EMG device, as suggested by our participants. Besides improving user experience, this may facilitate acquisition of good quality EMG data and prevent data loss, which has been encountered previously (e.g. [10,21]). For instance, the app could show whether the device is switched on and data are actually being registered, and monitor the EMG signal quality, in terms of skin-electrode contact impedance and signal-to-noise ratio. [24]

In the study of Prasad et al. real-time EMG data were collected, [25] as opposed to the current investigation, in which data were transferred after the end of the recording. Real-time data collection has the benefit of direct feedback to the user. However, continuous data emission during a sleeping period is unnecessary, and might even be considered as a threatening health hazard by certain individuals, [26] thus it is suggested that this feature is available for the first few minutes of the registration only, and subsequently turns off.

Both quantitative and qualitative data suggested that using the device was generally considered simple. The wireless design and small number of components may have contributed to this perception. Moreover, compared to other ambulatory EMG devices (e.g. [13,27–29]), a set up procedure for defining thresholds of maximum voluntary contraction (MVC) is not required. This is necessary if scoring of EMG events is based on a % MVC method, [30] which is not the case for BUTLER® GrindCare®. [17] Difficulties and uncertainty about the correct performance of such procedures have been reported, [10,21,31] which, in certain cases, lead to data loss. [10] The decision on whether an EMG scoring method should be based on a MVC threshold or times-noise-level approach should ideally be based on the criterion of validity, [30] however, participant compliance and adherence to the study protocol should also be taken into account.

Future implementations

A smartphone app utilizing the ecological momentary assessment (EMA) method, was recently introduced for the study of awake bruxism. [32,33] This too, seems a promising tool for future awake bruxism research. [33] Studies utilizing instrumental methods for assessing both circadian manifestations of bruxism, i.e. awake and sleep bruxism, are highly needed. [1] As in other healthcare fields, [34] smartphone-based technologies could prove useful. Future studies may aim at developing a multimodal instrument, able to assess both awake and sleep bruxism. An example is an app allowing assessment of awake bruxism by means of EMA, and which can be paired with an EMG device for recording muscle activity related to awake and sleep bruxism.

Strengths and limitations

The mixed methods design is considered a strength of this study. Quantitative measurements showed an overall good experience with the device, while qualitative data allowed an in-depth view of the factors that contributed to this good experience, but also to those that prevented it from being excellent. It could be argued that other qualitative methods, e.g. semi-structured interviews, [35] could provide more detailed information. However, this was

deemed unnecessary, given that the aim was the investigation of user experience, rather than the construct of a theory to understand health behaviors. [35] Moreover, by daily diary completion the risk of recall bias was lowered.

Certain limitations are acknowledged. The study sample was selected in a referral clinic, and possibly the experience of users might be different if they were recruited in other settings, e.g. a general dental practice. In this context it should be noted that the assessment of bruxism can be important in pediatric, [36] and certain vulnerable populations, e.g. those suffering from Parkinson's disease, [37] or individuals with developmental disabilities. [38] It is expected that user experiences in these populations can differ significantly from the present. Furthermore, our results were not controlled for the influence of psychosocial and sleep variables, which, to some extent, may contribute to the way one experiences the use of a device they should sleep with.

CONCLUSION

The use of the wireless BUTLER® GrindCare® device was well accepted for multiple overnight recordings of masticatory muscle activity during sleep. Curiosity for gaining insight into one's muscle activity was the most important factor that facilitated the use of the device, and this need was met through using a smartphone app. Detachment of the device and difficulties in using the app were the main factors that hampered its use.

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CONFLICT OF INTERESTS

M. Thymi reports grants from Sunstar Suisse SA, during the conduct of the study. M.C. Verhoeff reports Grants from Nederlandse Vereniging voor Gnathologie en Prothetische Tandheelkunde (NVGPT), grants from Nederlandse Wetenschappelijke Vereniging voor Tandheelkunde (NWVT), grants from Stichting Mondzorg en Parkinson, outside the submitted work. Dr. C.M. Visscher has nothing to disclose. Dr. Lobbezoo reports grants and other from Sunstar Suisse SA, during the conduct of the study. Grants from Somnomed-Goedegebuure, grants from Airway Management, outside the submitted work.

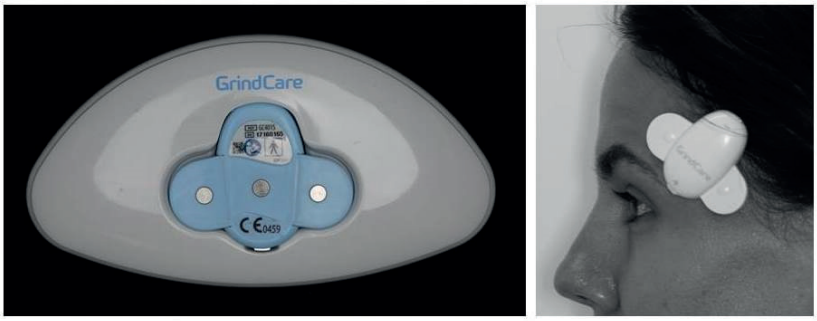

Figure 1. The BUTLER® GrindCare® device. Left: the device in the docking station; Right: the device attached to the skin

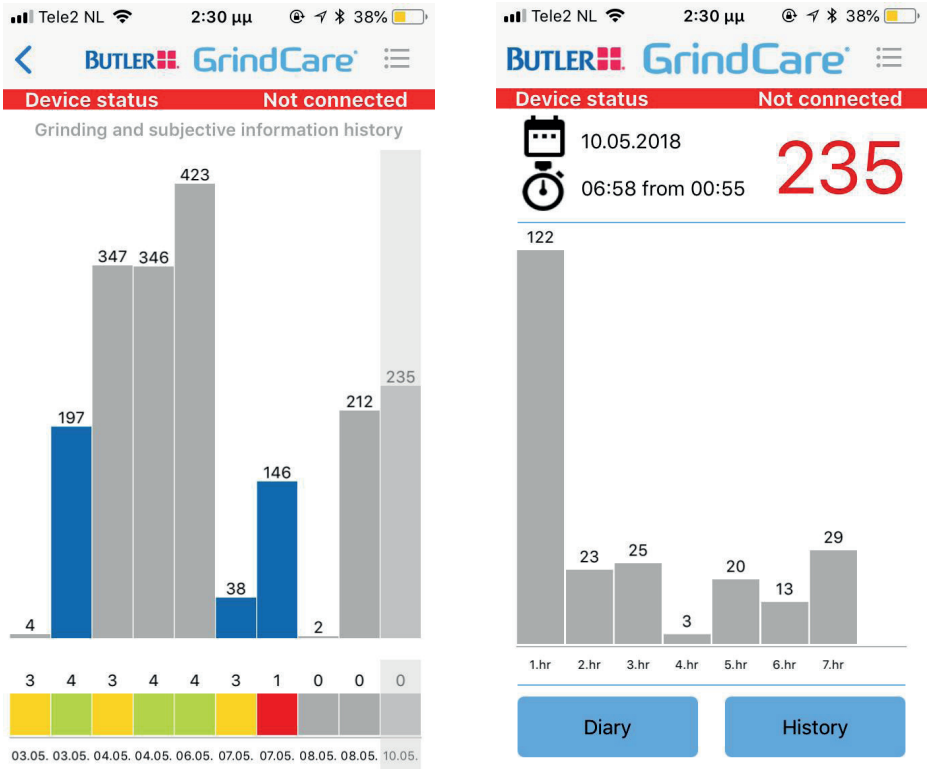

Figure 2. Screenshots of the GrindCare ® smartphone app. Left: visualization of the frequency of masticatory muscle events for 10 recordings – each bar represents one recording; Right: visualization of the frequency of masticatory muscle events for one recording – each bar represents one hour of recording

Table 1. Structure of diary

	Domains		Method of data collection	Time-point
Diary Section 1	1	Feelings and thoughts prior to sleeping with the device	Free text and 5-point Likert scales,	Evening (D1-D7)
	2	Time needed to place the device	Minutes and seconds	
	3	Reason(s) for not using the device	Multiple choice with option of free text	Evening (D1-D7, in case of non-use)
	4	Degree of disturbance of sleep due to the device	5-point Likert scale	Morning (D1-D7)
	5	Experiences related to sleeping with the device	Free text	
Diary Section 2	6	Degree to which sleeping with the device is pleasant or annoying	5-point Likert scale	End of follow-up
	7	Ease of using the device components: gelpads, charger, etc.	5-point Likert scale	
	8	Difficulties encountered while using the device	Free text	
	9	Reasons for (not) using the app		
	10	Suggestions and/or complaints regarding the use of the device		
	11	Willingness to recommend use of the device for diagnostic purposes of sleep bruxism	5-point Likert scale	

D = day

Table 2. Overview of diary data collected by 5-point Likert scales

	Questions	Median (25^{th} – 75^{th} quartile)
Diary Section 1	Ease or difficulty in placing the device (0 = extremely difficult, 5 = as easy as can be)	4 (4-5)
	Feeling of comfort in the prospect of sleeping with the device (0 = extremely uncomfortable, 5 = as comfortable as can be)	4 (3.75-4)
	Degree to which the device was disturbing during sleep (0= extremely disturbing, 5 = not disturbing at all)	4 (3-5)
Diary Section 2	Degree to which sleeping with the device is pleasant or annoying (0 = extremely annoying, 5 = as pleasant as can be)	4 (3.25-5)
	Ease or difficulty in using the device components: gelpads, charger, etc. (0 = extremely difficult, 5 = as easy as can be)	4 (3.25-5)
	Willingness to recommend use of the device for diagnostic purposes (0 = absolutely not, 5 = absolutely yes)	4 (4-4)

Table 3. Reasons for not performing a recording, n= 15, multiple reasons were given by some participants

Reason	Number of recordings	Number of participants
Reason not provided	11	4
Skin irritation	7	2
Did not feel like it	6	4
Device or app didn't work	6	3
Not sleeping at home	4	3
Forgot	3	2
Device disturbed children's sleep†	2	1
Not knowing how to place the device	1	1
Too tired in the evening	1	1
Time issues in the morning	1	1
Afraid it will disturb sleep	1	1

†This participant had to attend to his infant children during the night. When the children saw the device attached to his face they tended to play with it, which kept them from their sleep.

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Chapter 8

General Discussion

The studies included in this thesis have contributed to the body of knowledge regarding the consequences of bruxism, and more specifically its association with musculoskeletal signs and symptoms, and its effects on oral implants. Moreover, it has contributed to further development of bruxism diagnostic methods.

This chapter presents and discusses the main findings of the studies included in the thesis in three sections, namely Musculoskeletal signs and symptoms, The effects on oral implants, and Diagnosis of bruxism. Where appropriate, the implications for clinical practice and future research are given. The chapter ends by providing a general conclusion.

MAIN FINDINGS AND IMPLICATIONS

Musculoskeletal signs and symptoms

Chapters 2 and **3** present two investigations on the association between bruxism and musculoskeletal signs and symptoms.

In **chapter 2**, the question ”to what extent is bruxism associated with musculoskeletal signs and symptoms” was answered through a comprehensive systematic review of the literature. Both circadian manifestations, i.e., sleep and awake bruxism, were assessed in children and adult populations. Bruxism cases were sorted on the basis of assessment method, i.e., either self-report, or self-report plus clinical examination and instrumental methods. Musculoskeletal outcomes were grouped into six categories, i.e., functional signs and symptoms, muscle pain or non-painful symptoms, temporomandibular joint (TMJ) pain or non-painful TMJ symptoms, function-related pain, orofacial pain involving musculoskeletal structures, not fit for categories above, and structured temporomandibular disorder (TMD) diagnoses based on diagnostic systems other than the (research) diagnostic criteria for TMD (viz., RDC/TMD [1] or DC/TMD [2]). Experimental bruxism studies were assessed separately from the clinical studies. A qualitative synthesis of results of included studies was performed.

Fifty-one studies were included in this review. Despite this high number, there was insufficient evidence to allow for conclusions on the topics of association between a) awake bruxism and TMJ pain, and b) awake and sleep bruxism and non-pain symptoms and functional signs and symptoms for adult populations. The difficulties when drawing conclusions was the result of either the absence of relevant studies, and/or the use of poor case or outcome definitions. For child populations, studies utilizing instrumental methods for the assessment of bruxism

were greatly lacking.

The synthesis of results from experimental bruxism studies in healthy adults showed that the experimental increase of masticatory muscle activity can lead to transient pain and fatigue. In child populations, clinical studies utilizing self-report supported an association between awake bruxism and musculoskeletal pain, while conclusions regarding sleep bruxism and pain are similar to those of adult populations, which are presented below.

In adult populations, both clinical studies implementing self-report as well as those utilizing instrumental methods for the assessment of awake bruxism found a positive association with the presence of pain in the masticatory muscles. Studies using instrumental methods were of short duration, i.e., one, [3] seven, [4] and ten [5] days. Long-term associations between awake bruxism and muscle pain remain unknown. Fortunately, new diagnostic technologies are emerging that may allow for accurate awake bruxism diagnoses. Such technologies utilize the ecological momentary assessment (EMA) method (e.g. [6]), and may be combined with concurrent electromyographic recordings (EMG) (e.g. [7]). The ability to adequately assess awake bruxism behaviours [8] in larger cohorts, for longer periods of time is crucial to understand its association with musculoskeletal signs and symptoms. [9]

As for sleep bruxism in adult populations, studies using instrumental methods, i.e., EMG recordings and polysomnography (PSG), were fairly consistent in showing that sleep bruxism status, i.e., receiving a sleep bruxism diagnosis based on the Lavigne et al. criteria, [10] is not associated with the presence of musculoskeletal pain. When other sleep bruxism outcomes were evaluated, e.g., type and length of bruxism episodes and night-to-night variability, no consistent association was found with musculoskeletal outcomes. On the other hand, a positive association was found between self-reported sleep bruxism, with or without additional clinical examination, and TMD pain.

These findings suggest that, hitherto, different conclusions are drawn on the association between sleep bruxism and musculoskeletal pain, depending on how sleep bruxism is being assessed. Thus, the importance of consensus regarding adequate sleep bruxism diagnostic criteria is clear. This matter will be further discussed in the Diagnosis section of this chapter. Taken together, the main conclusion of this systematic review is that bruxism is to some extent associated with musculoskeletal symptoms, and that a direct linear causal relationship between bruxism and musculoskeletal signs and symptoms is not likely. The absence of a linear association between sleep bruxism and masticatory muscle symptoms is supported by

the findings presented in **chapter 3**. This chapter describes a clinical study on the presence and relationships of masticatory muscle symptoms in a group of probable sleep bruxers with and without painful TMD. Muscle symptoms were pain, unpleasantness, tiredness, tension, soreness, and stiffness, and were evaluated directly after a clinical exam according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) by means of a 0-10 numerical rating scale (NRS). The second arm of the study evaluated the relationship of these symptoms with frequency measures of masseter muscle EMG activity during sleep, i.e., mean number of EMG events per recording, mean number of EMG events per hour of recording, and night-to-night variability in EMG events, based on multiple night recordings.

The fist main finding was that the abovementioned masticatory muscle symptoms are highly prevalent in the sample of probable sleep bruxers, with 74% of the participants reporting three or more symptoms. This figure varies from 62% in the non-TMD group, to 90% in the TMD-pain group. Thus, individuals with self-reported sleep bruxism and clinical signs hereof, are very likely to report masticatory muscle symptoms, even in the absence of a TMD-pain diagnosis. The second main finding challenges the first, as no statistically significant associations were found between neither the presence, nor the intensity of these symptoms and EMG frequency measures of muscle activity during sleep.

When taken together, these findings have a number of implications. To start with, as discussed in **chapter 3**, it seems reasonable to suggest that the TMD phenotype includes symptoms other than pain. The importance of non-painful symptoms as precursors of TMD-pain onset has previously been shown in a large prospective cohort study. [11] Besides being precursors of subsequent TMD-pain, the mere burden of non-painful symptoms for the individual deserves further attention. It may be hypothesized that combinations of chronic non-painful symptoms can form an equal burden to an individual as pain. The example is given of the individual who is, on a daily basis, experiencing low-grade tension *and* stiffness *and* unpleasantness, or might be experiencing only tension, but of very high intensity. When other factors, such as psychological comorbidity and health beliefs are added to the mixture, it is imaginable that this individual may seek treatment. Furthermore, it is plausible that non-painful symptoms are expressed as proxies for pain, especially in males, as the expression of pain may be influenced by stereotypical beliefs of masculinity and gender. [12] Thus, further research on the role of non-painful symptoms in the pathophysiological paths of the development of TMD-pain, and treatment seeking behaviours is important.

Furthermore, the findings of **chapter 3** regarding the contrast between the high prevalence

of symptoms in self-reported sleep bruxers vs. the absence of a statistical association when masticatory muscle activity is instrumentally assessed combined with those of **chapter 2** suggest that interpretation of sleep bruxism self-reports should be approached with caution when orofacial symptoms are present. As discussed in **chapter 3**, selecting a sample based on self-reported bruxism might attract individuals with preconceived ideas about the harmfulness of bruxism. The experience of unexplained symptoms may lead an individual to search for a possible cause. This issue has previously been raised by Raphael et al., [13] who discuss that patients may be inclined to report sleep bruxism under the influence of clinicians' or sleep partners' opinions, a phenomenon also known as reporting bias. [14] In the same order, Camara-Souza et al. [15] report that the sample that was recruited in their study based on street advertisements 'were probably the ones experiencing the major consequences of sleep bruxism'. This issue is relevant in both the research, as well as the clinical setting. The implication for the first is that study samples should be carefully selected based on the research question. For example, a future study on the association between orofacial symptoms and instrumentally assessed masticatory muscle activity during sleep should include participants irrespective of self-reported sleep bruxism status, so as to minimise the bias arising from attracting individuals with a higher rate of symptoms. As for clinical practice, the conclusion arising from the current discussion is that clinicians should be cautious not to rush into blaming sleep bruxism as the cause for their patients' complaints and thus risk overlooking other, more 'difficult' issues, such as psychosocial and sleep comorbidity.

A final remark will be made regarding the investigation of musculoskeletal signs and symptoms and their relation with bruxism. The importance of adequate sleep and awake bruxism case definitions was highlighted above. Proper outcome definitions are equally important. The DC/TMD criteria are an excellent example of widely used, highly standardized criteria for clinical and research practice. [2] It is highly recommended that future studies continue using these criteria when investigating musculoskeletal pain and functional problems of the masticatory system, for the sake of comparability and internal validity. Researchers should be aware of possible updates of these criteria. Where possible, self-reports should be avoided. Further research on the development of standardized diagnostic criteria for non-painful symptoms is necessary. When overseeing this, the first step could be "choosing which symptoms should be evaluated". The results of the study in **chapter 3** showed that tiredness and tension were the most prevalent symptoms, thus our suggestion is to always include them in assessments. Tension and stiffness were consistently found to be correlated in our sample, irrespective of TMD-pain status, possibly pointing towards a phenotypic and/or linguistic overlap, which should be further investigated. As argued in **chapter 2**, the construct of unpleasantness might

have similarities with catastrophizing, which has been shown to be relevant in treatment seeking behaviours of TMD pain patients [16]. As such, it is suggested that unpleasantness should be included in assessments of non-painful orofacial symptoms. Besides stiffness and soreness, also symptoms of cramping, fatigue, pressure, and ache were evaluated in the study of Ohrbach et al. [11] As is the case for tension and stiffness, a possible phenotypic and/or linguistic overlap might be hypothesized for soreness, ache, and pain, as well as for tiredness and fatigue. Since the presence of three or more of these orofacial symptoms were important predictors of TMD pain onset in the study by Ohrbach et al., [11] it is suggested that these symptoms are included in future studies. Thus, the symptoms evaluated should at least be: unpleasantness, tension, stiffness, tiredness, fatigue, soreness, cramping, pressure, and ache. Internal consistency studies can help identify similar constructs and fine-tune this list of symptoms. Care should be taken when formulating diagnostic instruments, so that these symptoms are clearly discriminated from, and not confused with, descriptions of pain (e.g., as can be assessed by the McGill Pain Questionnaire [17]).

The effects on oral implants

As is the case for musculoskeletal signs and symptoms, the occurrence of complications of oral implants is a highly multifactorial phenomenon, [18,19] with bruxism being one of the possible risk factors. [20] **Chapters 4**, **5** and **6** describe two investigations on the effects of bruxism on oral implants.

The study described in **chapter 4** aimed to explore and critically analyse the attitudes and experiences acquired by experienced oral implantologists when dealing with bruxing patients in an everyday clinical, non-academic setting. For this purpose, nine semi-structured interviews were performed, followed by thematic analysis of acquired data. The qualitative study design allowed for a rich amount of information to emerge. The most clinically relevant findings of the study will be discussed here.

The interviews showed that implantologists had a generally open attitude when it came to performing implant treatments in patients with bruxism activity. Some complications were expected to occur, mainly fractures of superstructures' porcelain. However, their extent is not such that bruxism is considered a contraindication. This finding is in line with the current view that bruxism is not a de facto pathological activity. [21,22]

As mentioned by a number of interviewees, "real bruxers will break everything". Literature suggests that a cluster pattern among patients with implant failure is highly probable. [18] We

carefully hypothesize that these “real bruxers” correspond to the group of patients in which cluster failures will occur. Consequently, early recognition of this group is pivotal for optimal treatment planning, which, once again points to the importance of an adequate diagnostic instrument which can be used in everyday clinical practice.

In the absence of evidence-based criteria for the management of patients with bruxism, clinicians tended to control what could be controlled for by striving to make treatment choices which would allow for a safe distribution of expected occlusal forces. In general, however, these treatment choices varied extensively. A recurring item was the design and choice of the occlusion and articulation concept, which, as clinicians mostly agreed, is a crucial aspect for preventing complications. No uniform vision on ideal occlusion concepts emerged from the interviews, while it was a general view that fixed superstructures should be free from contacts during articulation. Recommendations on occlusal and articulation schemes based on a biomechanical rationale do exist in literature, [19,23] and ‘careful occlusal review’ is recommended for the prevention of technical complications of implant-supported fixed prostheses. [24] However, thus far, occlusal and articulation schemes have not been supported by evidence in bruxism populations. [25] As discussed in **chapter 4**, adjustments of the occlusion and articulation are readily accessible actions for daily practice, and the inclusion of this variable in future scientific investigations is strongly recommended.

Another interesting finding of this study is the prominent diversity in the attitudes regarding the importance of occlusal loading in the pathogenesis of peri-implant bone loss. As pointed out in the discussion section of **chapter 4**, such diversity is encountered in a number of other countries as well. [26,27] A previous systematic review of the literature was unable to provide unequivocal evidence in support of a cause-and-effect relationship between occlusal overload of oral implants and bone or implant loss, [28] and a more recent prospective study found that bone density might slightly increase over time in patients with implant-supported complete dentures and self-reported sleep bruxism. [29] Even so, clinical recommendations have been given to manage excessive forces related to parafunctional habits [30] and avoid inappropriate loading, [31] based on the presumption that these conditions may lead to severe bone loss. Interestingly, Dawood et al. [31] express their belief that failures due to excessive loading are distinctly different to peri-implantitis, a suggestion that has similarities with an earlier hypothesis on the existence of two distinct types of implant failures, namely infectious and traumatic. [32] The conduct of research on the topic of bruxism, and, in a more general sense, occlusal overload or trauma of oral implants is extremely challenging, [19] but still, as the results of our study show, highly necessary.

An attempt to investigate the effects of sleep bruxism on implants and peri-implant tissues was carried out by designing a single-centre, double-blind, prospective cohort study with a two-year follow-up period, the protocol of which is described in **chapter 5**. **Chapter 6** describes the outcomes and challenges that were encountered during the conduct of this study. In short, the design entailed the inclusion of 98 adults receiving implant-supported fixed suprastructures. Sleep bruxism was assessed by means of single-channel, ambulatory EMG recordings of the anterior temporalis muscle. A total of nine recordings per participant were performed. Primary outcomes were biological and technical implant complications.

As described in **chapter 6**, we were unable to conduct the study according to the published protocol, due to a number of setbacks. Consequently, and following the famous words of Thomas Edison – "Just because something doesn't do what you planned it to do doesn't mean it's useless" – we performed a critical evaluation of the study processes. This led to the distillation of 'lessons learned', which, in turn, can be used to design more successful research in the future.

The most important obstacle was the failure to reach the predefined sample size of 98 participants. Instead, only 11 individuals agreed to participate, of which six completed the two-year follow-up period. Clearly, this number is not sufficient to draw any conclusions on the main aims of the study. Thus, unfortunately, this thesis is not able to provide the long sought-for answer as for whether or not sleep bruxism is actually bad for oral implants. As discussed in **chapter 6**, committing to a longitudinal observational study with multiple sleep recordings might have been perceived as too burdening, and as such contributed to this disappointing participation rate. Of note, longitudinal cohort studies utilizing instrumental methods for assessments of sleep bruxism on multiple time points are practically absent not only in the field of oral implants, but also in other bruxism-related fields, such as those involving musculoskeletal signs and symptoms and tooth wear. [33] We were unable to retrieve such studies in either published, or unpublished [34] form. It is intriguing to speculate about the causes underlying this absence of studies. Quite possibly, the lack of an instrumental diagnostic method that is capable of diagnosing bruxism in a simple and cost-effective way might be at play here.

Finally, regarding the association between bruxism and oral implant complications, we suggest that the topic is equally complex as that of the association between bruxism and musculoskeletal complications. Interviewed clinicians repeatedly stated that many factors contribute to complications of oral implants, with bruxism being only one of those. Thus,

here too, the presence of a linear association is highly unlikely.

Diagnosis of bruxism

As repeatedly mentioned above, the presence of adequate diagnostic criteria for both sleep and awake bruxism are cornerstones of solid bruxism research. This view is in line with the research agenda set by an international team of experts, in which the necessity for good diagnostic tools is highlighted, and the 'A4 principle' is suggested for the ideal assessment of sleep and awake bruxism, i.e. 'accurate (reliable, valid), applicable (feasible), affordable (cost- effective) and accessible (suitable for everyday clinical use)'. [21] In the present thesis, the aspects of applicability and accessibility were probed in **chapters 4**, **6**, and **7**. The topic of bruxism diagnosis will be discussed below in three sections.

The importance of assessing the presence of bruxism

Results from the qualitative study described in **chapter 4** show that opinions on the importance of assessing the presence of bruxism in the oral implantology practice diverged. On one side practitioners expressed that bruxism assessment is a crucial element of all patient examinations, while on the other side of the spectrum it was claimed that the activity occurs in virtually everyone, so that specifically addressing it is unnecessary. The latter approach has some truth in it, insofar that some sleep bruxism activity is most likely present in everyone during the course of lifetime. [35] However, this is not the case for awake bruxism. Studies on the prevalence of self-reported awake bruxism involving teeth contact has found figures between 22.1% and 33% [36], while emerging evidence utilizing EMA shows a prevalence of 14.5% for teeth contact, 3.7% for teeth clenching and .1% for teeth grinding while awake in a young adult sample [8]. Furthermore, the intensity of both sleep [37] and awake [4] bruxism can vary, as does the co-occurrence of risk factors, such as smoking and poor bone quantity, [38] that may interact with bruxism and intensify its negative effects. Thus, it is strongly recommended that both awake and sleep bruxism are assessed in the oral implantology clinic, alongside with other relevant risk factors. The question then remains of how this assessment may be best carried out.

Conclusions and suggestions for self-report and clinical examination

Instrumental methods for the diagnosis of sleep and awake bruxism are practically absent for widespread use in daily practice, which forces clinicians to use what is left, i.e. self-report and clinical examination.

Indeed, the results of the study presented in **chapter 4** showed that practitioners largely

rely on clinical inspection for assessing bruxism, even though it was acknowledged that this is not a watertight diagnostic method. A number of extra- and intraoral clinical signs indicative of bruxism were reported; however, no uniform set of criteria was observed among practitioners, nor was there always a clear distinction made between signs of sleep and awake bruxism. Clinical signs of bruxism and their limitations in terms of validity have been discussed in the literature before. [35,39,40] Furthermore, patient self-report was generally not considered a trustful source of information for sleep bruxism by participants in our study, an attitude that is in line with scientific literature. [41] Interestingly, it was not uncommon for clinicians in our study to trust their gut feeling as an indicator of bruxism being present.

It is unlikely that self-report and clinical examination methods will ever reach the validity level of instrumental diagnostic methods. At the same time, it is unrealistic to expect that these approaches will be abandoned in the near future in both the clinical, as well as the research setting, since they are readily available, simple, and low-cost compared to instrumental diagnostic methods. Therefore, we suggest that these methods at least become highly standardized, i.e., an 'assessment of bruxism in the clinic' tool is developed. This will enhance uniform clinical assessments of patients in the clinic, comparability of research results, and translatability of research results to clinical practice. Moreover, a structured evaluation of clinical signs will facilitate much needed future research on the association between bruxism and health outcomes. [9] Suggestions for the design of such a tool are presented below.

First, self-report needs to be standardized, and for this purpose, the widely available 'Oral Behaviours Checklist' can be used. [42] Self-reports might be influenced by comorbid conditions, and evidence suggests that the presence of myofascial TMD pain can be associated with over-reporting sleep bruxism [13], while the presence of TMD pain and headache may be related with less reporting of awake bruxism. [43,44] Such information should be available for clinicians interpreting the results of a questionnaire. Second, a simple, chair-side checklist of extra- and intraoral clinical signs [39] may be developed. The checklist should be accompanied by detailed instructions of use, as is the case for other highly standardized diagnostic instruments, such as the DC/TMD [2]. Reliability of such a tool needs to be assessed for sleep and awake bruxism in different populations, e.g., children, adults, and individuals with developmental disabilities, and under different circumstances, e.g., dentate or edentate, with or without removable prostheses. International consensus on a clinical tool for the assessment of bruxism is important, and hereby a call is made for including this topic in the bruxism research agenda. [9,21]

Conclusions and suggestions for instrumental assessments

More knowledge on the epidemiology of both sleep and awake bruxism is highly needed. [9] Succeeding in this goal requires optimal diagnostic instruments [21] which can be implemented in large scale studies, and are able to capture the time-variant nature of both sleep and awake bruxism. [9]

Investigating the validity of instrumental devices was beyond the scope of this thesis. Instead, a study was carried out to explore the experience of individuals with the use of a portable, wireless, single-channel EMG device, that pairs with a smartphone app to assess masticatory muscle activity during sleep, in order to detect factors that might facilitate and/or hamper its utilization in future scientific research (**chapter 7**). The initiative for performing this study arose from observing the reluctance of individuals to participate in the study described in **chapter 5**, which, as described in **chapter 6**, seemed to be related to a perceived burden from committing to a lengthy study, and performing multiple night recordings. This led to the desire to document the burden that can be caused by multiple night recordings, which will allow for fine-tuning future versions of the EMG device, anticipate on certain problems during the conduct of a study, and provide candidate study participants with proper information during the informed consent procedure.

The results described in **chapter 7** show that the use of the device was well accepted for multiple overnight recordings by individuals attending an Orofacial Pain and Dysfunction referral clinic. Participants used the device for a median of 5 recordings, when given the choice to use it between one and seven nights. Two main pitfalls were detected in this study, namely detachments of the device during sleep and difficulties in using the smartphone app. The former issue occurred in 20.6% of the recordings, and was also observed in a similar rate (23%) the study described in **chapter 6**. The latter issue was mostly related to the app's functionality. Both issues should be addressed by the manufacturer in future versions of the device. Until then, researchers utilizing this device are advised to be very thorough in their instruction given to study participants.

Curiosity for gaining insight into one's masticatory muscle activity during sleep was the most important facilitating factor, through creating motivation for using the device. The smartphone app mediated this process, by enabling visualization of the muscle activity. As discussed in **chapter 7**, after taking into account the findings of studies utilizing smartphone-based technologies for the study of awake bruxism [7,45] we suggest that these technologies offer valuable tools for the research of the hard to grasp, time-variant sleep and awake bruxism,

and should further be developed.

A final note will be made regarding the implications of the results of this thesis on the topic of scoring sleep bruxism activity. As described in **chapter 6**, an important issue was brought to light during the conduct of this clinical study, namely the rate of unsuccessful sleep recordings. In order to obtain useful EMG data, quality criteria for the assessment of the acquired EMG signals were set, namely acceptable signal-to-noise ratio (SNR) (i.e., >10), during a sufficient length of the recording (i.e., at least 75% of the recording). Furthermore, three maximum voluntary contractions (MVC) were required within the first 30 minutes of the recording, so as to allow for scoring of EMG events based on the %MVC criterion [10]. In total, 94 overnight recordings were performed, of which only 44 (47%) fulfilled the pre-established quality criteria. The most prevalent issues for the 50 failed recordings were: absence of MVCs (44%), low SNR (16%), and short recordings due to detachment of the device's electrode (23%). Similar high rates of EMG recording failures were not found in the literature. This may be the result of either underreporting the issue, of the issue actually not occurring that often, and/or of the issue not being equally relevant, due to alternative EMG scoring methods. Examples of such are the times-noise-level [46] and moving average method [47]. The importance of MVC for scoring sleep bruxism should be taken under the loop in future research. Doubts about the correct performance of EMG recording set-up procedures that require participants to relax and clench have been reported before. [48] When a scoring method depends on the presence of an MVC, but a participant forgets to perform this, the recording is rendered unusable. Subsequently, if future evidence suggests that scoring methods which are not dependent on MVCs are equally capable of accurately capturing the presence of sleep bruxism, they should be preferred for reasons of being less sensitive to the risk of data loss.

CONCLUSION

Bruxism may to some extent be considered a behaviour with negative implications, i.e., musculoskeletal signs and symptoms and a possible risk for oral implant complications. Linear associations are not likely. Adequate bruxism diagnostic methods are cornerstones for future relevant research and more predictable clinical treatment.

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Chapter 9

Summary

Bruxism is a masticatory muscle activity that can occur during sleep and/or wakefulness. Sleep bruxism is characterised by rhythmic or non-rhythmic mandibular movements, while awake bruxism involves repetitive or sustained tooth contact, and/or bracing or thrusting of the mandible. It may lead to negative health outcomes, such as musculoskeletal signs and symptoms and complications of oral implants. The exact association, however, is still not fully understood. Moreover, the diagnosis of both sleep and awake bruxism is challenging, with instrumental methods that can lead to a definite diagnosis not being widely available. The purpose of this thesis was to investigate the association between bruxism and musculoskeletal signs and symptoms (chapters 2 and 3), as well as the association between bruxism and oral implant complications (chapters 4, 5, and 6). Moreover, aspects related to the applicability of diagnostic methods for bruxism in the clinic were studied (chapters 6 and 7).

Chapter 1 offers a general introduction, in which the aims of the thesis are described, and the research questions are presented.

Chapter 2 describes a systematic review of the literature, designed to answer the question ”to what extent is bruxism associated with musculoskeletal signs and symptoms?”. Case-control, cross-sectional, prospective cohort, and experimental bruxism studies were included in the review. The experimental studies showed that experimental increase of masticatory muscle activity can lead to transient musculoskeletal pain and fatigue. Results from case-control, cross-sectional, and prospective cohort studies support a positive association between awake bruxism and the presence of masticatory muscle pain in both children and adult populations. However, studies utilizing instrumental methods for the assessment of awake bruxism in larger cohorts, for longer periods of time are lacking. Self-reported sleep bruxism appears to be positively associated with temporomandibular disorder (TMD) pain. This association is no longer consistent when instrumental methods are used to assess the muscle activity. There were too few studies to allow for solid conclusions on the topic of functional signs and symptoms, as well as for symptoms other than pain. The main conclusion of this review was that bruxism is to some extent associated with musculoskeletal signs and symptoms, and that a direct linear causal relationship is not likely. Taken together, the review underlines the need for proper diagnostic methods for both sleep and awake bruxism.

Chapter 3 continues on the topic of masticatory muscle symptoms. It describes a clinical study which investigated the presence of masticatory muscle symptoms, i.e., pain, unpleasantness, tiredness, tension, soreness, and stiffness in a group of probable sleep bruxers, with and without painful TMD. Furthermore, the association between these symptoms and frequency

measures of masticatory muscle electromyographic (EMG) activity during sleep were investigated. Muscle symptoms were evaluated on a 0-10 numerical rating scale directly after a clinical exam using the Diagnostic Criteria for Temporomandibular Disorders. Muscle activity during sleep was assessed by multiple overnight EMG recordings, and EMG outcome measures were: mean number of EMG events per recording, mean number of EMG events per hour of recording, and night-to-night variability in EMG events. The study showed that muscle symptoms are highly prevalent in probable bruxers, i.e., individuals who reported sleep bruxism and presented intraoral clinical signs hereof. Those with TMD pain report significantly more, and more intense symptoms, as compared to the probable bruxers without TMD pain. Pain is the least prevalent and intense symptom in both subgroups, indicating that the TMD phenotype may consist of more than only pain symptoms. Furthermore, and in line with the findings of chapter 2, no significant correlation was found between the six symptoms and any EMG frequency measures of masticatory muscle activity during sleep.

In **chapter 4** the focus shifts towards the association between bruxism and oral implant complications. The attitudes of experienced oral implantologists when dealing with bruxing patients in the everyday clinical, non-academic setting were explored through semi-structures interviews. These showed that the clinicians have a generally open attitude regarding implant treatment in patients with (suspected) bruxism. Certain complications are expected to occur, but their extent is not such that bruxism should per se be considered a contraindication for oral implantology. Treatment choices vary, but there is a general consensus that occlusion and articulation schemes are important for the protection of the suprastructure. Prominent controversy amongst clinicians is encountered with respect to bruxism being a causative factor of peri-implant bone loss, with some arguing pro, and others against such an involvement. The diagnosis of bruxism is set mainly by clinical examination, and it is acknowledged that this comes with difficulties; one may never be sure if bruxism is actually present. If more accurate diagnostic methods are to be developed these should be simple in their use.

Chapter 5 describes the protocol of a single-centre, double-blind, prospective cohort study with a follow-up time of 2 years, designed to investigate the association between sleep bruxism and (peri-)implant complications. The design entailed the inclusion of 98 adults receiving implant-supported fixed suprastructures. Sleep bruxism was assessed by means of single-channel, ambulatory EMG recordings of the anterior temporalis muscle. A total of nine recordings per participant were performed. Primary outcomes were biological and technical implant complications. **Chapter 6** describes the outcomes of the study and critically evaluates the process of the study conduct. Several challenges were encountered, which hampered

completion of the study according to the protocol. The most important obstacle was failure to reach the predefined sample size. Subsequently, no conclusions could be drawn on the main aims of the study. The demanding study protocol, according to which multiple sleep recordings had to be performed over a longer period of time, is considered an important factor that contributed to this failure. Moreover, difficulties were faced during the assessment of sleep bruxism, with EMG recordings being insufficient for scoring of muscle events. This was mainly the result of detachment of the EMG device during sleep and non-compliance of participants with the instruction to perform maximum voluntary contractions (MVC) within the first 30 minutes of each recording. This procedure was required for subsequent scoring of the EMG signal based on the %MVC method. Taken together, from the conduct of the study it was learned that a pragmatic and accurate sleep bruxism diagnostic tool is needed for future successful prospective cohort studies.

Chapter 7 describes a mixed methods study designed to explore the experience of individuals with the use of a portable EMG device that pairs with a smartphone app for the assessment of masticatory muscle activity during sleep. This design allowed the detection of factors that could facilitate and /or hamper its utilization in future scientific research. The study showed that the device is well accepted for multiple overnight recordings within the period of one week. The most important factor that facilitated its use is engaging the curiosity of the user through visualising the muscle activity on a smartphone. The most important factors that hampered its use involve difficulties in using the smartphone app and detachments of the device during sleep. The results of the study suggest that smartphone-based technologies are promising tools for the diagnosis of both sleep and awake bruxism.

Finally, **chapter 8** discusses the main findings of the studies included in the thesis, and presents their implications for clinical practice and future research.

Chapter 10

Samenvatting

SAMENVATTING

Bruxisme is een kauwspieractiviteit die aanwezig kan zijn tijdens slapen en/of waken. Slaap bruxisme kenmerkt zich door ritmische of niet-ritmische bewegingen van de mandibula, terwijl waak bruxisme zich kenmerkt door repetitief of aanhoudend contact van de tanden/kiezen en/of het fixeren van, of duwen met de onderkaak. Het kan tot negatieve gezondheidsuitkomsten leiden, zoals musculoskeletale tekenen en symptomen, en complicaties van orale implantaten. De precieze associatie is echter niet volledig begrepen. Daarnaast is de diagnose van zowel slaap als waak bruxisme uitdagend, doordat instrumentele methodes die tot een definitieve diagnose kunnen leiden niet op grote schaal beschikbaar zijn. Het doel van dit proefschrift was het onderzoeken van zowel de associatie tussen bruxisme en musculoskeletale tekenen en symptomen (hoofdstukken 2 en 3), als de associatie tussen bruxisme en complicaties van orale implantaten (hoofdstukken 4, 5 en 6). Verder is onderzoek gedaan naar aspecten gerelateerd aan de toepasbaarheid van diagnostische methoden voor bruxisme in kliniek (hoofdstukken 6 en 7).

Hoofdstuk 1 behelst een algemene introductie, waarin de doelen van dit proefschrift zijn beschreven, en de onderzoeksvragen zijn gepresenteerd.

Hoofdstuk 2 beschrijft een systematisch literatuuronderzoek, welk is ontworpen om de vraag "in hoeverre is bruxisme geassocieerd met musculoskeletale tekenen en symptomen?" te beantwoorden. Patiënt-controle, cross-sectionele, prospectieve cohort en experimentele bruxisme studies zijn in het literatuuronderzoek geïncludeerd. De experimentele studies lieten zien dat het experimenteel verhogen van de kauwspieractiviteit kan leiden tot kortdurende musculoskeletale pijn en vermoeidheid. De resultaten van de patiënt-controle, cross-sectionele en prospectieve cohort studies ondersteunen een positieve associatie tussen waakbruxisme en de aanwezigheid van pijn in de kauwspieren, in zowel kinderen als volwassen populaties. Echter, studies die gebruik maken van instrumentele methodes voor het beoordelen van waakbruxisme in grotere cohorten, en langere tijdsperiodes ontbreken. Zelfgerapporteerd slaapbruxisme blijkt positief geassocieerd te zijn met temporomandibulaire disfunctie (TMD) pijn. Deze associatie blijft niet langer consistent zodra instrumentele methodes worden gebruikt voor het beoordelen van kauwspieractiviteit. Er waren te weinig studies om een solide conclusie te kunnen trekken voor de onderwerpen van functionele tekenen en symptomen, alsmede voor symptomen anders dan pijn. De hoofdconclusie van dit literatuuronderzoek is dat bruxisme tot op bepaalde mate geassocieerd is met musculoskeletale tekenen en symptomen, en dat een direct lineaire verband niet aannemelijk

is. Tezamen onderstreept dit literatuuronderzoek de noodzaak voor juiste diagnostische methodes voor zowel slaap- als waakbruxisme.

Hoofdstuk 3 gaat verder op het onderwerp van symptomen van de kauwspieren. Het beschrijft een klinische studie die de aanwezigheid heeft onderzocht van symptomen van de kauwspieren, te weten pijn, onaangenaamheid, vermoeidheid, spanning, zeer en stijfheid, in een groep personen met waarschijnlijk slaapbruxisme, met of zonder TMD pijn. Daarnaast is de associatie onderzocht tussen deze symptomen en frequentie uitkomstmaten van electromyografische (EMG) kauwspieractiviteit gedurende de slaap. Kauwspiersymptomen zijn geëvalueerd op een 0-10 numerieke ratingschaal, direct na een klinisch onderzoek volgens de Diagnostische Criteria voor Temporomandibulaire Disfunctie. Kauwspieractiviteit gedurende de slaap is beoordeeld door multipele nachtelijke EMG opnames, en EMG uitkomstmaten waren: gemiddeld aantal EMG-gebeurtenissen ('events') per opname, gemiddeld aantal EMG-gebeurtenissen per uur van opname, en nacht-tot-nacht variabiliteit van EMG-gebeurtenissen. De studie toonde een hoge prevalentie van kauwspiersymptomen in een groep waarschijnlijk bruxisten, d.w.z. personen die slaapbruxisme rapporteren en hier intraorale klinische tekenen van vertonen. Degenen met TMD pijn rapporteren meer, en meer intense symptomen, vergeleken met de waarschijnlijk bruxisten zonder TMD pijn. Pijn is het minst prevalente en intense symptoom in beide subgroepen, wat erop wijst dat het TMD fenotype mogelijk door meer symptomen bestaat dan alleen pijn. Daarnaast, en in dezelfde lijn als de bevindingen van hoofdstuk 2, is er geen significant verband gevonden tussen de zes symptomen en de EMG frequentie uitkomstmaten van EMG kauwspieractiviteit gedurende de slaap.

In **hoofdstuk 4** verschuift de aandacht naar de associatie tussen bruxisme en complicaties van orale implantaten. De attitudes van ervaren orale implantologen in het omgaan met bruxerende patiënten in de dagelijkse, niet klinische setting zijn verkend door middel van semigestructureerde interviews. Deze toonden dat de clinici over het algemeen een open attitude hebben als het gaat om implantologische behandelingen bij patiënten met (suspect) bruxisme. Bepaalde complicaties worden verwacht, maar de omvang hiervan is niet zodanig dat bruxisme per definitie als een contra-indicatie voor orale implantologie moet worden beschouwd. Behandelkeuzes variëren, maar er bestaat algemene consensus dat occlusie en articulatie concepten belangrijk zijn voor de bescherming van de suprastructuur. Prominente controverse tussen clinici wordt tegengekomen als het gaat om bruxisme als causale factor voor verlies van peri-implantair bot, waarbij sommigen voor, en anderen tegen een degelijk verband pleiten. De diagnose van bruxisme wordt voornamelijk door middel van klinisch

onderzoek gesteld, en het is erkend dat dit gepaard gaat met moeilijkheden; men kan er niet zeker van zijn of bruxisme daadwerkelijk aanwezig is. Indien preciezere diagnostische methodes worden ontwikkeld zouden deze simpel in hun gebruik moeten zijn.

Hoofdstuk 5 beschrijft het protocol van een single-centre, dubbelblinde, prospectieve cohort studie met een vervolgtijd van 2 jaar, die is ontworpen om de associatie tussen slaapbruxisme en (peri-)implantaat complicaties te onderzoeken. Het ontwerp hield de inclusie van 98 volwassenen die implantaat-gedragen, niet uitneembare suprastructuren zouden ontvangen in. Slaapbruxisme werd geëvalueerd door middel van één-kanalige, ambulante EMG opnames van het anterieure deel van de temporalis spier. In totaal zijn er negen opnames uitgevoerd. Primaire uitkomstmaten waren biologische en technische implantaatcomplicaties. **Hoofdstuk 6** beschrijft de uitkomsten van de studie en evalueert de uitvoering ervan op een kritische manier. Een aantal uitdagingen zijn aangetroffen en deze hebben de voltooiing van de studie volgens protocol belemmerd. De meest belangrijke belemmering was het falen van het bereiken van de gepredefinieerde steekproefgrootte. Als gevolg hiervan konden er geen conclusies worden getrokken voor de doelstellingen van de studie. Het veeleisende protocol, volgens welk multipele slaapopnames moesten worden uitgevoerd binnen een lange tijdspanne, wordt beschouwd als een belangrijke factor die heeft bijgedragen aan dit falen. Daarnaast zijn er moeilijkheden ondervonden gedurende het evalueren van slaapbruxisme, waarbij EMG opnames ontoereikend waren voor het scoren van spier-gebeurtenissen. Dit was voornamelijk het resultaat van het loslaten van het EMG apparaat gedurende de slaap en niet-nakoming door de participanten van de instructie om maximale vrijwillige contractie (MVC) uit te voeren binnen de eerste 30 minuten van elke opname. Deze procedure is vereist zodat het EMG signaal vervolgens volgens de %MVC methode kan worden gescoord. Dat samengenomen, werd door het uitvoeren van de studie geleerd dat een pragmatisch een precies diagnostisch instrument voor slaapbruxisme noodzakelijk is voor toekomstige succesvolle prospectieve cohort studies.

Hoofdstuk 7 beschrijft een gemengde methoden studie die is ontworpen om te verkennen wat de ervaring is van personen met het gebruik van een draagbaar EMG apparaat dat zich koppelt met een smartphone app voor het evalueren van kauwspieractiviteit gedurende de slaap. Dit ontwerp liet het opsporen van factoren toe die het gebruik van het apparaat in toekomstig wetenschappelijk onderzoek kunnen bevorderen of tegenhouden. De studie toonde dat het apparaat goed wordt aanvaard voor multipele nachtelijke opnames gedurende een week. De meest belangrijke factor die het gebruik bevordert is het engageren van de nieuwsgierigheid van de gebruiker door het visualiseren van de spieractiviteit op een smartphone. De meest

belangrijke factoren die het gebruik van het apparaat tegenhouden hebben betrekking op moeilijkheden in het gebruik van de smartphone app en loslatingen van het apparaat gedurende de slaap. De resultaten van de studie suggereren dat smartphone-gebaseerde technologieën veelbelovende instrumenten zijn voor de diagnose van zowel slaap- als waakbruxisme.

Tot slot, **hoofdstuk 8** bespreekt de meest belangrijke bevindingen van de studies die onderdeel maken van dit proefschrift, alsmede hun implicaties voor de klinische praktijk en toekomstig onderzoek.

Chapter 11

About the author

Publications, presentations and posters

Acknowledgements

ABOUT THE AUTHOR

Magdalini Thymi was born in 1988 in Corfou, Greece. In 2005 she graduated from high school at the Alkinoös Lyceum in Corfou. She studied Dentistry in the Aristoteles University of Thessaloniki, Greece, were she graduated in 2011. Three weeks after receiving her dental degree she moved to The Netherlands. She worked as a general dentist in Haarlem before attending the postgraduate program of Oral Kinesiology at the Academic Centre for Dentistry Amsterdam (ACTA) in 2013. While following this program, she started her PhD research in 2014.

Since her graduation from ACTA in 2016 she is fully dedicated to the field of Orofacial Pain and Dysfunction. She worked as a differentiated dentist at the Centre for Special Dental Care of the Haga Ziekenhuis in The Hague between 2016 and 2017. From 2017 on she works as a clinician at the Stichting Bijzondere Tandheelkunde in Amsterdam. Since 2014 het clinical work has been combined with research, on the fascinating topic of bruxism.

She speaks Greek, Dutch, English and is working on her Arabic. She happily and gratefully lives in the beautiful city of Amsterdam.

PUBLICATIONS, PRESENTATIONS AND POSTERS

List of publications

Included in this thesis

- Associations between sleep bruxism and (peri-) implant complications: a prospective cohort study. Thymi M, Visscher CM, Yoshida-Kohno E, Crielaard W, Wismeijer D, Lobbezoo F. BDJ Open. 2017 Apr 14;3:17003. doi: 10.1038/bdjopen.2017.3.
- Experience with bruxism in the everyday oral implantology practice in the Netherlands: a qualitative study. Thymi M, Rollman A, Visscher CM, Wismeijer D, Lobbezoo F. BDJ Open. 2018 Nov 9;4:17040. doi: 10.1038/s41405-018-0006-4.
- Clinical jaw-muscle symptoms in a group of probable sleep bruxers. Thymi M, Shimada A, Lobbezoo F, Svensson P. J Dent. 2019 Jun;85:81-87. doi: 10.1016/j.jdent.2019.05.016.
- To what extent is bruxism associated with musculoskeletal signs and symptoms? A systematic review. Baad-Hansen L, Thymi M, Lobbezoo F, Svensson P. J Oral Rehabil. 2019 Sep;46(9):845-861. doi: 10.1111/joor.12821.
- Associations between sleep bruxism and (peri-)implant complications: lessons learned from a clinical study. Thymi M, Visscher CM, Wismeijer D, Lobbezoo F. BDJ Open. 2020 6:2. ttps://doi.org/10.1038/s41405-020-0028-6.
- Patient-based experiences with the use of an ambulatory electromyographic device for the assessment of masticatory muscle activity during sleep. Thymi M, Verhoeff MC, Visscher CM, Lobbezoo F. Accepted for publication, Journal of Oral Rehabilitation, February 2020.

Other

- Consensus-based clinical guidelines for ambulatory electromyography and contingent electrical stimulation in sleep bruxism. Lobbezoo F, Aarab G, Ahlers MO, Baad-Hansen L, Bernhardt O, Castrillon EE, Giannakopoulos NN, Grønbeck A, Hauschild J, Holst-Knudsen M, Skovlund N, Thymi M, Svensson P. J Oral Rehabil. 2019 Aug 20. doi: 10.1111/joor.12876.

List of presentations and posters

Related to this thesis

- To what extent is bruxism associated with musculoskeletal signs and symptoms? A systematic review. Oral Presentation. Nederlandse Vereniging voor Gnathologie en Prothetische Tandheelkunde (NVGPT), 1-11-2017, Utrecht, The Netherlands
- Experience with bruxism in the everyday oral implantology practice in the Netherlands: a qualitative study. Poster, International Association for Dental Research (IADR), poster ID #1503, 26-7-2018, London, UK
- Clinical jaw-muscle symptoms in a group of probable sleep bruxers. Oral Presentation.

European Academy of Orofacial Pain and Dysfunction (EAOPD), 31-9-2019, Noordwijk, The Netherlands

Other

- Verwezen voor forse, maar onbegrepen pijnklachten: een diagnostische zoektocht. Oral Presentation. Centraal Overleg Bijzondere Tandheelkunde (COBIJT), 21-9-2019, Apeldoorn, The Netherlands
- Gnathologie op een Centrum voor Bijzondere Tandheelkunde: de (on)mogelijkheden. Oral Presentation. Stichting Bijzondere Tandheelkunde (SBT), 8-11-2019, Amsterdam, The Netherlands

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EXPLORING THE FACETS OF BRUXISM

MAGDALINI THYMI