

Global co-occurrence of bruxism and temporomandibular disorders: A meta-regression analysis

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Abstract

Background. Bruxism and temporomandibular disorders (TMD) are closely related, yet the relationship between bruxism and TMD remains one of the most debated topics in the literature.

Objectives. The aim of the study was to estimate the overall proportions of the co-occurrence of bruxism and TMD, and the prevalence of TMD in individuals with bruxism by continent. Additionally, factors that have an influence on these proportions, including geographical region, sex and other demographic variables, were analyzed.

Material and methods. A synthesis of data from 6 meta-analyses and systematic reviews published up to October 2024 was conducted. The data was extracted from 30 studies that analyzed 31 populations, with a total of 37,680 participants, of whom 5,117 were diagnosed with both bruxism and TMD. The analyses were conducted using the R statistical language.

Results. The global co-occurrence of bruxism and TMD was 17%, with significant differences observed between continents. In North America, the co-occurrence of these 2 conditions was 70%, followed by 24% in South America, 14% in Europe and 9% in Asia. The analysis revealed that the sex of the participants was a significant factor, as higher proportions of female participants in a study sample increased the likelihood of the co-occurrence of TMD and bruxism. The mean prevalence of TMD among patients with bruxism was 63.5%, with the highest rate observed in North America (98.3%) and the lowest in Asia (53.9%).

Conclusions. The meta-analysis underscores the high prevalence of TMD in individuals with bruxism, highlighting significant geographical variations in the co-occurrence of these conditions. A 1% increase in the proportion of female participants in a study group was associated with a 4.4% rise in the probability of the co-occurrence of TMD and bruxism. These findings suggest that temporal factors and the average age of participants did not significantly contribute to observed variability across studies. The results underscore the importance of geographical and demographic factors in understanding the interplay between bruxism and TMD.

Keywords: TMD, bruxism, temporomandibular disorders, association, connection

Highlights

- The global prevalence of bruxism and TMD co-occurrence is 17%, with regional variations: 70% in North America; 24% in South America; 14% in Europe; and 9% in Asia.
- A 1% increase in the female proportion in a study sample raises the probability of co-occurrence by 4.4%.
- The overall prevalence of TMD among individuals with bruxism is 63.5%, with North America showing the highest prevalence at 98.3%.
- Geographical and demographic factors influence the co-occurrence of bruxism and TMD, highlighting the need for further research, particularly in North America.

Introduction

Temporomandibular disorders (TMD) are a group of conditions characterized by dysfunction and pain in the temporomandibular joint (TMJ), masticatory muscles and surrounding tissues. Symptoms of TMD may include facial pain, difficulty opening the mouth, joint clicking or popping, and limited jaw mobility.¹

According to the 2018 consensus,² bruxism is defined as the activity of the masticatory muscles, which involves either grinding or clenching the teeth and/or bracing or pushing the jaw. This condition is categorized into 2 types: sleep bruxism (SB); and awake bruxism (AB). Sleep bruxism manifests during sleep and can be either rhythmic or irregular, whereas awake bruxism occurs while awake and involves repetitive or prolonged tooth contact and/or jaw movement. Bruxism is not considered a disorder in healthy individuals but rather a behavior that could serve as a risk factor or offer protection for certain medical conditions.²

Bruxism and TMD share a multifactorial etiology encompassing biological (e.g., genetic and anatomical), psychological (e.g., stress, emotional disorders) and environmental aspects (e.g., lifestyle, habits). The co-occurrence of bruxism and TMD underscores the complex interaction between these factors, which complicates the determination of their precise etiology and necessitates a comprehensive diagnostic and therapeutic approach.^{3–6}

Manfredini and Lobbezoo emphasize that the relationship between bruxism and TMD remains among the most debated topics in dental literature, mainly due to uncertainties surrounding etiological and diagnostic aspects of both conditions.⁷

Over the years, several systematic reviews have analyzed the association between bruxism and TMD. A systematic review conducted by Manfredini and Lobbezoo identified a positive relationship between bruxism and TMD pain, based on studies that used self-diagnosis or clinical diagnosis of bruxism.⁷ However, these studies were subject to potential biases and confounding factors, while more quantitative and specific research methods have demonstrated a much weaker association. The authors observed that experimental jaw clenching did not reflect clinical

TMD pain.⁷ A systematic review by Jiménez-Silva et al. suggested a possible association between sleep bruxism and myofascial pain, arthralgia, and joint pathologies.⁸ A meta-analysis by Mortazavi et al. found a positive relationship between bruxism and TMD, with the presence of bruxism increasing the likelihood of future TMD development.⁹ In contrast to the abovementioned associations, polysomnographic studies have not observed a connection between SB and TMD.^{10–12} The most recent study demonstrated that SB is more frequently associated with TMJ pain and functional jaw limitations than AB.¹³ This observation highlights the complexity of the issue and the need for further research.¹⁴

In 2024, 2 meta-analyses examined the prevalence of TMD³ and bruxism⁴ across continents. These studies indicated that geographical factors may influence the prevalence of these conditions. The global prevalence of TMD was estimated at 34%,³ while the global prevalence of bruxism (both SB and AB) was estimated at 22.22%.⁴ When analyzed separately, the prevalence of SB was estimated at 21%, and the prevalence of AB at 23%.⁴ The continental analysis revealed a high co-occurrence of bruxism and TMD in the Americas (Fig. 1). However, these findings do not allow for a definitive determination of whether bruxism and TMD co-occur due to interdependence.

A review of the available literature did not yield a conclusive answer regarding the inherent association between bruxism and TMD. Consequently, a meta-regression analysis was conducted based on the synthesized data from previously published meta-analyses and systematic reviews.

The primary objectives of the study were to estimate the pooled prevalence of (1) bruxism (both SB and AB) and TMD co-occurrence and (2) TMD prevalence among individuals with bruxism across continents. The influence of continents on these proportions was assessed using the meta-regression, with continents serving as categorical moderators. Based on previously published research analyzing the occurrence depending on the continent,^{3,4} a hypothesis was formulated that both phenomena would co-occur, particularly with regard to North and South America.

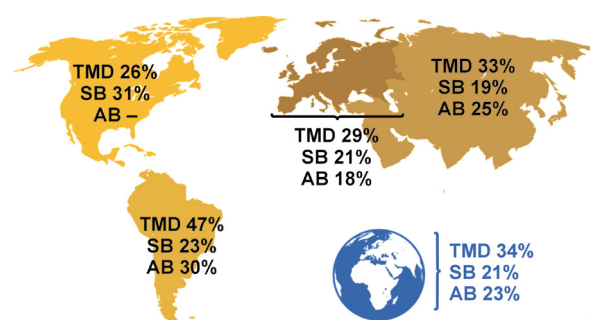


Fig. 1. Results of epidemiological studies on temporomandibular disorders (TMD) and bruxism by continent^{1,2}

SB – sleep bruxism; AB – awake bruxism.

Material and methods

The project was registered in the Open Science Framework (OSF) database (<https://osf.io/2afqr>). The research was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 checklist.¹⁵ The project commenced on October 29, 2024. The following terms were used to search PubMed®, Web of Science and Scopus databases: “Bruxism”; “Temporomandibular Disorders”; “TMD”; and “Systematic Reviews”.^{3,4,16} The search was conducted for articles published before October 29, 2024. Only systematic reviews and meta-analyses investigating the co-occurrence of bruxism and TMD were included in the study.

In the first phase of the study, the search was performed independently by 2 authors (BPZ and AP), and any discrepancies were resolved by the third author (GZ). Using the specified keywords, a total of 239 records were retrieved from the 3 selected databases. Titles were initially reviewed, resulting in the exclusion of 222 records. Subsequently, abstracts were analyzed and duplicates were removed. Six full-text articles were selected for further analysis. The following systematic reviews and meta-analyses were accepted for data extraction: Manfredini and Lobbezoo⁷; Jiménez-Silva et al.⁸; Mortazavi et al.⁹; de Oliveira Reis et al.¹⁷; Achmad et al.¹⁸; and Al-Jewair et al.¹⁹

The second phase of the study involved importing data from the included articles. Data analysis and import were conducted independently by 2 authors (BPZ and AP) under the supervision of the third author (GZ). In the event of any disagreement between the 2 authors, the supervisor was to make the final decision. However, this situation did not occur, as there was unanimous agreement between the 2 authors. Based on the 6 studies, data from 30 individual studies examining 31 populations were imported for the analysis of the co-occurrence of bruxism and TMD (Fig. 2).^{20–49} The 31 analyzed populations included a total of 37,680 participants, 5,117 of whom were diagnosed with both bruxism and TMD. Detailed information about the studies are provided in the supplementary materials (Table A.1; <https://osf.io/c38eg>). The flow diagram was adapted from the PRISMA guidelines (Fig. 2).¹⁵

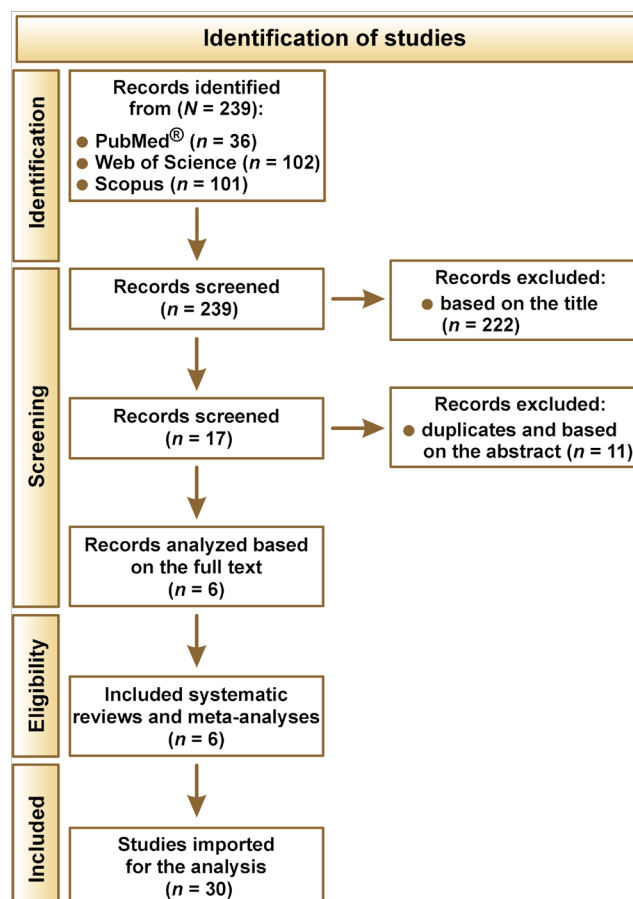


Fig. 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram of the study

Statistical analysis

A meta-analysis was conducted to estimate the pooled prevalence of events across studies. The analysis was performed using the generalized linear mixed model (GLMM) framework, which allows for the incorporation of both within-study and between-study variability. The logit transformation of proportions was applied as the effect size measure, as is recommended for meta-analyses involving proportions to stabilize variance and ensure appropriate weighting of studies.⁵⁰ The inverse variance method was used for weighting study estimates.

The confidence intervals for the pooled estimates were calculated using the normal approximation interval based on the summary measure method, which provides robust interval estimation for proportions.⁵¹

The back-transformation of pooled logit proportions to the original scale was applied to enhance the interpretability of the findings. Statistical analyses were performed without assuming a common heterogeneity estimate across subgroups (τ^2 not constrained to be common), allowing for subgroup-specific variability. Additionally, a random-effects model was employed, as it is more appropriate when clinical or methodological diversity is expected among included studies.⁵² It accounts for

heterogeneity by assuming that the true effect sizes may vary across studies rather than being fixed.

Heterogeneity was quantified using several metrics. The between-study variance (τ^2) was estimated using the maximum likelihood (ML) method, which provides a likelihood-based estimate of heterogeneity and is particularly useful for meta-analyses with substantial variability.⁵³ The τ^2 value was then used to compute τ , representing the standard deviation of the true effect sizes. The I^2 statistic, which quantifies the percentage of total variation in effect estimates attributable to heterogeneity rather than sampling error, was calculated as described by Higgins and Thompson.⁵⁴ Additionally, the H-statistic, an alternative to I^2 for assessing heterogeneity, was computed to offer further insights into the degree of variability across studies.

Heterogeneity was formally assessed using both the Wald test and the likelihood ratio test (LRT). The Wald test evaluates heterogeneity by comparing the observed variance to the expected variance under the homogeneity assumption.⁵¹ The likelihood ratio test compares the likelihood of the data under the random-effects model to the likelihood under a fixed-effects model, providing a more robust assessment of heterogeneity, particularly in datasets with high variability.⁵⁵

Subgroup differences were evaluated using a random-effects model for subgroup analysis, which allows for the estimation of between-group variability while accounting for within-group heterogeneity. The assessment of subgroup differences was conducted using the Q-statistic, as described by Borenstein et al.⁵⁶ A forest plot was used to visually depict the results of the GLMM framework.

Publication bias was assessed using a combination of visual and statistical methods. Visual inspection of the funnel plot was used to identify patterns of asymmetry that might suggest potential bias.⁵⁷ The statistical tests for funnel plot asymmetry included Begg's rank correlation test and Peters' linear regression test. Begg's test evaluates the correlation between study effect sizes and their variances, relying on a rank-based approach to detect asymmetry.⁵⁸ Peters' test assesses the relationship between study effect sizes and their precision, using a linear regression framework that is particularly sensitive to detecting asymmetry in meta-analyses of proportions.⁵⁹

The influence analysis was conducted to identify studies with a disproportionate impact on the meta-analytic results. The analysis employed a range of statistical methods, including standardized residuals, difference in fits (DFFITS), Cook's distance, covariance ratio, leverage ("hat"), and leave-one-out diagnostics. Standardized residuals identified potential outliers, while DFFITS and Cook's distance detected influential studies that affected predicted values and overall model fit.^{51,60} The covariance ratio and leverage assessed the impact of individual studies on the precision of the model. The leave-one-out analysis evaluated changes in heterogeneity (τ^2 , Q) and pooled

estimates after excluding each study. The use of diagnostic plots facilitated the visualization of these metrics, enabling the identification of influential studies.

In cases where the test for subgroup differences yielded significant results, a meta-regression was conducted to examine the potential influence of moderators on effect sizes and to identify which subgroups exhibited significant differences. The analysis was performed using a mixed-effects model, incorporating both fixed effects for moderators and a random effect to account for between-study variance.⁵³ The restricted maximum likelihood (REML) method was used to estimate the residual heterogeneity (τ^2), providing a robust estimate of variability not explained by the included moderators.⁵¹ The significance of individual predictors was assessed using Wald-type z-tests, while the overall significance of all moderators was evaluated using the omnibus test of moderators (Q_M), which compares the model with moderators to a null model without moderators. The statistical significance of moderators was determined at a predefined alpha level ($\alpha = 0.05$).

The papers were initially exported to Zotero, v. 6.0.36 (Corporation for Digital Scholarship, Vienna, USA). Subsequently, the data from the papers was exported to Microsoft Excel (Microsoft Corp., Redmond, USA). The analyses were conducted using the R Statistical language, v. 4.3.3 (<https://cran.r-project.org/src/base/R-4>) on Windows 11 Pro 64 bit (build 22631; Microsoft Corp.), using the meta (v. 7.0.0),⁶¹ dmetar (v. 0.1.0),⁶² report (v. 0.5.8),⁶³ ggplot2 (v. 3.5.0),⁶⁴ dplyr (v. 1.1.4),⁶⁵ and psych (v. 2.4.6.26) packages.⁶⁶

Results

A total of 31 studies comprising 37,680 individuals, among whom 5,117 reported the co-occurrence of bruxism and TMD, were included in the analysis. The random-effects model yielded an overall pooled prevalence of 17.1% (95% confidence interval (CI): 11.4–24.9). However, the heterogeneity among the included studies was found to be extremely high ($I^2 = 99.4\%$, 95% CI: 99.3–99.5), indicating that nearly all observed variability in the effect sizes was due to differences between the studies rather than a random error. This finding was further corroborated by high residual heterogeneity ($\tau^2 = 1.76$) and the Q statistic ($Q = 4983.69$, $p < 0.001$). Additionally, the LRT confirmed the presence of significant heterogeneity (LRT = 5876.73, $p < 0.001$).

Subgroup analysis by continent revealed substantial differences in the pooled proportions. Specifically, North America exhibited the highest pooled prevalence of bruxism and TMD co-occurrence at 69.8% (95% CI: 61.0–77.4). This finding was accompanied by moderate heterogeneity ($I^2 = 79\%$, $\tau^2 = 0.0357$), based on only 2 studies. South America exhibited a pooled prevalence

of 24.1% (95% *CI*: 15.1–36.3), characterized by higher heterogeneity ($I^2 = 96\%$, $\tau^2 = 0.6406$). Asia demonstrated the lowest pooled prevalence at 9.4% (95% *CI*: 3.4–23.3), with heterogeneity remaining extremely high ($I^2 = 99\%$, $\tau^2 = 1.7883$). Europe, with the largest number of included studies ($n = 15$), exhibited a pooled prevalence of 13.7% (95% *CI*: 8.0–22.3), accompanied by very high heterogeneity ($I^2 = 100\%$, $\tau^2 = 1.3529$) (Fig. 3).

The test for subgroup differences revealed statistically significant variation in pooled prevalence across continents ($Q = 79.09$, $p < 0.01$). This finding suggests that geographical location may play an important role in the observed differences in the co-occurrence of bruxism and TMD (Fig. 3).

The extreme heterogeneity observed across studies and subgroups underscores the necessity for the establishment of standardized diagnostic criteria and methodologies in future research in order to better understand the global burden of bruxism and TMD co-occurrence.

The influence analysis reveals that while certain studies have a measurable impact on the results of the meta-analysis, no single study exerts a significant influence (Figure A.1, supplementary materials; <https://osf.io/c38eg>). High heterogeneity remains a concern, and specific studies contributing to this variability should be further reviewed. The overall pooled estimate demonstrates stability, suggesting that the observed variability is attributable to broader differences across the included studies rather than isolated outliers.

The results of the pooled proportions are displayed in Fig. 3 as forest plots, with each individual study listed on the left, grouped by continent, and represented by a square and a horizontal line. The square denotes the study's effect size (proportion), and its dimensions reflect the weight of the study in the meta-analysis, with larger squares signifying a greater influence. The horizontal line extending from each square represents the 95% *CI* of the effect size. A longer line indicates greater uncertainty, while a shorter line reflects more precision in the estimate. The co-occurrence of bruxism and TMD by continent subgroups is further visualized in Fig. 4.

The vertical dashed line in the plot signifies the null effect, which serves as a reference point for comparison. Studies with squares and *CI*s entirely to the right of the line suggest positive proportions, while those positioned to the left indicate negative or lower proportions. At the bottom of each subgroup, a diamond is displayed, providing a summary of the pooled estimate for that subgroup. The center of the diamond denotes the pooled effect size, while the width reflects the 95% *CI* of the subgroup. Narrower diamonds indicate more precise pooled estimates. Similarly, the diamond situated at the very bottom of the plot signifies the overall pooled effect size across all studies, providing a summary of the total effect.

As illustrated in Fig. 3, the 95% *CI* values overlapped across all continents, with the exception of North

America. This finding indicates that there are no statistically significant differences between the proportions of individuals with bruxism and TMD reported for Asia, Europe and South America. However, to formally evaluate the significance of differences in proportions between continents, a meta-regression analysis was performed, with North America designated as the reference category.

To account for potential confounding effects, the meta-regression model was adjusted for a key sociodemographic factor: the proportion of females in the study sample. This value varied widely across studies, ranging from 15.5% to 85.6%, with a median of 64% (*IQR*: 51.24–79.22). The inclusion of this adjustment in the analysis was intended to provide a more accurate assessment of the geographical differences in the co-occurrence of bruxism and TMD, while accounting for the variability in sex distribution across studies.

The meta-regression analysis demonstrated significant differences in the co-occurrence of bruxism and TMD across continents. Specifically, North America exhibited the highest prevalence of bruxism and TMD compared to Asia and Europe. South America did not differ significantly from North America. The proportion of females in the study sample was also found to be a significant moderator, with higher values associated with increased prevalence of the co-occurrence of both conditions (Table 1). These findings highlight the importance of geographical and demographic factors in the understanding of the co-occurrence of bruxism and TMD.

Furthermore, there were no significant differences in the co-occurrence of the 2 conditions across Asia, Europe and South America.

Additional meta-regression models were conducted to evaluate the potential impact of other predictors, such as the year of the survey and the mean age of the studied individuals, on the co-occurrence of bruxism and TMD. The results indicated that neither the year of the survey ($p = 0.508$) nor the mean age of the study participants ($p = 0.362$) had a statistically significant effect on the co-occurrence of the 2 conditions. These findings imply that temporal factors and the average age of participants did not meaningfully contribute to the variability in the observed proportions across studies.

The funnel plot presented in Fig. 5 visually depicts the relationship between the logit-transformed proportion (effect size) and the standard error for each study included in the meta-analysis. Each circle corresponds to an individual study, with its position on the x-axis indicating the effect size and its position on the y-axis showing the level of precision (inversely proportional to the standard error). Studies with larger standard errors (smaller sample sizes) are positioned near the bottom of the plot. The dashed lines represent pseudo-confidence limits, which indicate the expected distribution of studies in the absence of bias.

The funnel plot is generally symmetrical, indicating that publication bias may not constitute a significant concern

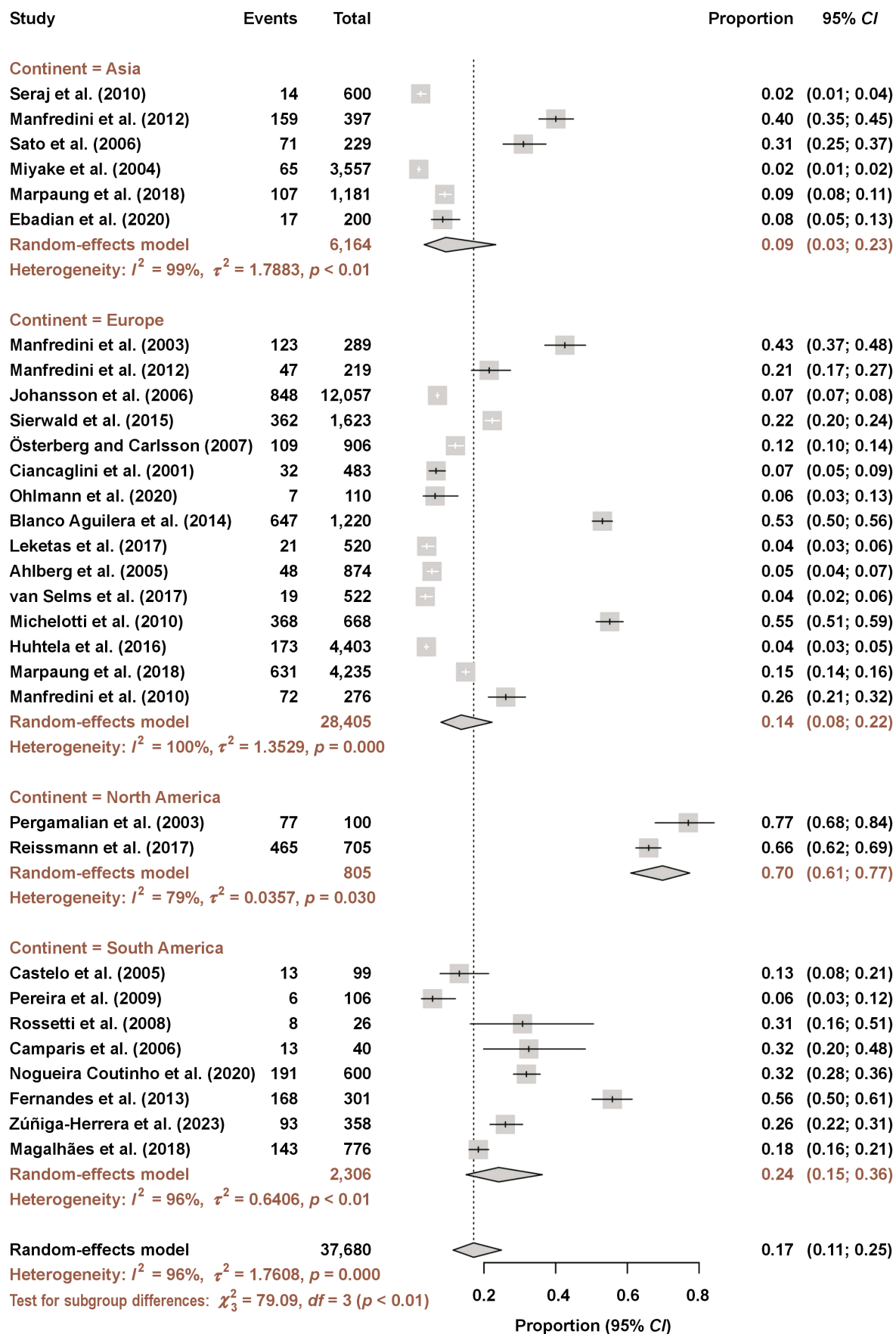


Fig. 3. Forest plot for the overall proportion of co-occurrence of bruxism and temporomandibular disorders (TMD) among subgroups by continent
CI – confidence interval; df – degrees of freedom.

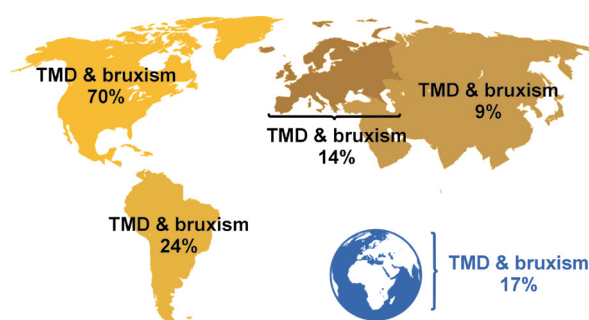


Fig. 4. Graphical representation of the results of the analyzed studies on the co-occurrence of temporomandibular disorders (TMD) and bruxism

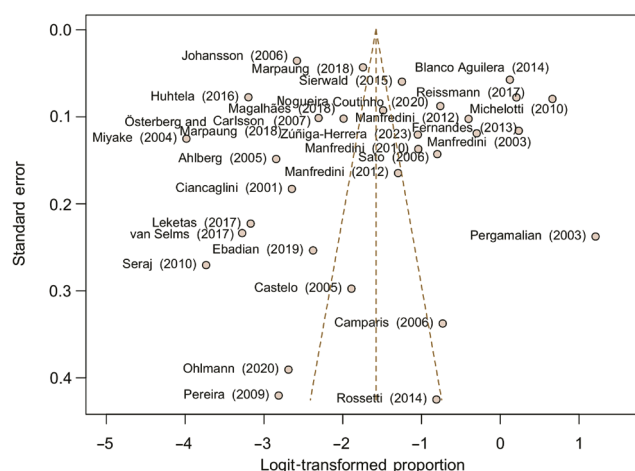


Fig. 5. Funnel plot assessing publication bias in the meta-analysis on the co-occurrence of bruxism and temporomandibular disorders (TMD) among adult patients

within the context of this meta-analysis. The majority of studies are situated within the pseudo-confidence limits, particularly those with smaller standard errors (larger sample sizes). However, a few studies with larger standard errors and extreme effect sizes, such as those on the far left (e.g., Ohlmann et al.³⁵ and Pereira et al.²¹), fall outside the pseudo-confidence limits. These studies imply the presence of heterogeneity or methodological discrepancies rather than systematic publication bias.

The assessment of funnel plot asymmetry was performed using 2 statistical methods: Begg's rank correlation test; and Peters' linear regression test. Peters' test, which evaluates asymmetry based on the inverse of the total sample size, yielded a bias estimate of 137.68 (standard error (SE) = 88.76), with a test statistic of $t(29) = 1.55$ ($p = 0.132$). This finding suggests an absence of statistically significant evidence supporting small-study effects or publication bias. Similarly, Begg's rank correlation test, which examines the association between effect sizes and their variances, demonstrated a bias estimate of -55.00 ($SE = 58.84$, $z = -0.93$, $p = 0.349$), providing no significant evidence for funnel plot asymmetry. The results of both tests suggest that the outcomes of the meta-analysis were not influenced by publication bias or the effects of small studies.

Meta-analysis of the pooled prevalence of TMD among subjects diagnosed with bruxism

A meta-analysis was conducted to estimate the pooled prevalence of TMD among adult patients with bruxism, stratified by continent. The analysis included 29 studies (after excluding the study by Marpaung et al.⁴⁷ as an influential study⁵¹), comprising a total of 8,462 participants with bruxism, of whom 4,486 experienced TMD. Using a random-effects model, the overall pooled prevalence of TMD was estimated at 63.5% (95% CI : 50.4–74.9).

The analysis revealed substantial heterogeneity across studies ($\tau^2 = 2.1669$, $\tau = 1.47$, $I^2 = 98\%$, $H = 7.41$), with the test for heterogeneity being highly significant ($Q = 1593.76$, $p < 0.001$).

When stratified by continent, the estimated prevalence of TMD varied. In Asia, the pooled prevalence was 53.9% (95% CI : 25.5–79.9), with high heterogeneity ($\tau^2 = 2.2371$, $I^2 = 97\%$). In Europe, the pooled prevalence was 62.2% (95% CI : 44.1–77.5), also with substantial heterogeneity ($\tau^2 = 1.9144$, $I^2 = 99\%$). In North America, the prevalence was markedly higher at 98.3% (95% CI : 73.7–99.9), with no

Table 1. Meta-regression coefficients with the proportion of co-occurrence of bruxism and temporomandibular disorders (TMD) as an outcome

Predictor	Estimate (log-odds)	OR	95% CI	p-value	Interpretation
Intercept	-2.60	0.07	0.01–0.54	0.010*	The baseline probability of co-occurrence in North America, with no female subjects included in the study sample.
South America	-0.97	0.38	0.09–1.59	0.186	The probability of co-occurrence is 0.38 times that of North America (not significant).
Asia	-2.22	0.11	0.03–0.46	0.003*	The probability of co-occurrence is 0.11 times that of North America (significant difference).
Europe	-2.00	0.14	0.04–0.51	0.003*	The probability of co-occurrence is 0.14 times that of North America (significant difference).
Proportion of females	0.04	1.04	1.02–1.06	<0.001*	A 1% rise in the proportion of females in the study sample increases the probability of co-occurrence by 4.4%.

* statistically significant ($p < 0.05$, logistic regression test); OR – odds ratio; CI – confidence interval.

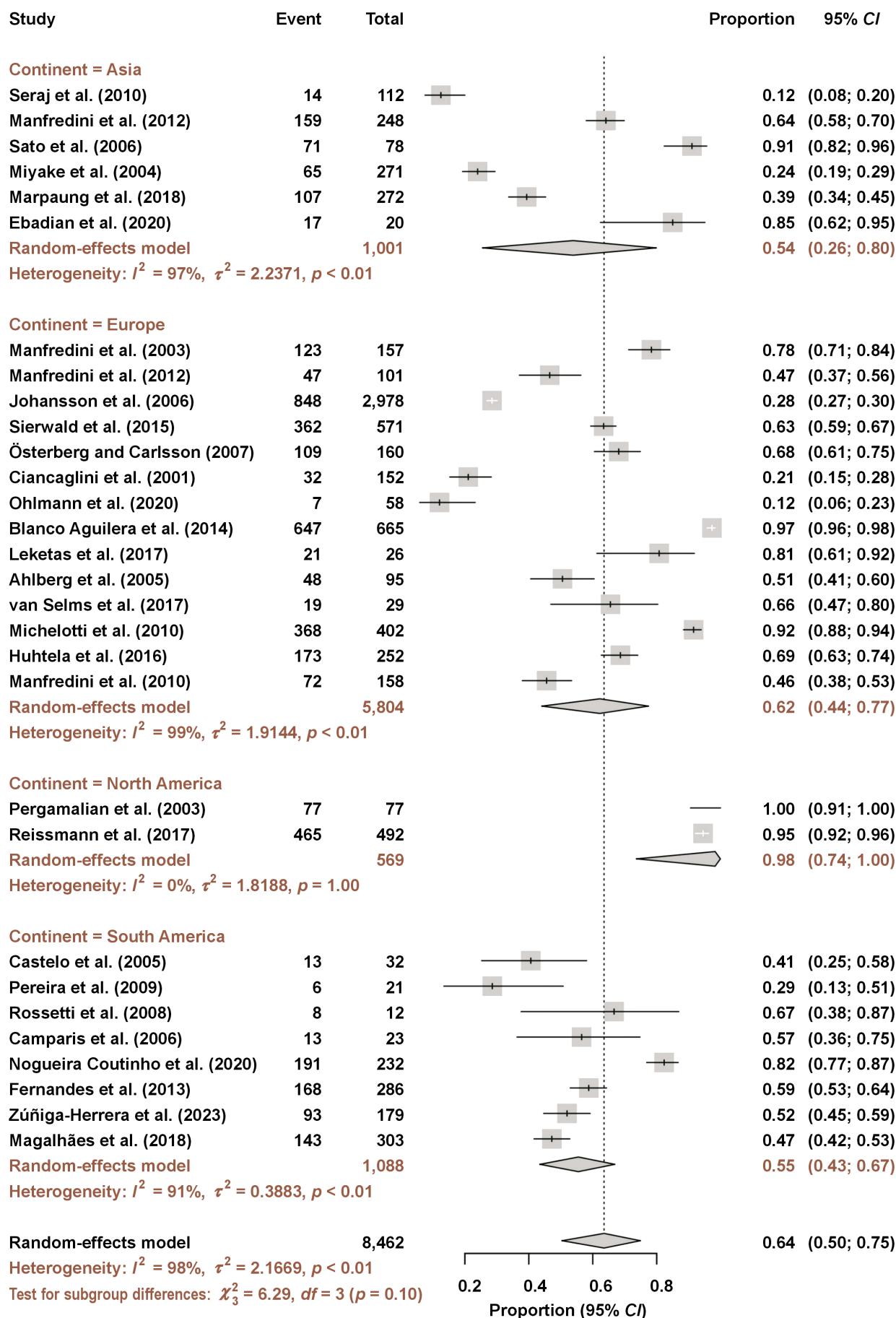


Fig. 6. Forest plot for the overall proportion of temporomandibular disorders (TMD) in patients with bruxism among subgroups by continent

observed heterogeneity ($I^2 = 0\%$). In South America, the pooled prevalence was 55.5% (95% CI: 43.5–66.9), with moderate heterogeneity ($\tau^2 = 0.3883$, $I^2 = 91\%$) (Fig. 6).

The test for subgroup differences across continents was not statistically significant ($p = 0.098$), suggesting that the observed differences in proportions between continents may not represent meaningful variation. However, the notably higher prevalence of TMD in North America compared to other continents warrants further investigation to identify possible methodological or population-specific factors.

In summary, the results highlight a high prevalence of TMD in patients with bruxism globally, but also underscore substantial heterogeneity across studies. The results are visualized by forest plots in Fig. 6.

The influence analysis identified the study by Marpaung et al.⁴⁷ as influential. Upon its removal, the majority of the remaining studies contributed to the overall meta-analytic model without exerting disproportionate influence (Figure A.2, supplementary materials; <https://osf.io/c38eg>).

Standardized residuals predominantly fall within acceptable bounds, with only minor deviations observed for a few studies, suggesting that no extreme outliers affect the model fit. The DFFITS values are generally low, indicating that no single study strongly influences the estimated parameters. However, a few studies showed slightly elevated values, pointing to moderate influence. The Cook's distance remained minimal across studies, with only minor increases observed in a single or 2 studies, which do not substantially alter the pooled effect size. The covariance ratio remained consistent for the majority of studies, except for 1 study⁴⁷ that demonstrated a noticeable drop, potentially affecting the precision of the model estimates. Leave-one-out τ^2 and Q statistics demonstrate stability in heterogeneity estimates, with only slight variations for a few studies, indicating that the overall heterogeneity is not driven by a single study. The analysis of hat values and study weights revealed no indications of extreme leverage or disproportion, confirming that the contributions of individual studies are balanced.

Overall, among the remaining 29 studies (30 populations), while a few exhibited mild influence, none exerted an undue impact on the findings of the meta-analysis.

The funnel plot presented in Fig. 7 demonstrates a predominantly symmetrical distribution of studies around the pooled effect size, with no pronounced asymmetry. While a slight imbalance is observed, particularly a tendency for fewer studies with smaller proportions on the left side of the plot, this imbalance is not strongly pronounced.

The distribution of smaller studies, characterized by higher standard errors, appears slightly more dispersed, which is anticipated due to their heightened susceptibility to variability. In contrast, larger studies, characterized by lower standard errors, are more consistent and cluster

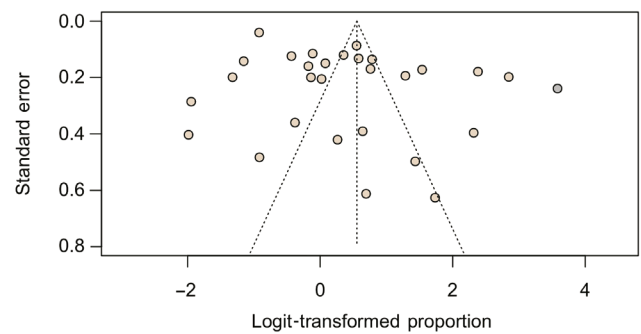


Fig. 7. Funnel plot assessing publication bias in the meta-analysis on the occurrence of temporomandibular disorders (TMD) among adult patients diagnosed with bruxism (no labels due to overlap)

closely around the pooled effect size. This pattern is commonly observed in meta-analyses and does not necessarily imply the presence of bias.

Begg's rank correlation test indicated no significant evidence of funnel plot asymmetry ($z = 0.23$, $p = 0.817$). The bias estimate was 13.00 ($SE = 56.05$), suggesting that any potential asymmetry is likely due to random variation rather than systematic bias. Similarly, Peters' linear regression test found no evidence of asymmetry ($t(27) = 0.90$, $p = 0.378$). The bias estimate was 25.78 ($SE = 28.77$). This approach, which evaluates the relationship between effect sizes and their precision, further confirms the absence of significant bias.

The results from both tests align with the visual inspection of the funnel plot, indicating that the overall results of the meta-analysis are unlikely to have been influenced by publication bias. While minor visual discrepancies in the funnel plot were identified, they appear to be attributable to random variation rather than systematic bias. Consequently, the meta-analytic conclusions can be interpreted with a high degree of confidence, as there was no substantial evidence to suggest that publication bias had an impact on the pooled estimates.

Discussion

The primary objectives of the study were to estimate the pooled proportions of (1) bruxism (both SB and AB) and TMD co-occurrence and (2) TMD prevalence among individuals with bruxism across continents. The influence of continents on these proportions was assessed using meta-regression, with continents serving as categorical moderators.

The analysis of the co-occurrence of bruxism and TMD revealed a global proportion of 17.1%, with significant differences across continents. The highest proportion was observed in North America (69.8%) and the lowest in Asia (9.4%). In meta-regression, sex was identified as a significant factor, with an elevated proportion of females correlating with an increased likelihood of TMD and bruxism co-occurrence. Conversely, other factors, such as the year

of the study or the average age of the participants demonstrated no statistically significant impact on the variability of the results.

The strengths of the analysis include a large study sample (31 populations, 37,680 individuals) and no substantial evidence of publication bias, as confirmed by a symmetrical funnel plot and statistical tests such as Begg's rank correlation test and Peters' linear regression test. The results emphasize the significance of geographical and demographic factors in understanding the co-occurrence of these conditions. North America, which exhibited the highest proportion, demonstrated moderate heterogeneity ($I^2 = 79\%$), a finding that may be indicative of more consistent diagnostic methods in this region.

Examining the average proportion of TMD among bruxism patients, the global TMD prevalence was found to be 63.5%, which underscores the pervasive nature of TMD in this group. North America exhibited the highest proportion of TMD among patients with bruxism (98.3%), while Asia recorded the lowest prevalence (53.9%). A notable strength of the analysis is the meticulous assessment of the influence of individual studies on the outcomes. The exclusion of the study by Marpaung et al.⁴⁷ improved model stability, underscoring the meticulous approach employed. The absence of asymmetry in the funnel plot and the results of Begg's and Peters' tests suggest no significant publication bias, thereby adding confidence to the conclusions.

Previous systematic reviews support the association between bruxism and TMD. For instance, Manfredini and Lobbezoo demonstrated a positive association between bruxism and TMD pain,⁷ while Jiménez-Silva et al. suggested that bruxism is likely linked to TMD.⁸ Similarly, Mortazavi et al. found a positive relationship,⁹ and de Oliveira Reis et al. concluded that children with bruxism are at greater risk of developing TMD.¹⁷ On the other hand, Al-Jewair et al. emphasized that the evidence remains inconclusive, particularly regarding the relationship between TMD and SB.¹⁹

Given the global TMD prevalence of 63.5% among bruxism patients and the lack of significant publication bias, it can be inferred that bruxism frequently occurs in conjunction with TMD. This finding is consistent with the 2018 consensus, which acknowledged that bruxism alone does not always cause problems. However, when exacerbated by concomitant risk factors, it can contribute to complications.² Consequently, bruxism may be an etiological factor for TMD, particularly in the presence of additional contributing factors such as geographical, ethnic,^{3,4} genetic,^{67,68} or hormonal influences.^{4,69}

The study's limitations primarily pertain to the substantial heterogeneity of the results, which complicates interpretation and underscores differences between populations and study methodologies. Diagnostic criteria for TMD, such as the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) and DC/TMD,¹ are globally accepted. However, no standardized

criteria for bruxism existed until the Standardized Tool for the Assessment of Bruxism (STAB) was introduced in 2020,⁷⁰ with pilot test results published in 2023.⁷¹ Further research using standardized protocols is recommended.

Standardized research protocols and tools are essential for the evaluation of the impact of SB and AB on TMD. A review conducted by Manfredini and Lobbezoo highlighted that studies based on questionnaires or self-reported data often exhibit limited accuracy in assessing SB; however, they consistently indicate a positive association with TMD-related pain.⁷² In contrast, studies employing instrumental methods, such as surface electromyography (sEMG) or polysomnography, have frequently demonstrated weaker associations or even a lack of correlation between SB and TMD pain.⁷² However, it should be noted that the literature in this field remains inconclusive, and the causal relationship between TMD and bruxism remains a subject of debate. Numerous publications have noted the absence of a definitive link between these phenomena.^{2,10–12} A literature review presents both supporting and contradictory arguments regarding this association, necessitating further analysis.^{7–9,17–19} Recent polysomnographic studies have confirmed previous findings indicating no association between SB, in its current definition, and TMD. For instance, Sinclair et al. emphasized the lack of such a relationship in their conclusions.¹⁰ Additional studies support these observations. Wieckiewicz et al.¹² noted that the distribution of TMD was similar among patients with SB and non-bruxers, while Smardz et al.¹¹ found that the occurrence of TMD-related pain is not correlated with the intensity of SB. These findings underscore the need for further research analyzing the impact of bruxism (both SB and AB) on TMD while considering its different subtypes.

However, in a comparative study analyzing which form of bruxism is associated with TMD, Cigdem Karacay and Sahbaz demonstrated that AB is linked to TMJ pain and is also associated with greater functional jaw limitations compared to SB.¹³ These examples highlight the complexity of the relationship between SB, AB and TMD.

In light of the findings, it is important to acknowledge the potential influence of cultural differences in emotional expression and pain perception on the outcomes.^{73,74} However, to minimize their impact, we applied advanced statistical methods, including subgroup analysis and meta-regression, which enabled us to assess the role of moderators. Additionally, the lack of a shared heterogeneity estimate among the groups (τ^2 not constrained to a common value) enabled the analysis of regional differences, while the random-effects model accounted for the variability between the studies.^{50,54} To identify potential systematic biases stemming from cultural differences, we employed funnel plots and asymmetry tests (Begg's rank correlation test and Peters' linear regression test).^{58,59}

In the present study, the distinction between AB and SB was not considered. This decision stemmed from

limitations in the data obtained from previously imported reviews. Moreover, the studies included in this meta-regression were primarily based on questionnaires or self-reported data, rather than sEMG or polysomnography.^{20–49} While this may introduce some error, the currently imported data from the reviews did not allow for a different approach. Therefore, further research in this area is recommended.

Another significant limitation of the current study is treating TMD as a homogeneous disease entity, despite the fact that TMD encompass various disorders with distinct clinical presentations, pathophysiological mechanisms and demographic distributions. Temporomandibular disorders represent a broad category that includes, among others, myogenous pain, joint–muscle instability and inflammatory joint processes, each with different causes and mechanisms.¹ Failing to differentiate between them may lead to excessive generalization of the results and limit their interpretation; therefore, we recommend caution in analyzing the findings.

A notable limitation of the study is the significant heterogeneity of the included studies, which stems from the use of different assessment methods, including self-reports, clinical exams and quantitative evaluations of bruxism. The incorporation of different diagnostic tools, such as RDC/TMD, DC/TMD and other scales, may result in divergent outcomes, which complicates direct data pooling and increases the risk of error. The detailed information regarding the used tools can be found in the supplementary materials (<https://osf.io/c38eg>). However, the current scientific data does not permit the application of an alternative approach. The use of a random-effects model partially accounts for this variability; however, it does not eliminate the potential for disparate outcomes across studies. This approach is consistent with previous systematic reviews and meta-analyses.^{7–9,17–19} Therefore, further research in this area is recommended.

Additionally, the lack of significant differences across continents ($p = 0.098$; Fig. 6) may be attributable to limitations in the sample, despite the presence of evident disparities in proportions. For example, in North America, the data was derived from 2 studies, thereby limiting the generalizability of the findings. As evidenced in previous meta-analyses on the prevalence of TMD or bruxism by continent, insufficient data were collected for Africa and Australia, highlighting a need for further research on the co-occurrence of bruxism and TMD in these regions.^{3,4}

Conclusions

In summary, the present study suggests that bruxism may contribute to the development of TMD, particularly when additional factors such as geographical, ethnic, genetic, or hormonal influences are involved. The estimated prevalence of the co-occurrence of bruxism and TMD in

the global population is 17%. In North America, the co-occurrence of these 2 conditions was 70%, followed by 24% in South America, 14% in Europe, and 9% in Asia. A higher proportion of female participants in study samples significantly increases the likelihood of bruxism and TMD co-occurrence, regardless of the continent. Specifically, a 1% increase in the proportion of females in a study group was associated with a 4.4% increase in the probability of co-occurrence. In Asia, the probability of bruxism and TMD co-occurrence was 89% lower than in North America (the reference group). A similar trend was observed in Europe, where the likelihood was 86% lower than in North America. These findings imply that temporal factors and the average age of participants did not significantly contribute to the observed variability across studies.

The overall prevalence of TMD among patients with bruxism was 63.5%. In North America, this prevalence was the highest (98.3%). This was followed by Europe (62.2%), Asia (53.9%) and South America (55.5%). The notably higher proportion of TMD in North America compared to other continents warrants further investigation to identify potential methodological or population-specific factors.

These findings underscore the importance of geographical and demographic factors in understanding the co-occurrence of bruxism and TMD. The meta-analytic conclusions can be interpreted with a high degree of confidence, as there was no substantial evidence to suggest that publication bias had an impact on the pooled estimates.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets supporting the findings of the current study are openly available in the Open Science Framework at <https://doi.org/10.17605/OSF.IO/2AFQR>.

Consent for publication

Not applicable.

Use of AI and AI-assisted technologies

Not applicable.

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