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Instrumental assessment of sleep bruxism: A systematic review and meta-analysis

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ABSTRACT

This systematic review and meta-analysis (MA) aimed to evaluate the diagnostic validity of portable electromyography (EMG) diagnostic devices compared to the reference standard method polysomnography (PSG) in assessing sleep bruxism. This systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement and was registered with PROSPERO prior to the accomplishment of the main search. Ten clinical studies on humans, assessing the diagnostic accuracy of portable instrumental approaches with respect to PSG, were included in the review. Methodological shortcomings were identified by QUADAS-2 quality assessment. The certainty of the evidence analysis was established by different levels of evidence according to the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework. A meta-analysis of diagnostic test accuracy was performed with multiple thresholds per study applying a two-stage random effects model, using the thresholds offered by the studies and based on the number of EMG bruxism events per hour presented by the participants. Five studies were included. The MA indicated that portable EMG diagnostic devices showed a very good diagnostic capacity, although a high variability is evident in the studies with some outliers. Very low quality of evidence due to high risk of bias and high heterogeneity among included studies suggests that portable devices have shown high sensitivity and specificity when diagnosing sleep bruxism (SB) compared to polysomnography. The tests performed in the MA found an estimated optimal cut-off point of 7 events/hour of SB with acceptably high sensitivity and specificity for the EMG portable devices.

1. Introduction

Bruxism is a masticatory muscle activity that can occur during sleep (rhythmic or non-rhythmic activity) and in wakefulness (characterized by repetitive jaw activity with or without tooth contact), respectively. It is not considered in healthy subjects as a disorder, but as a behavior that can be a risk factor and/or protective factor for certain clinical consequences and comorbidities [1–5]. An objective and reliable diagnosis of

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sleep bruxism (SB) is complex. Nonetheless, different methods (instrumental and non-instrumental tools) have been proposed for its assessment, which has different connotations and levels of certainty [6]. The non-instrumental approach includes the roommate testimony and the patient himself (self-reported bruxism), and the study of dental, muscular, and temporomandibular joint signs and symptoms (clinical examination). These methods do not necessarily indicate whether bruxing activity exists or not at the time of the examination, while this activity is influenced by different factors and is not constant over time [3,7–11].

These difficulties in assessing SB are contributing significantly to the overestimation of the prevalence of SB and the quality of existing studies since the variability of bruxism (chronological fluctuation) means that there is no linear or direct relationship between bruxism and tooth wear, which makes it difficult to calculate accurate prevalence values [12–15]. In addition to the evaluation methods described above, there are instrumental tools, and polysomnography (PSG) is the gold standard [16,17]. However, PSG is time-consuming and has an associated cost and effort, which hinders its use in clinical research protocols and daily clinical practice. The portable electromyography (EMG) devices have the advantage of being simpler to use and lower cost and can be used at home allowing multiple nights recording, although the EMG portable devices' reliability has not yet been fully validated [18,19].

In some cases, SB does not manifest as an isolated entity. It can be accompanied by other types of activities typical of different associated disorders such as obstructive sleep apnea (OSA). This situation increases the difficult achieving a high diagnostic yield with EMG devices. Besides criteria for neurophysiological analysis vary between studies [20–25]. In addition, it is recommended that the standard EMG cut-off points should not be used to establish the presence or absence of bruxism in individuals who do not present any clinical manifestations of bruxism [14].

Differentiating between masticatory muscle activity (mma), rhythmic masticatory muscle activity (RMMA), sleep-related oromotor activity (OMA), and recognize bruxing activity is a challenge during the PSG analysis itself. It is essential to conduct a study that collects all variables to recognize the diagnostic reliability of EMG and PSG compared studies. This task would facilitate improvements in the design of future observational studies with the use of this type of device and therefore the diagnostic performance for SB.

2. Material and methods

This systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement and was registered with PROSPERO prior to the completion of the main search (Protocol Record Number CRD42023416131) [26].

2.1. Definition of diagnostic standard of reference for sleep bruxism

At present, widely accepted reference criteria for the diagnosis of SB refer to the original publication by Lavigne et al. [17], The authors established sound cut-off thresholds for PSG-recorded jaw-motor activity to identify individuals with sleep bruxism, as diagnosed according to the American Academy of Sleep Medicine guidelines (AASM) [16]. The resulting EMG bursts may be combined to define different types of bruxism episodes (i.e., phasic/rhythmic, tonic, or mixed), depending on the duration of each burst and the between-burst intervals. The 1996 PSG-based criteria and their successive 2007 update are commonly considered the best available diagnostic method to detect SB [17].

The 2015 Carra's overview or the 2020 AASM scoring is also accepted [16,27]. Although the criteria above mentioned are research criteria, classically are being used for the validation or comparison of several diagnostic methods for the clinical evaluation of the SB. Therefore, they will be adopted here as the standard of reference for reviewing the validity of the other instrumental approaches proposed for SB measurement in a home environment.

2.2. Study selection

Original observational studies that analyze the sleep bruxism assessment with electromyography portable devices and Polysomnography records were included in the present review.

The study population included patients diagnosed with SB or with RMMA, mma, and OMA which were discarded as SB activity. To be diagnosed, assessment with EMG or PSG via instrumental evaluation, based on the published criteria [15–17,28,29].

2.3. Search strategy

We performed the search for studies on PubMed and Web of Science from inception until March 2023. The main search strategy on PubMed was carried out using non-MesH terms, adding a Boolean operator (OR and/or AND) to combine them. There were no restrictions on language, as recommended by principal guidelines [30].

Non-MeSH terms included "sleep bruxism", "motor activity", "electromyography", or "polysomnography"". The complete search strategy can be found in Appendix **A**and the PICO strategy in the following Table 1.

This search string was used on PubMed database and modified, if needed, in other consulted databases. The search strategy was conducted by three independent reviewers and the reference list of the original studies were screened manually, to identify possible articles. Authors were contacted for further information if necessary.

2.4. Selection and data extraction

All articles identified from databases were screened by three reviewers. Articles were screened by titles and abstracts to select articles based on the inclusion and exclusion criteria to identify potentially eligible studies. Then, two researchers independently reviewed the full text of all studies to establish which articles should be included. Any disagreement on the eligibility of studies for inclusion was resolved by consensus.

Data extraction of included studies contains information about sample size, patient status, method of SB assessment, and diagnostic yield of the instrumental devices. Data was extracted by duplicate.

2.5. Quality appraisal

The studies that were pertinent for inclusion underwent a quality assessment by adopting the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool [31]. This is an improved, redesigned tool with respect to the original instrument [32]. Although it is not specifically a reporting guideline, it represents a useful tool to rate the risk of bias and the applicability concerns of primary diagnostic studies included in systematic reviews. The tool comprises four key domains that discuss (i) patient selection; (ii) index test; (iii) reference standard, (iv) flow of patients through the study and timing of the index test and reference standard. For each domain, specific signaling questions are formulated to help reviewers assessing each domain in terms of risk of bias; the first three domains are also assessed in terms of concerns regarding applicability. Reviewers are thus able to judge the risk of bias as 'low risk of bias', 'high risk of bias' or 'unclear'. The applicability rating for the same domain refers to the potential concerns that the included patients and setting do not match the review question. Reviewers are thus able to judge applicability as 'low applicability concerns', 'high applicability concerns' or 'unclear'. All the other signaling questions and specifications can be found in the original publication [31]. In this investigation, QUADAS-2 ratings were assigned by two of the authors, who took each decision by consensus. In addition, kappa coefficient (κ) was calculated

Table 1
PICO strategy.

PICO elements	Keywords	Search Items	Search strategies
P (Patient or Population)	Patients diagnosed with SB or with RMMA, mma, OMA which were discarded as SB activity	Sleep bruxism	Sleep bruxism OR Masticatory activity OR Sleep related oromotor activity
I (Intervention)	Electromyography (EMG) portable devices	Instrumental assessment using electromyography	Electromyography OR Portable device
C (Comparison)	Polysomnography (PSG)	Instrumental assessment using polysomnography	Polysomnography
O (Outcome)	SB diagnostic yield	Accuracy	

to assess reliability prior to any consensus. Inter-rater reliability was estimated using $\kappa > 0.7$ indicating a high level of agreement, κ of 0.5–0.7 indicating a moderate level of agreement and $\kappa < 0.5$ a low level of agreement [33].

2.6. Certainty of evidence

The certainty of the evidence analysis was established by different levels of evidence according to the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework, which is based on five domains: study design, imprecision, indirectness, inconsistency, and publication bias [34]. The evidence was classified into the following four levels: high quality (all five domains are satisfied), moderate quality (one of the five domains are not satisfied), low quality (two of the five domains are not satisfied), or very low quality (three of five domains are not satisfied) [35].

2.7. Statistical analysis

For statistical analysis, the program R Ver. 4.1.3 (R Foundation for Statistical Computing, Institute for Statistics and Mathematics, Welthandelsplatz 1, 1020 Vienna, Austria) was used.

A meta-analysis of diagnostic test accuracy (MA-DTA) was performed with multiple thresholds per study applying a two-stage random effects model [36], using the thresholds offered by the studies and based on the number of EMG bruxism events per hour presented by the participants.

For the MA-DTA, the rates of true positives (TP), false positives (FP), true negatives (TN) and false negatives (FN) rates were calculated from the data provided by the studies consisting of sensitivity, specificity or predictive value. Positive (TP) and total number of participants, using the appropriate formulas [36].

Heterogeneity was analyzed by estimating the between-study variance τ^2 as well as with the I^2 estimator, defining heterogeneity as not important (<30 %), moderate (30%–50 %), large (50%–75 %) and important (>75 %)

The sensitivity and specificity of the model with its confidence interval were calculated. The Youden Index was also calculated as a measure of diagnostic precision, which takes values from 0 (no precision) to 1 (perfect precision).

On the other hand, the Summary Receiver Operator Curve (SROC) of each model was calculated by comparing the sensitivity and 1-specificity to calculate the Area Under the Curve (AUC). The AUC defines the diagnostic capacity of a test as excellent (>0.9), very good (0.8–0.9), good (0.7–0.8), sufficient (0.6–0.7), poor (0.5–0.6) and not relevant (<0.5).

Publication bias was analyzed using the asymmetry regression test described by Deeks et al. (2005) as well as with the funnel plot with the effective sample size which draws the Diagnostic Odds Ratio, defined as the ratio between the probability of obtaining a positive result in a person with bruxism and the probability of obtaining a positive test in a healthy person (the higher its value, the better the diagnostic discrimination of the test) against Effective Study Sample Size defined as the estimate of the sample size required to achieve the same level of precision if that sample was a simple random sample [37].

3. Results

Overall, 3233 papers were identified using electronic databases (PubMed: 2212; Web of Science: 1021). After removing duplicates and screening by title and abstract, 25 studies remained for full-text analysis. After full text reading by 2 different authors, 15 studies were excluded, and 10 studies were finally included. Finally, only 5 studies were eligible for quantitative analysis. A flowchart of the selection process was created according to PRISMA guidelines and is shown in Fig. 1 [26].

3.1. Study characteristics

All of them compared different instrumental methods for SB assessment, however in some cases there was lack of comparison with PSG, some of the tools were not EMG devices, and in one case the study was conducted in children population.

The present systematic review included 10 studies, including a total of 226 patients (bruxers and healthy participants), 143 males and 83 females, with age ranging from 18 to 63 years. The characteristics of the included studies are shown in Table 2.

Two of the selected studies compared the Bruxoff device versus PSG [38,48], two of them analyzed the Bitestrip device performance [41,44], another two studies compared a single channel EMG (FLA-500-SD) versus PSG [40,43], and the four remaining studies assessed the diagnostic accuracy of different portable devices such as an ambulatory electrode set (AES) [42], the Grindcare device [45], EMG-telemetry recordings [47], and a biosignal recorder [39].

In terms of comparison, all included studies adopted PSG criteria as the standard for comparison versus different EMG devices. Although most of studies were carried out on single-nights recordings with portable devices, one study was conducted during five nights in one week [45].

Even though the whole 10 studies selected accomplished the inclusion criteria and were included in the qualitative analysis, only 5 [38,40,41,45,48] were able to be selected for the quantitative analysis due to important data limitations of the remaining 5 ones.

3.2. Outcomes

Measurements of SB were based on EMG devices and SB was scored according to different criteria. Five studies used Lavigne's criteria [17,38,39,41,44,47], three used Carra's overview [27,42,45,48], and two used AASM criteria [16,40,43].

A variety of different types of EMG activity have been accounted for in certain studies [40,47]. Different EMG signal acquisition characteristics are used between the studies [49]. In summary, 10 studies are included in the review [38–45,47,48]. 5 of these 10 studies are selected for the meta-analysis [38,40,41,45,48], and 3 of the 5 studies included in the meta-analysis used two different cut-off points for the SB diagnosis [38,40,48], so will appear duplicates in Fig. 3.

3.3. Risk of bias assessment

Risk of bias was evaluated with QUADAS-2 scale and can be found in Fig. 2.

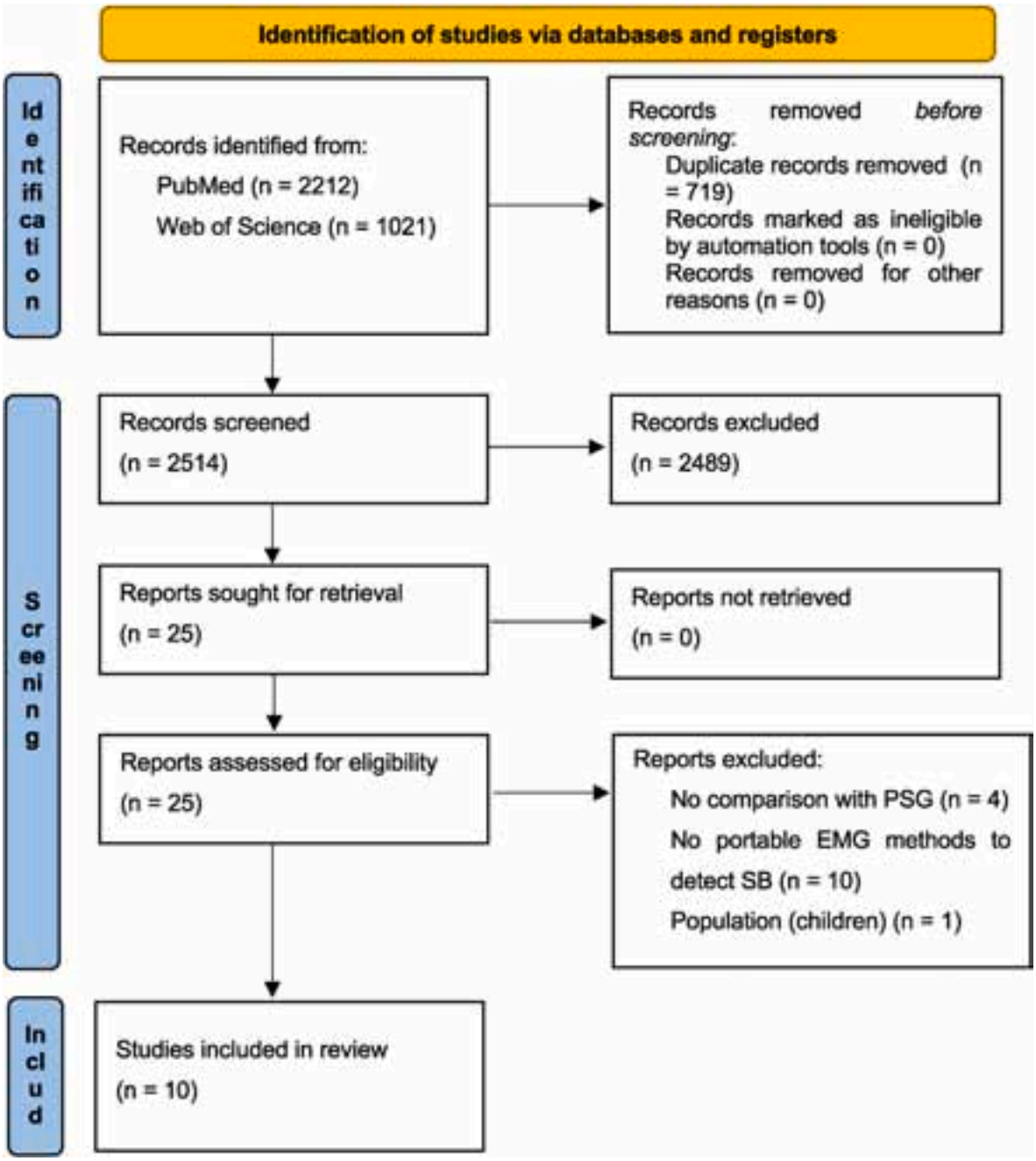

Fig. 1. Flowchart of the selection process according to 2020 PRISMA guidelines.

Only one study was classified as low risk of bias [41], while the remaining nine studies were classified as high risk of bias [38–40,42–45,47,48]. The main concern was the patient selection domain, as most of the studies recruited healthy volunteers and a group known to have bruxism.

The inter-rater reliability for the risk of bias was considered high, according to the kappa coefficient ($\kappa = 0.849$).

3.4. Quantitative analysis

The forest plots show similar values of sensitivity and specificity. Uncertainty is large in both, in the case of sensitivity due to greater variability in the estimates, and in the case of specificity due to lower precision with larger confidence intervals Fig. 3.

Five studies were included, of which 2 presented a single cut-off and 3 had two cut-offs, including a total of 136 participants [38,40,41,45,48]. With optimal cut-off at 7 events/hour, the model presents important heterogeneity ($I^2 = 94.211$ % and $\tau^2 = 0.05$). The model shows significant differences in the results of the EMG test between the participants with the result of TP and FP but not in the interaction between these groups and the different cut-offs. Both sensitivity and specificity are very high and the AUC values for each of them remain at very good values Table 3.

The survival curve with the rates of true and false positives shows a progressive increase in both as the threshold is higher, reaching the maximum value of TP and minimum of FP with the optimal cut-off, in which the Youden index presents a maximum value of 0.579. (Supplementary material. Fig. 1).

The SROC curve presents an AUC = 0.837 at the optimal cut-off which indicates a very good diagnostic capacity of the EMG test,

Table 2
Characteristics of the included studies.

First author, year	Study sample	Diagnosis device	Device diagnosis criteria	Type of episodes accounts	Type of PSG system, PSG diagnosis criteria	Findings
Castroflorio et al. *2014* [38]	N = 25 (12F, 13 M, 28 ± 10,7 years) case-control design (14 'probable' SB, 11 no SB) diagnostic validity study	Bruxoff (EMG and ECG) device	10 % MVC + 20 % increase in heart rate >4 episodes/h Analyses were performed automatically and manually	RMMA SB: phasic, tonic or mixed Myoclonus: phasic, tonic or mixed	Embletta X100®; Flaga, Iceland (PSG type II - Ambulatory) SB present or absent based on Lavigne et al.'s criteria (1996)) [17]– 10 % MVC	Manual scoring: Accuracy (ROC) = 89 %. Sensitivity = 83,3 %. Specificity = 84,6 % Automatic scoring: Accuracy (ROC) = 91 %. Sensitivity = 91,6 %. Specificity = 84,6 % Agreement = 63 % (k = 0.33).
Gallo et al. *1997* [39]	N = 5 (1F, 4 M, between 21 and 36 years) diagnostic validity study	BSR -Biosignal recorder	20 % of highest occurring bursts	SB: phasic, tonic or mixed myoclonus	PSG-AV (Sleep laboratory) No tonic events were recognized from the PSG tracings SB present or absent based on Lavigne et al.'s criteria (1996) [17]– 20 % MVC. Frequency: numbers of episodes	
Maeda et al. *2019* [40]	N = 20 (17 M, 3F, 21.6 ± 1.6 years) with a clinical history of SB, diagnostic validity study	FLA-500-SD (A single-channel ultraminiature wearable EMG device)	>2 × baseline amplitude Best cut-off 5.5 EMG-episode/h	phasic, tonic, and mixed episodes Excluded episodes: Wake-OMA-episodes and Sleep-OMA-episodes	PSG-AV (Sleep laboratory) for two not consecutive nights, SB present or absent based on AASM criteria [16], 5–20 % MVC	Sensitivity = 100 % Specificity = 100 % (Cut-off 5.5/h for sleep bruxers), For variables by a burst unit, EMG- burst-all/h and EMG-burst-5% had higher values of sensitivity and specificity.
Mainieri et al. *2012* [41]	N = 49 (32F, 17 M, 41,2 ± 12.9 years) with a clinical history of SB, diagnostic validity study	BiteStrip (EMG) device	30 % MVC Cut-off and grading: 0 = no bruxism (≤ 39 episodes), 1 = mild bruxism (40–70 episodes), 2 = moderate bruxism (75–124 episodes) and 3 = severe bruxism (125 episodes)	RMMA SB: phasic, tonic or mixed	PSG-AV (Sleep laboratory) SB present or absent based on Lavigne et al.'s criteria (1996) [17]– 20 % MVC.	Agreement = 87.8 %. (75,8–94,3 %). Kappa = 0,71 (0,44–0,97). Sensitivity = 84,2 % (68,7–93,9 %). PPV = 100 % (89,1–100 %).
Miettinen et al. *2018* [42]	N = 12 (5 M, 7F, 21–25 years) case-control design (N = 6 Six self-assessed SB, N = 6 controls)	AES-Ambulatory electrode set	Positive teeth-grinding history or at least one RMMA event with teeth-grinding sounds in the recording	RMMA OMA (excluded) Arousal	PSG-AV (Sleep laboratory) SB present or absent based on Carra's overview (2015) [27]	AES yielded similar diagnoses as standard PSG in all subjects, video recording and sleep stage scoring help reaching the highest specificity of sleep bruxism diagnostics
Sakuma et al. *2022* [43]	N = 20 healthy students (12 M, 8), 21,9 ± 1,8 years), reliability study	FLA-500-SD (A single-channel ultraminiature wearable EMG device)	>2 × baseline amplitude	A cluster of bursts was defined as an episode. They did not exclude EMG bursts during the wake stage as well oromotor activities other than SB that could be discriminated in sleep stage analyses and audio-video analyses using PSG-AV	PSG-AV (Sleep laboratory) The mean interval for both sleep studies was 28.8 days SB present or absent based on AASM criteria [16], 5–20 % MVC	The number of SB bursts and episodes recorded under laboratory conditions was statistically significantly smaller than that recorded at home
Shochat et al. *2007* [44]	N = 18 (13 M, 5F, 31 ± 13 years) case-control design (N = 6 SB subjects, 4 with OSA. N = 8 controls) diagnostic validity study	BiteStrip (EMG) device	30 % MVC	SB index	PSG-AV (Sleep laboratory) SB present or absent based on Lavigne et al.'s criteria (1996) [17]– 20 % MVC. Frequency: events/recording.	Sensitivity = 71–72 % PPV = 59–81 % Bland-Altman plots showed good agreement
Stuginski-Barbosa et al. *2016* [45]	N = 20 (15F, 5 M, 27,1 ± 4,9 years), case-control design (N = 10 SB group, N = 10 controls)	GrindCare (EMG) device	20 % of 60 % MVC Best cutoff: 18 EMG/h or higher in three consecutive nights and 19 EMG/h or higher in five consecutive nights	SRA events described by Jadidi (2008) [46] Oromotor episodes separated by 3-s intervals were recognized as RMMA, SB: phasic, tonic or mixed	Ambulatory PSG system (Alice 5 International, Philips Respironics, USA) + Audio-video 2 consecutive nights SB present or absent	Sensitivity = 79 % Specificity = 78 % (3–5 consecutive nights) Bland-Altman analysis of the EMG bursts/h showed positive

(*continued on next page*)

Table 2 (*continued*)

First author, year	Study sample	Diagnosis device	Device diagnosis criteria	Type of episodes accounts	Type of PSG system, PSG diagnosis criteria	Findings
	diagnostic validity study				based on Carra's overview (2015) [27]	agreement between the methods
Yamaguchi et al. *2012* [47]	N = 8 (4F, 4 M, 29,9 ± 10,9 years) tooth grinding current history diagnostic validity study	Electromyographic telemetry recorder (TEL-EMG)	Two times higher than baseline	RMMA, OMA: T-OME, *O*-OME (*O*-OME wake, *O*-OME sleep), masseter and temporal EMG bursts	PSG-AV (Sleep laboratory) SB present or absent based on Lavigne et al.'s criteria (1996) [17] – 20 % MVC. Frequency: events/h. Oromotor activity during wakefulness was excluded.	Sensitivity = 98 % PPV = 23.1 %
Yanez-Regonesi et al. *2023* [48]	N = 49 (F38, M11, 50 ± 17,7 years) diagnostic validity study	Bruxoff (EMG and ECG) device	10 % of MVC + 20 % increase in heart rate >4 episodes/h	RMMA index SB: phasic, tonic or mixed Myoclonus: phasic, tonic or mixed	PSG-AV (Sleep laboratory) SB present or absent based on Carra's overview (2015) [27]– 10 % MVC.	Sensitivity = 83.3 % Specificity = 72 % (SB index = 2 ep/hour) Sensitivity = 33 % Specitifity = 90 % (SB index = 4 ep/hour) the Bland–Altman plot revealed a consistent and systematic difference

Abbreviatures: n (number of subjects), F (female), M (male), EMG (electromyogram), ECG (electrocardiogram), RMMA (rhythmic masseter muscle activity), PSG (polysomnography), SB (sleep bruxism), MVC (maximum voluntary contraction), PSG-AV (audio-video recording polysomnography), OMA (oromotor activities), AES (ambulatory electrode set), AES-SS (ambulatory electrode set sleep stage), AES-V (ambulatory electrode set video), SRA (signal recognition algorithm), ROC (receiver operating characteristic), TEL-EMG (Telemetry electromyogram), T-OME (true oromotor episode), *O*-OME (other oromotor episode), OME (oromotor episode), OSA (obstructive sleep apnea), MEMG (masseter electromyogram), TRT (total recording time), TST (total sleep time), BSG (biosignal recording).

although a high variability is evident in the studies with some outliers Fig. 4.

The non-significant Egger test indicates the absence of publication bias (t (5) = 1.156, p = 0.3) (Supplementary material. Fig. 2).

3.5. Certainty of evidence

Certainty of evidence was assessed with GRADE recommendations tool. The overall quality was assessed as very low-quality Table 4. Most concerns were about high risk of bias among included studies due to sample population, small number of included studies, and high inconsistency among included studies.

4. Discussion

The present review evaluated the existing literature related to instrumental SB assessment in adult population (age ≥18 years). Following the last recommendations for bruxism assessment it is necessary to count with affordable and reliable portable devices, so it turns imperative to analyze and compare different devices and evince the state of the art of the instrumental assessment for SB [6]. Considering the clinical significance of the selected paper, it should be highlighted that, according to the classification proposed by Lobbezoo et al. [2], all the studies were based on a definitive diagnosis of SB by means of EMG portable devices records against the Gold Standard (PSG).

To our knowledge, this is the most recent systematic review and meta-analysis comparing the diagnostic accuracy of EMG and PSG. Manfredini et al. found in 2014 that the available information on the validity of portable diagnostic approaches in comparison to PSG recordings was insufficient to support the use of any non-PSG technique as a stand-alone diagnostic method [18]. However, six of the ten studies included in this analysis were not yet available at that time. Additionally, since 2013, there has been a natural evolution of technology for EMG devices, and a significant discussion regarding the SB diagnosis criteria has taken place [2,6,14,50].

Measurements of SB were based on EMG recordings and were scored according to different criteria. Five studies used Lavigne's criteria [17,39,41,44,47,48], three used Carra's overview [27,38,42,45], and two used AASM criteria [16,40,43]. The SB metrics have been a recurrent issue for more than thirty years and there is still uncertainty in dentistry regarding their optimization and clinical relevance [15]. One of the main problems in all the studies reviewed was to determine the cut-off points to distinguish by EMG means between bruxers and no bruxers [14,15,51]. The model accepting seven events/hour as the optimal cut-off point brings significant heterogeneity to the results. This may be partly justified by the different types of devices. This cutoff point is higher than those traditionally reported in the literature [15,17,27]. Probably both the frequency and amplitude of muscle activity could serve to broaden the gradation of the severity criteria for SB. However, this amount of activity does not always correlate with the negative clinical consequences of SB.

Colonna et al. supports the concept that sleep-time masticatory muscle activity (sMMA) events are quite frequent in healthy adults, and the differences observed over several nights recording span were not significant [52]. These results indicated that these data could be similar to those of subjects with underlying conditions that may lead to an additive bruxism activit with possible clinical consequences [52]. Consequently, it would be more appropriate to speak about the "severity of muscular activity, of greater or lesser frequency" instead of the degree of bruxism.

According to this concept, it would be desirable in the future to carry out clinical studies about the severity of SB activity where these cut-off points were studied based on the negative clinical consequences or on the putative protective role against other entities such as OSA [53] On the other hand, Ohlmann et al. found that bruxism activity was highly variable over time. The consequence of this fact is the absence of a reliable correlation between sMMA and the SB index that should be considered when diagnosing SB [51]. EMG can be used to a definitive diagnose of SB and complements other procedures like medical and social history, clinical interviews, and examinations [54].

Most studies were carried out on single-night recordings, and only one study was conducted during five nights in one week [45]. This is probably the result of one of the major limitations of these studies. Performing a sleep study and meticulously analyzing records is expensive and time-consuming. In addition, it is assumed that there may be a first-night laboratory effect (FNE). However, Byun et al. observed that the highest incidences of FNE occurred in OSA, simple snoring, hypersomnia, and male patients [55]. The results of Hasegawa et al. showed

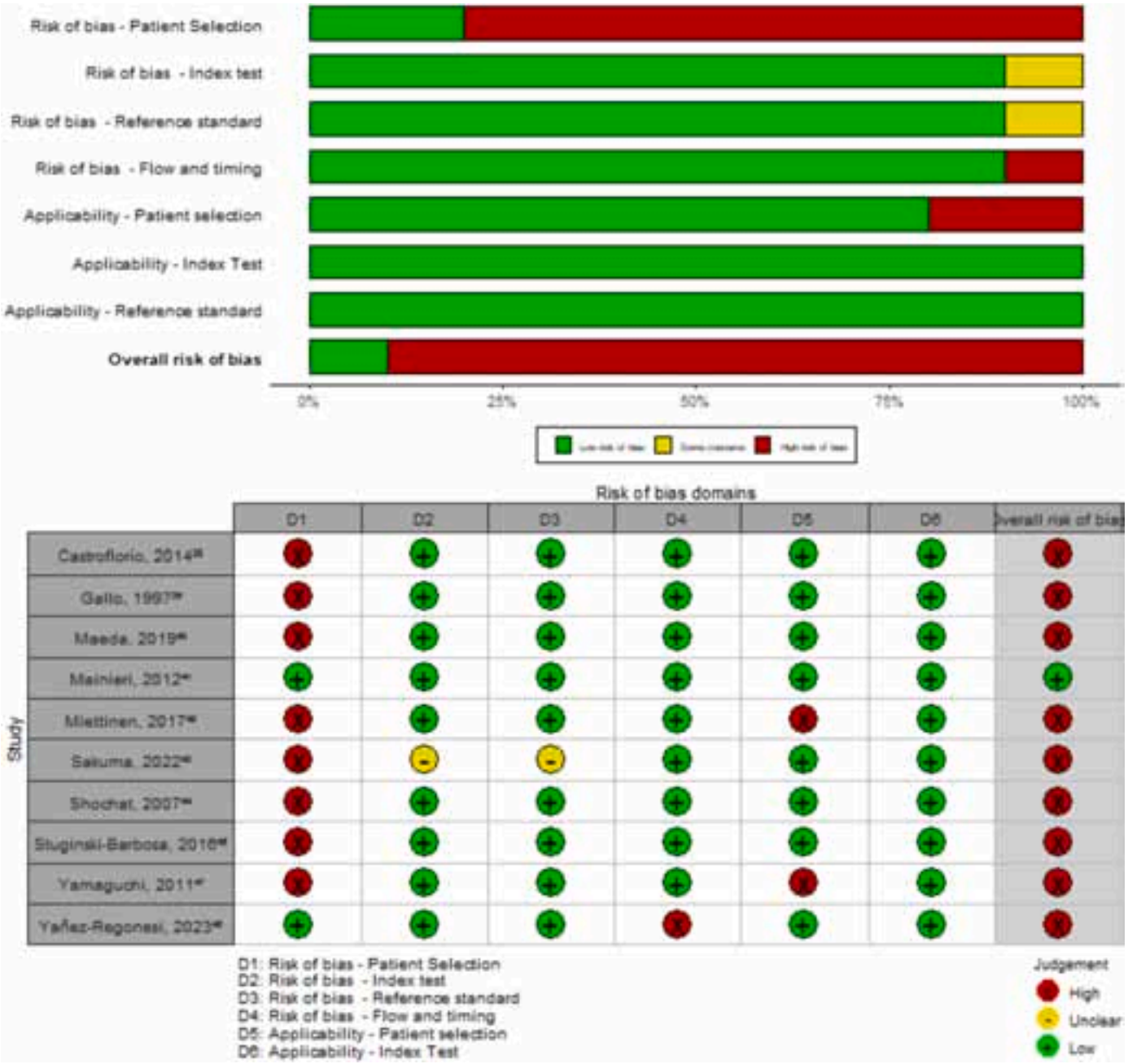

Fig. 2. Risk of bias evaluated with QUADAS-2 scale.

Fig. 3. Forest plots of sensitivity and specificity outcomes.

Table 3
Model outcome.

	Coefficient (SE)	95%CI	t statistic
(Intercept)	−0.055 (SE = 0.713)	−1.453, 1.343	−0.076
Group	−1.887 (SE = 0.898)	−3.647, −0.128	−2.102
Cutoff	1.018 (SE = 0.601)	−0.161, 2.196	1.693
Group:Cutoff	−0.47 (SE = 0.552)	−1.552, 0.612	−0.851
Sensitivity (95%CI)			
Estimation	0.707 (0.369, 0.974)		
AUC	0.837 (0.382, 0.967)		
Specificity (95%CI)			
Estimation	0.872 (0.55, 0.974)		
AUC	0.836 (0.44, 0.965)		

SE: Standard error; 95%CI: 95 % confidence interval; AUC: Area Under a Curve; Group: true and false positive rate subjects.

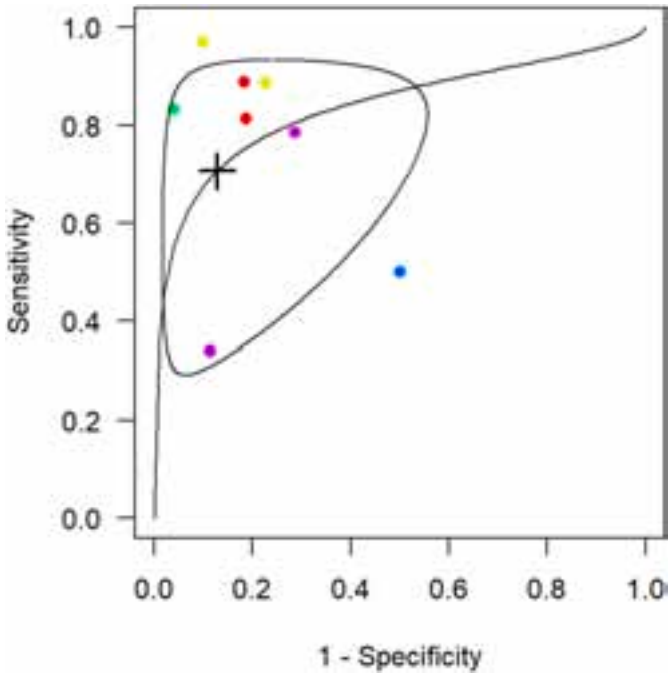

Fig. 4. SROC curve. Cross represents the summary point that corresponds to the threshold that maximizes the Youden index surrounded by its 95 % confidence interval region).

no overall FNE on severity of RMMA frequency in young and healthy patients with SB. Therefore, in clinical practice, one-night sleep recording may be sufficient for moderate-high frequency SB patients [56]. Nonetheless, mma/RMMA frequency in the first night could be confirmed by a second night recording, and the burst duration, total SB duration during sleep period, and changes in heart rate also are important to quantify.

The overall quality was assessed as very low-quality. Most concerns were about the high risk of bias in terms of sample population, small number of included studies, and high inconsistency among studies. This fact could be explained because of the high cost of PSG, and the time required for both PSG and EMG analysis. These factors make difficult to collect a large sample quickly, and there are often records that need to be discarded due to interference or failures.

The main bias problem was in the patient selection domain, as most of studies recruited healthy volunteers to compare versus a selected group of subjects clinically defined as bruxists. According to QUADAS-2 recommendations, patients should enroll all consecutive, or a random sample of eligible patients with a suspected disease. However, most of included studies selected patients with known SB. This could introduce some potential bias, which could overstate diagnostic accuracy. Future studies should include randomly selected patients without a clearly diagnostic of SB.

Our findings are in line with Casett et al. [19] indicating a very good diagnostic capacity of the EMG test, considering the inclusion of three more studies comparing EMG devices with PSG in this review. However, a high variability is evident in the selected studies with some outliers. The best performance in terms of sensitivity was reached by the FLA-500-SD device when the cut-off point was considered >2 episodes/hour (97 %) and in second place when was analyzed with cut-off points >4 episodes/hour (89 %), both analyses performed in the same study [40]. The same sensitivity was obtained by the Bruxoff device [38] with the automatic analysis (89 %). Conversely, the Bruxoff device shown the poorest performance in sensitivity barely reaching a 34 % in another study [48] when the cut-off point was >4 episodes/hour with the manual and automatic analysis indistinctly, however, its performance was followed by the Grindcare device which reached a 50 % of sensitivity [45]. When specificity was compared, the highest results were achieved by the Bitestrip device which reached an excellent 96 %, followed by the FLA-500-SD with cut-off points >4 episodes/hour [40].

It is important to note that SB also occurs concomitantly or secondarily to other sleep disorders, such as OSA. Current research trends suggest that when it comes to assessing SB, it is necessary not only to refine the gold standard PSG but also to consider any present comorbidities [6,54]. In the absence of EEG and concomitant AV recordings, several motor phenomena may not be excluded [27,57].

It should be noted that most of the studies included for analysis were feasibility or proof-of-concept studies. These studies analyze the feasibility and to some extent evaluate the probability of success of the measuring instrument under evaluation, considering physiological and technical aspects, as well as presenting its full potential in the clinical setting, providing valuable data for decision-making and diagnostic screening. Since SB involves fluctuating activity, using portable tools in the patient's natural environment would provide more continuous measures of muscle activity [14,49]. All this information could help to identify the negative clinical consequences that may arise in patients with sleep bruxism, leading to a more personalized medicine approach for this condition.

4.1. *Strengths and limitations of this systematic review and meta-analysis*

This review has different strengths. First, a comprehensive and exhaustive search strategy was used to identify all relevant studies, reviewing different databases, checking reference lists, and being performed by triplicate. Second, methodological quality was performed by duplicate and with high inter-rater reliability, something that other reviews did not evaluate [18,19]. Although the short number of studies that have been published comparing the diagnostic capacity of EMG portable devices, a meta-analysis was able to be performed.

However, this study presents some limitations. First, the results should be analyzed carefully because most of the included studies had

Table 4
Quality assessment of validity of portable devices to diagnose sleep bruxism.

Number of studies (subjects)	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Quality	Pooled sensitivity	Pooled specificity
5 (n = 163)	Serious[a]	Serious[‡]	Not serious	Serious[b]	Not serious	Very Low	0.707	0.872

[a] High risk of bias among included studies. ‡High heterogeneity among included studies (>90 %).
[b] Wide confidence intervals regarding sensibility and specificity.

high risk of bias as they incurred in methodological issues when recruiting patients. Second, the diagnosis of SB was based on different criteria, such as Lavigne's, Carra's or AASM criteria, highlighting the lack of consensus when diagnosing SB. Third, high heterogeneity was found across included studies when data was pooled, which make it difficult to draw strong conclusions.

5. Conclusions

Very low quality of evidence suggests that portable devices have shown high sensitivity and specificity when diagnosing sleep bruxism compared to polysomnography, but this should be taken with caution due to existing biases.

The tests performed in the meta-analysis found an estimated optimal cut-off point of 7 events/hour of Sleep Bruxism with acceptably high sensitivity and specificity for the electromyographic portable devices.

Practice points

1) SB assessment through EMG portable devices is a more practical approach that can be easily used in research and in clinical practice when compared to PSG. In general, a good diagnostic capacity was observed in the meta-analysis that can encourage to clinicians to give a try to these methods.
2) It's important to note that SB is a complex condition that is often associated with other health issues, becoming crucial to include all the relevant factors in the instrumental assessment equation. Further, considering artificial intelligence, the emergence of new technologies, and big data to create future instrumental tools could be useful to create better algorithms for the diagnostic tools used for sleep bruxism detection by taking into account the aforementioned factors.

Research agenda

1) In order to improve the accuracy of observational studies in the instrumental assessment of SB, it would be beneficial to establish standard criteria, not only considering the RMMA but the whole mma for programming and analyzing EMG activity.
2) It would be beneficial to design studies that evaluate the validity of the EMG devices compared with PSG in the OSA population to investigate if the respiratory events could act as a confusion factor in the final evaluation of SB with the portable EMG devices.
3) It would be desirable to carry out clinical studies about the severity of SB activity where several cut-off points were studied based on the negative clinical consequences or on the putative protective role against other entities. This could be useful for studying vulnerability factors and phenotypes associated with sleep bruxism.

Contributions of authors

Conceptualization, R.C–V, E.A.S.R. and J.N·C.Z.; Methodology, R.C–V., O.M.P., E.M.O, C·C·F., E.A.S.R. and J.N·C.Z. Formal analysis, O.M.P, E.M.O, C·C.F. and J.N·C.Z.; Writing - Original Draft, R.C–V., O.M.P., E.M.O, C·C·F., E.A.S.R. and J.N·C.Z.; Supervision, I.A.G., F.J.M.O., E.A.S–R.; Resources E.A.S.R; Writing-Review and editing, All the authors; Project administration, R.C–V and E.A.S–R.

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Data availability statement

The data presented in this study are available on request from the corresponding authors.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Search string

Search string (PubMed)

((sleep bruxism) OR (masticatory activity) OR (sleep-related oro-motor activity)) AND (electromyography OR polysomnography OR (portable device))

N = 2212 (April 03, 2023). Included: 10.

Search string (Web of Science)

((sleep bruxism) OR (masticatory activity) OR (sleep-related oro-motor activity)) AND (electromyography OR polysomnography OR (portable device))

N = 1021 (April 03, 2023). Included: 0.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smrv.2024.101906.

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Abbreviation Term

AASM: American academy of sleep medicine
AES: Ambulatory electrode set
AES-SS: Ambulatory electrode set stage
AES-V: Ambulatory electrode set video
AUC: Area under the curve
AV: Audio and video
BSG: Biosignal recording
ECG: Electrocardiogram
EMG: Electromyogram
FNE: First night effect
FN: False negative
FP: False positive
MA: Meta-analysis
MA-DTA: Meta-analysis diagnostic test accuracy
MEMG: Masseter electromyogram
mma: Masticatory muscle activity
MVC: Maximum voluntary contraction
OMA: Sleep related-oromotor activity
OME: Oromotor episode
O-OME: Other oromotor episode
OSA: Obstructive sleep apnea
PSG: Polysomnography
PSG-AV: Polysomnography audio video
RMMA: Rhythmic masticatory muscles activity
ROC: Receiver operator curve
SB: Sleep bruxism
sMMA: Sleep-time masticatory muscle activity
SRA: Signal recognition algorithm
SROC: Summary receiver operator curve
TEL-EMG: Telemery electromyogram
T-OME: True oromotor episode
TN: True negative
TP: True positive
TRT: Total recording time
TST: Total sleep time