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# The BruxChecker System for Quantitatively Assessing Sleep Bruxism at the Dental Level: Reliability, Reference Values and Methodological Considerations

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## ABSTRACT

**Background:** There is a need for reliable instruments that can quantitatively assess sleep bruxism at the dental level.

**Objectives:** This study aimed to determine the test–retest reliability of the occlusal peeled area using the BruxChecker, the methodological aspects that affect this reliability, and the reference values in a population of dental students.

**Methods:** Eighty-four dental students participated in this test–retest study (median age, 21.7 years; 74 women). A BruxChecker was worn for 3 consecutive nights and scanned after each night in the plaster model and by transillumination. The relative and absolute peeled areas were measured using the FIJI software, and BruxChecker perforation was determined visually. Reliability was assessed by the intraclass correlation coefficient (ICC) and Cohen's kappa.

**Results:** The absolute and relative peeled areas of the BruxChecker by transillumination after 2 or 3 nights provided the highest ICC values, which ranged from 0.918 to 0.929. BruxChecker perforation was present in 45% of the participants, with a kappa value of 0.777. The respective median peeled areas were 84.3 $mm^2$ and 9.9% for the absolute and relative values after using the BruxChecker for three nights. Ranges for the 10th–90th percentiles were 4.7%–17.0% and 39.4%–143.4 $mm^2$, respectively.

**Conclusions:** The BruxChecker system demonstrates excellent reliability in measuring the occlusal peeled area in the studied population. This study proposes reference values for absolute and relative peeled areas after using the BruxChecker for three nights and scanning by transillumination.

## 1 | Introduction

Bruxism is a repetitive jaw-muscle activity that occurs during sleep or wakefulness and is characterised by clenching or grinding the teeth and/or by bracing or thrusting the mandible [1]. Bruxism may be a harmless behaviour, a protective factor, or a risk factor for negative clinical consequences, including tooth wear, dental treatment failure, and pain and dysfunction of the masticatory muscles and temporomandibular joints [2–7]. The prevalence of sleep bruxism in the adult population ranges from 8% to 22% [8–13], with variability probably due to the different methods used for assessment [14, 15]. The diagnosis of sleep or awake bruxism can be graded as 'possible' based on self-report, 'probable' based on self-report and clinical examination, and 'definite' based on self-report, clinical examination, and polysomnography [7]. Recently, the Standardized Tool for the Assessment of Bruxism and its abbreviated version, BruxScreen, have been developed to provide a comprehensive, multidimensional evaluation of bruxism [16, 17]. Since polysomnography is an expensive and a complex technique, ambulatory electromyographic recording systems and oral devices have been proposed to assess sleep bruxism activity at the muscular and dental levels [18–20].

The BruxChecker is a 0.1-mm thick transparent sheet adapted to the maxillary (or mandibular) arch and painted on the external (occlusal) surface with a red dye [20]. When worn during sleep for a few consecutive nights, it does not modify the activity of masticatory muscles, but the area of red film peeled by tooth grinding correlates with masseter electromyographic activity during sleep and, consequently, provides information about the consequences of sleep bruxism at the dental level [20, 21]. Most researchers and clinicians use the device to determine the pattern of grinding based on laterotrusive and mediotrusive side contacts [22, 23]. However, few studies have used the BruxChecker to quantify sleep bruxism at the dental level by either measuring the extension of the peeled red surface or determining the presence of perforated areas [21, 24–27]. Unfortunately, different studies have used a variety of methods, such as the number of nights using the BruxChecker, outcomes of sleep bruxism (e.g., absolute/relative occlusal grinding area, perforated area), and the techniques used [21, 24–27]. To consider the BruxChecker an accurate instrument for quantifying sleep bruxism at the dental level, a standardised methodology is required to provide reliable measurements that can be contrasted with reference values. In addition, the degree of agreement of sleep bruxism outcomes between those obtained with the BruxChecker and those obtained with the BruxScreen protocol would provide valuable information for clinical and research purposes [16, 28]. Finally, elucidating the intensity of association between several factors and BruxChecker outcomes would help to understand the aetiology, pathophysiology, and consequences of sleep bruxism at the dental level.

The primary aim of this study was to determine the test–retest reliability of measuring the occlusal peeled area using the BruxChecker in dental students. As secondary aims, we also assessed the methodological aspects that affect this reliability and established reference values for the occlusal peeled area measured with the BruxChecker. In addition, we determined the degree of agreement between the occlusal peeled area and clinical findings of the BruxScreen protocol and explored the factors associated with the intensity of sleep bruxism at the dental level.

## 2 | Material and Methods

### 2.1 | Study Design and Participants

We performed a prospective test–retest study from November 2023 to March 2024 at the University of Barcelona Dental School. Overall, 109 third-year students undertaking a dental degree were invited to participate. The following inclusion criteria were used: (i) aged 18–45 years, (ii) healthy dentition with at least 24 natural teeth without severe malocclusion, (iii) not undergoing active orthodontic treatment, (iv) not taking sedative drugs or having a chronic disease, and (v) sleeping at night with a minimum interruption. Participants who did not use the BruxChecker for three nights were excluded from the analysis.

Most participants had taken part in a previous investigation [29]. All participants signed a written informed consent form approved by the Ethics Committee of the University of Barcelona Dental Hospital (Ref. 24/2023). All procedures were conducted according to the principles of the Helsinki Declaration. Reporting follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

### 2.2 | Clinical Procedure

Participants were interviewed to collect data on age and gender. They were also asked to complete the self-report BruxScreen questionnaire [16]. The first part consists of 6 questions assessing self-perceived frequency of clenching and grinding while awake and during sleep, including teeth contact and mandible bracing, on a 5-point scale (0, never; 1, sometimes; 2, regularly; 3, often; 4, always). The second part assessed the frequency of jaw symptoms (pain, unpleasantness, sensitivity, tiredness, tension, stiffness) upon awakening or at any other time and when moving the jaw during meals or at any other time. These assessments used the same 5-point scale. Finally, the third part comprised two questions assessing the frequency of jaw lock during meals or at any other time [16].

A single examiner conducted the clinical assessment form of the BruxScreen protocol [16]. She determined the presence or absence of masseter muscle hypertrophy while the muscles were relaxed and contracted; of lip-, cheek-, and tongue-indentations; and of traumatic lesions in the tongue and tori. Occlusal/incisal wear per sextant plus palatal wear in sextant 2 was assessed as follows: 0, no wear; 1, wear within enamel; 2, wear with dentin exposure and loss of crown height $<1/3$rd; 3, loss of crown height $>1/3$rd but $<2/3$rd; and 4, loss of crown height $>2/3$rd. Clinical signs were considered to determine whether tooth wear was mainly mechanical, mainly chemical, or both mechanical and chemical [30, 31].

Bilateral bite force was measured using the Innobyte system (Kube Innovations, Montreal, QC, Canada), according to the manufacturer's instructions [29]. With the participant seated, a single examiner inserted the mouthpiece into the individual's mouth with a new disposable cover, placing their upper central incisors against the protruding stop at the front of the mouthpiece; cheek guards were also placed against their molars. The participant was asked to close slowly to ensure that the mouthpiece was placed correctly between the maxillary and mandibular arches, and once confirmed, the participant was instructed to bite on the mouthpiece with maximum effort for a few seconds. Three measurements were performed, allowing the participant to rest between them, and the average of the top two values was used for analysis [29].

The occlusal contact area at the maximum intercuspation position (ICP) was determined by bite registration. An addition silicone (Occlufast Rock, Zhermack) was applied to the occlusal surface of the mandibular teeth, and participants were asked to close their mouth to the ICP as hard as they could for 1 min. The occlusal registration was removed, trimmed, and scanned using a Transparent Materials Adapter (HP Scanjet G4050, Hewlett Packard, Palo Alto, CA, USA), and each occlusal registration image was converted to grayscale for analysis using ImageJ software (National Institutes of Health, USA). Spatial calibration was performed using a known distance and the relationship between each of the 256 greys. The thickness of the occlusal registration was determined using a stepped wedge of Occlufast [32]. Occlusal contact was considered present if the interocclusal distance was ≤200 μm [33].

The BruxChecker comprised a 0.1 mm thick transparent plate of polyvinyl chloride with the external surface painted with a red dye (Scheu-Dental, Iserlohn, Germany). It was fabricated in a Biostar VII (Scheu-Dental), heated at 230°C for 15 s, and adapted to a maxillary plaster model. Trimming was performed along the gingival margin for the buccal face and extended 2 mm from the cervical line at the palatal face. When the maxillary third molars were present, they were covered if completely erupted.

All participants were instructed to wear the BruxChecker during sleep for three consecutive nights [34]. They were taught how to take the device off and on without scratching it with their fingernails. They were also asked to write down the hours and minutes they had kept it in their mouth and the duration of sleep each night with the device in place.

We requested that the device be returned each day for scanning, after which the same device was returned to the participant. Scanning was according to two procedures (Figure 1). First, each BruxChecker was fitted in its plaster model, placed upside down on the glass surface of the scanner next to a 5 euro cent coin to calibrate the space, and scanned and saved in the JPEG format at 300 dots per inch. The second procedure involved placing the BruxChecker upside down without the model and scanning by transillumination using the Transparent Materials Adapter (HP Scanjet G4050, Hewlett Packard). Previously, each maxillary plaster model had been scanned without the BruxChecker and saved in the JPEG format (Figure 1A).

To determine test–retest reliability, all participants were invited to repeat testing with a new BruxChecker for three consecutive nights, 2 weeks after the first session. The new BruxChecker was fabricated in the same plaster model and by applying the same procedure as the first BruxChecker.

## 2.3 | Assessment of the BruxChecker Peeled Area

BruxChecker images were analysed using the FIJI software program (ImageJ; National Institutes of Health, Bethesda, MD, USA). Images of the plaster model of the maxillary arch were calibrated at 12 pixels/mm, and the occlusal perimeter was selected and saved as a region of Interest (ROI) file (Figure 1B,C).

The BruxChecker image fitted on the plaster model was transformed with multiple points of equivalence, using the plaster model as the reference image. The 'transform' plugin was used, applying a similarity class transformation with the least squares transformation method (Figure 1D). The selected occlusal perimeter (ROI file) was applied to the transformed image, cleaned, and saved as a spatially calibrated colour image (Figure 1E). This colour image was then converted to a grayscale 8-bit format showing the occlusal peeled areas as black marks, using the colour threshold and the hue (130–230), saturation (0–115) and brightness (90–255) colour space channels (Figure 1F). When converting the coloured and spatially calibrated images to grayscale, the same coloured and spatially calibrated image was added as an overlay with 30% opacity to correct the occlusal peeled boundaries with the FIJI brush options, as needed [35]. The relative and absolute occlusal peeled surface areas were measured on the grayscale images as a percentage of the occlusal surface and in millimetres squared, respectively.

The BruxChecker image obtained by transillumination was flipped horizontally and transformed by using multiple points of equivalence with the BruxChecker fitted on the plaster model as a spatially calibrated reference image (Figure 1G). The selected occlusal perimeter (ROI file) was applied to the transformed image, cleaned, and saved as a spatially calibrated colour image (Figure 1H). This colour image was then converted to a grayscale 8-bit format to show the occlusal peeled area as black marks, using the colour threshold and CIELAB colour space with threshold values of 125–255, 0–115, and 0–255 for channels $L^*$, $a^*$, and $b^*$, respectively. We corrected the occlusal peeled boundaries with the FIJI brush options if needed (Figure 1I) [35]. The relative and absolute areas of the peeled occlusal surfaces were also measured.

Perforations of the BruxChecker were assessed visually by direct inspection after wear for 3 nights. The number of tooth regions with perforation was determined before dichotomising the variable as perforated or not perforated. In addition, the perforated area was determined using the BruxChecker, scanned by transillumination, converting the colour image to 8-bits, and applying a threshold value of 250 for grey levels (Figure 1J).

## 2.4 | Data Analysis

Sample size was calculated based on an 80% probability of obtaining a 0.1 total width of the 95% confidence interval (CI) of an intraclass correlation coefficient (ICC) estimated at 0.9 [36]. We required a sample of at least 78 participants.

Several ordinal variables from BruxScreen were dichotomised to have the group with high values comparable to the prevalence of sleep bruxism (8%–22%) [8–13], Therefore, the following cut-offs were used for scores or sum scores: 3 for self-perceived frequency of clenching during sleep; 1 for self-perceived frequency of grinding during sleep; 7 for the six bruxism questions; 9 for the frequency of any jaw symptoms; 3 for the presence of any sign on non-dental tissues; and 6 for tooth wear per sextant. Similarly, the relative peeled areas after using the BruxChecker for three nights and after analysis by transillumination were dichotomised at 4 different cut-offs: the median (10%), the level proposed by Hokama et al. (100 $mm^2$ or 11.7%) [21], and for compatibility with the range of prevalence of sleep bruxism (14% and 17%). The occlusal peeling rate was calculated by dividing the occlusal peeled area by the time in hours using the BruxChecker or after sleeping with the BruxChecker in place for three nights.

We assessed the reliability of quantitative BruxChecker variables by the ICC using a two-way random effects model and absolute agreement for single measures. The smallest detectable

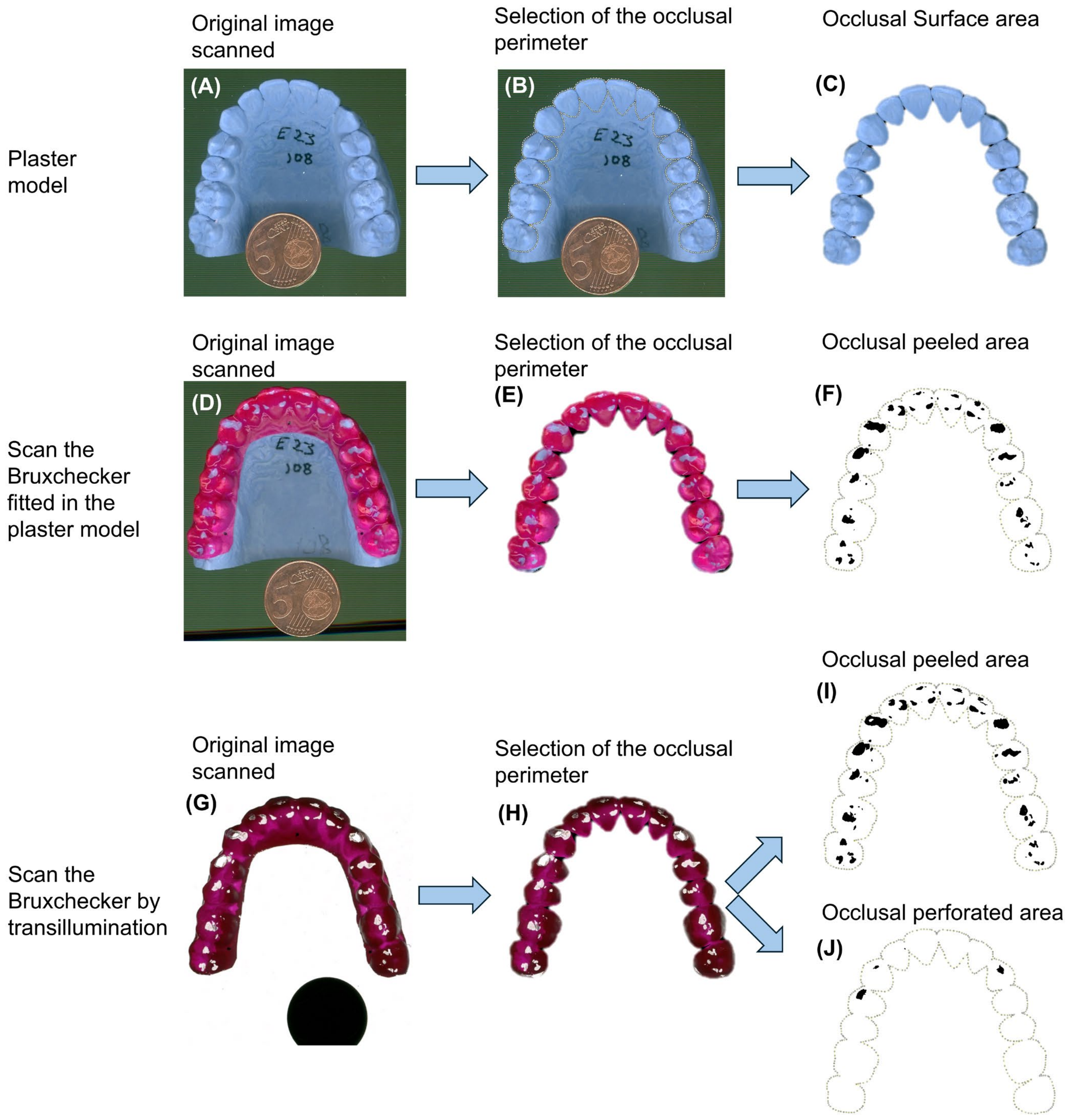


**FIGURE 1** | Image processing of the maxillary plaster model and BruxChecker. (A) Maxillary plaster model without the BruxChecker scanned in JPEG format. (B) Selection of the occlusal perimeter saved as an ROI file. (C) Occlusal surface area. (D) BruxChecker fitted on the plaster model scanned. (E) Occlusal surface of the BruxChecker fitted on the plaster model and spatially calibrated. (F) Black and white image showing the peeled area as black marks. (G) BruxChecker scanned by transillumination. (H) Occlusal surface of the BruxChecker scanned by transillumination and spatially calibrated. (I) Black and white image showing the peeled area as black marks from the BruxChecker scanned by transillumination. (J) Black and white image showing the perforated area as black marks from the BruxChecker scanned by transillumination.

difference (SDD) was determined as the smallest statistically significant amount of change that could be detected with a measurement device on two different occasions, calculated as follows: $SDD = 1.96 \times \sqrt{2} \times SEM$. Reliability of ordinal (number of tooth regions perforated) and dichotomous (BruxChecker perforated) variables was assessed by weighed kappa and Cohen's kappa, respectively.

The Kolmogorov–Smirnov test was used to confirm distribution normality for occlusal surface area, occlusal contact area, maximum bite force, and occlusal peeled area. A mean test–retest value was calculated for the BruxChecker-related variables assessed by different methods to provide reference values. The 10th, 25th, 50th, 75th and 90th percentiles for occlusal peeled area and for peeling rate were calculated by different methods.

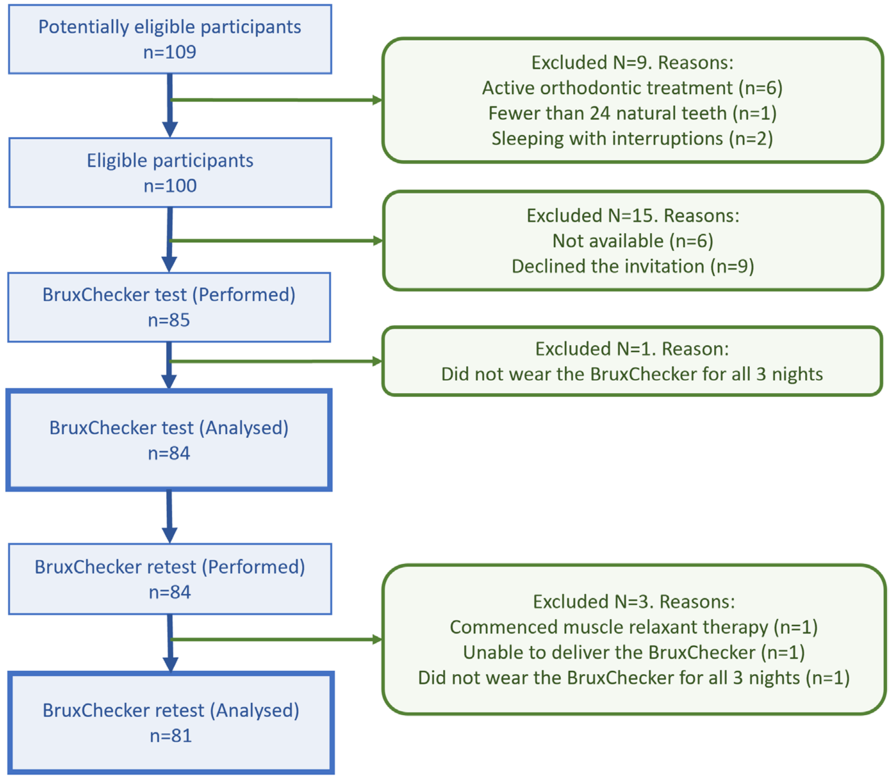


**FIGURE 2** | Flowchart of the test–retest reliability study.

The degree of agreement between BruxChecker and BruxScreen dichotomised variables was assessed using the kappa values. Bivariate and multivariate associations between gender, age, occlusal surface area, occlusal contact area, maximum bite force, and occlusal peeled area were examined using Pearson's correlation and multiple linear regression with a stepwise forward method. The relationships between perforating the BruxChecker and the peeled area, occlusal contact area, and maximum bite force were examined by *t*-test.

All data were analysed in IBM SPSS, Version 29 (IBM Corp., Armonk, NY, USA) and *p*-values of $<0.05$ were considered significant.

## 3 | Results

Among the 109 dental students invited to participate, 9 did not meet the inclusion criteria (6 had active orthodontic treatment, 2 slept with interruptions, and 1 had $<24$ natural teeth), 6 were not available, and 9 did not accept the invite (Figure 2). In addition, one participant did not wear the BruxChecker for all three nights. Therefore, data from 84 participants were included in the final analysis, with partial data missing for several participants.

Three participants did not finish the retest (1 had started muscle relaxants; 1 did not deliver the BruxChecker at the end of the study; 1 did not wear the BruxChecker for three nights). Thus, 81 participants were included in the test–retest analysis. Another 8 and 13 participants did not deliver the BruxChecker after the first or second night respectively, in the test and/or retest part of the study. The Occlufast record of one participant was incorrect and another reported pain in the maxillary right central incisor due to dental trauma, so their maximum bite force was not assessed. Other issues were related to using the BruxChecker and included the following: one showed partial discoloration in the test phase only; one reported that the BruxChecker came out of their dental arch and that it was found slightly deformed and out of their mouth; one reported that their tongue and sheets were stained red; and a few complained about some degree of discomfort and/or a minor sleeping difficulties.

The 84 participants included in the final analysis had a median age of 21.7 years (range, 19.9–40.4) and 74 (86.9%) were females (Table 1). After the third night, visual inspection revealed that 38 participants (45%) presented at least one perforation in the BruxChecker at the test session and 39 (48%) did so at the retest, with 35 (42%) showing BruxChecker perforation at both sessions. Males showed significantly higher occlusal surface areas, higher bite forces, higher frequencies of masseter hypertrophy, and BruxChecker use for less time than females. However, no gender differences were observed in occlusal contact area, occlusal peeled area, frequency of perforation, and other variables assessed by BruxScreen.

Table A1 shows the ICC and SDD values of different sleep bruxism parameters assessed with the BruxChecker. Absolute or relative occlusal peeled area ($mm^2$ or % of occlusal surface) measured by transillumination of the BruxChecker worn for 2 or 3 nights provided the highest ICC values, ranging from 0.918 to 0.929 (95% CI, 0.87–0.95). Calculating the peeling rate by hours of BruxChecker use or sleeping did not improve the reliability. Visual inspection for BruxChecker perforation after 3 nights provided a Cohen kappa value of 0.777 (Table A1).

**TABLE 1** | General participant data and bruxism-related data obtained using the BruxScreen and BruxChecker.

| | *N* | Total | Females ($n = 74$) | Males ($n = 10$) | Significance |
|---|---|---|---|---|---|
| General data | | | | | |
| Age in years, median | 84 | 21.7 | 21.7 | 22.2 | 0.240[a] |
| Occlusal surface area in mm$^2$, mean (95% CI) | 84 | 859 (843–876) | 849 (833–865) | 934 (868–1000) | < 0.001[b] |
| Occlusal contact area in mm$^2$, mean (95% CI) | 83 | 91.5 (83.4–99.7) | 89.7 (81.5–98.0) | 105.0 (69.1–140.1) | 0.229[b] |
| Maximum bite force in newtons, mean (95% CI) | 83 | 694 (661–726) | 680 (647–712) | 796 (649–943) | 0.021[b] |
| BruxScreen | | | | | |
| Clenching often or always during sleep, *n* (%) | 84 | 21 (25.0%) | 17 (23.0%) | 4 (40.0%) | 0.243[c] |
| Presence of grinding during sleep, *n* (%) | 84 | 17 (20.2%) | 14 (18.9%) | 3 (30.0%) | 0.413[c] |
| Frequent awake/sleep bruxism activity, *n* (%) | 84 | 20 (23.8%) | 18 (24.3%) | 2 (20.0%) | 0.763[c] |
| Frequent jaw symptoms, *n* (%) | 84 | 18 (21.4%) | 17 (23.0%) | 1 (10.0%) | 0.348[c] |
| Masseter muscle hypertrophy, *n* (%) (any case) | 84 | 19 (22.6%) | 14 (18.9%) | 5 (50.0%) | 0.027[c] |
| Presence of 3 or more intra-oral signs on non-dental tissues, *n* (%) | 84 | 18 (21.4%) | 17 (23.0%) | 1 (10.0%) | 0.348[c] |
| Tooth wear per sextants scored as 6 or more, *n* (%) | 84 | 35 (41.7%) | 29 (39.2%) | 6 (60.0%) | 0.210[c] |
| Tooth wear mainly mechanical, *n* (%) | 84 | 69 (82.1%) | 60 (81.1%) | 9 (90.0%) | 0.489[c] |
| BruxChecker | | | | | |
| Time of BruxChecker use for 3 nights in hours, mean (95% CI) | 84 | 21.8 (21.3–22.3) | 22.1 (21.6–22.7) | 19.4 (17.7–21.1) | < 0.001[b] |
| Time of sleep with the BruxChecker for 3 nights in hours, mean (95% CI) | 84 | 20.1 (19.6–20.6) | 20.3 (19.8–20.8) | 18.5 (17.2–19.8) | 0.015[b] |
| Occlusal peeled area at 3rd night in %, mean (95% CI) | 84 | 10.6 (9.6–11.6) | 10.4 (9.3–11.4) | 12.3 (8.8–15.8) | 0.220[b] |
| Occlusal peeled area at 3rd night mm$^2$, mean (95% CI) | 84 | 91.3 (83–100) | 88.3 (79–97) | 114 (79.5–149) | 0.058[b] |
| Perforation in the BruxChecker at 3rd night, *n* (%) | 84 | 38 (45.2%) | 32 (43.2%) | 6 (60.0%) | 0.318[c] |

[a]Mann–Whitney *U* test.
[b]Student *t*-test.
[c]Chi-squared test.

The median (10th–90th percentiles) for occlusal peeled area had an absolute value of 84.3 mm$^2$ (39.4%–143.4 mm$^2$) and a relative value of 9.9% (4.7%–17.0%) after BruxChecker use for three nights (Table 2). Therefore, applying a cut-off at 10.0%, 11.7%, 14.0%, and 17.0% as a relative peeled area would consider 50%, 37%, 23%, and 10% of participants to be bruxers, respectively. Figure 3 shows the correlation between the relative and absolute peeled areas, their relationship with BruxChecker perforation, and the application of each cut-off (85 mm$^2$ or 10.0%, 100 mm$^2$ or 11.7%, 120 mm$^2$ or 14.0%, and 150 mm$^2$ or 17.0%).

Self-report of grinding during sleep and a tooth wear score of ≥ 6 by sextan obtained by BruxScreen showed the most agreement with the extension of the peeled area assessed by BruxChecker, regardless of the cut-off used (Table 3). Considering the six questions about the frequency of different aspects of bruxism and the presence of masseter muscle hypertrophy and mechanical tooth wear, both detected by clinical inspection, showed weak agreement with the peeled area detected by BruxChecker. Frequent jaw symptoms and the presence of three or more intra-oral signs on non-dental tissues showed no agreement with BruxChecker outcomes. After three nights, using BruxChecker perforation

**TABLE 2** | Occlusal peeled area and peeling rate assessed using the BruxChecker.

| Percentile | Relative peeled area (%) | | | | Absolute peeled area (mm²) | | | |
|---|---|---|---|---|---|---|---|---|
| | Peeled area (%) | | | Peeling rate (%/h sleep) | Peeled area (mm²) | | | Peeling rate (mm²/h sleep) |
| | 1-night ($n=84$) | 2-nights ($n=79$) | 3-nights ($n=84$) | 3-nights ($n=84$) | 1-night ($n=84$) | 2-nights ($n=79$) | 3-nights ($n=84$) | 3-nights ($n=84$) |
| Minimum | 1.1 | 2.3 | 2.8 | 0.12 | 8.9 | 18.2 | 23.0 | 0.96 |
| 10th | 2.8 | 4.0 | 4.7 | 0.24 | 24.2 | 32.6 | 39.4 | 2.01 |
| 25th | 4.4 | 6.4 | 6.9 | 0.35 | 35.4 | 52.8 | 64.0 | 3.13 |
| 50th | 6.9 | 9.1 | 9.9 | 0.50 | 57.6 | 78.7 | 84.3 | 4.18 |
| 75th | 9.5 | 12.3 | 13.7 | 0.67 | 79.8 | 107.6 | 117.6 | 6.01 |
| 90th | 12.4 | 15.3 | 17.0 | 0.92 | 108.9 | 130.3 | 143.4 | 7.76 |
| Maximum | 19.3 | 20.0 | 21.9 | 1.12 | 168.1 | 207.9 | 223.3 | 11.68 |

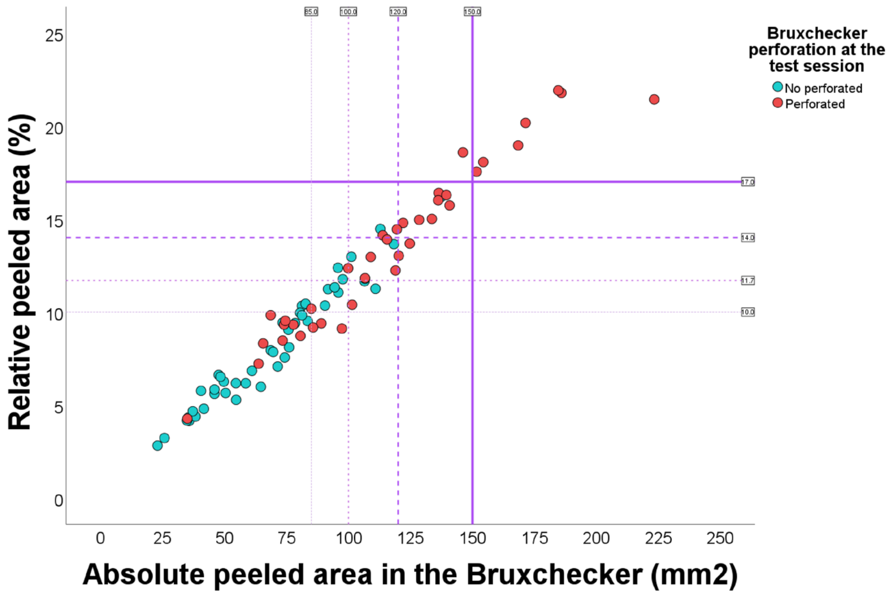


**FIGURE 3** | Correlation Between the relative and absolute peeled areas, their relationship with BruxChecker perforation and the application of four cut-offs.

as the sole diagnostic criterion for bruxism failed to show any agreement with BruxScreen symptoms or clinical signs, but it did show a strong agreement with the peeled area at cut-offs of 11.7% and 13% respectively (Table 3).

Occlusal contact area at ICP and maximum bite force were positively associated with the peeled area of the BruxChecker after wear for 3 consecutive nights and expressed as a percentage (Table 4). Among these two factors, occlusal contact area at ICP was the most important factor affecting the peeled area of the BruxChecker in the stepwise regression analysis (adjusted $R^2=0.12$). Individuals who perforated the BruxChecker at the test session peeled more of the BruxChecker surface area (13.4%) compared with those who did not (8.3%) ($p<0.001$; $t$-test). However, perforating the BruxChecker at the test session was not associated with either the maximum bite force or the occlusal contact area at ICP ($p>0.05$; $t$-test).

## 4 | Discussion

The results of this study indicate that the BruxChecker system provides excellent reliability in the quantitative assessment of sleep bruxism at the dental level by measuring the peeled area in the studied population. Research has already shown that the peeled area of BruxChecker correlates positively with the number of bruxism bursts and episodes measured by electromyography in a healthy population [21]. When coupled with the agreement between some BruxScreen outcomes in the present study, it seems that the BruxChecker system is a valid instrument for quantitatively assessing the grinding type of sleep bruxism at the dental level.

The present results also suggest that several methodological considerations affect reliability. When the BruxChecker is worn for two or three nights, the reliability is higher compared

**TABLE 3** | Agreement and significance between BruxScreen variables and BruxChecker outcomes dichotomised at different cut-offs.

| | Bruxchecker | | | | |
|---|---|---|---|---|---|
| | **Cut-off at 10% of peeled area** | **Cut-off at 11.7% of peeled area** | **Cut-off at 14% of peeled area** | **Cut-off at 17% of peeled area** | **Bruxchecker perforation** |
| BruxScreen variables | | | | | |
| Clenching often or always during sleep | 0.084 ($p=0.378$) | 0.068 ($p=0.514$) | 0.082 ($p=0.452$) | 0.080 ($p=0.391$) | 0.025 ($p=0.800$) |
| Presence of grinding during sleep | 0.324 ($p<0.001$) | 0.323 ($p=0.001$) | 0.364 ($p<0.001$) | 0.219 ($p=0.028$) | 0.167 ($p=0.071$) |
| Frequent awake/sleep bruxism activity | 0.204 ($p=0.030$) | 0.145 ($p=0.164$) | 0.165 ($p=0.129$) | 0.091 ($p=0.339$) | 0.098 ($p=0.315$) |
| Frequent jaw symptoms | 0.107 ($p=0.239$) | 0.076 ($p=0.455$) | 0.134 ($p=0.220$) | 0.114 ($p=0.244$) | 0.043 ($p=0.647$) |
| Masseter muscle hypertrophy | 0.180 ($p=0.052$) | 0.111 ($p=0.283$) | 0.048 ($p=0.661$) | 0.102 ($p=0.290$) | −0.030 ($p=0.755$) |
| Presence of 3 or more intra-oral signs on non-dental tissues | 0.010 ($p=0.909$) | −0.148 ($p=0.145$) | −0.074 ($p=0.496$) | 0.025 ($p=0.796$) | −0.058 ($p=0.541$) |
| Tooth wear per sextants scored as 6 or more | 0.331 ($p=0.002$) | 0.353 ($p=0.001$) | 0.319 ($p=0.001$) | 0.202 ($p=0.006$) | 0.008 ($p=0.941$) |
| Tooth wear mainly mechanical | 0.156 ($p=0.058$) | 0.063 ($p=0.365$) | 0.084 ($p=0.103$) | 0.013 ($p=0.677$) | 0.125 ($p=0.111$) |
| BruxChecker | | | | | |
| Perforation in BruxChecker | 0.356 ($p=0.001$) | 0.487 ($p<0.001$) | 0.422 ($p<0.001$) | 0.226 ($p=0.001$) | |

*Note:* Using the cut-off at 10%, 11.7%, 14%, and 17% of the peeled area would assign as a bruxer the 50%, 37%, 23%, and 10% of the participants, respectively. Agreement is expressed as kappa values.

**TABLE 4** | Bivariate and multivariate relationship between different factors and the relative occlusal peeled area assessed by transillumination after 3 nights of BruxChecker use.

| | ***n*** | **Correlation with relative peeled area**[a] | **Significance (*p*)** | **Multivariate regression model, B (95% CI)**[b] |
|---|---|---|---|---|
| Gender | 84 | 0.135 | 0.110 | |
| Age (years) | 84 | 0.078 | 0.239 | |
| Occlusal surface area ($mm^2$) | 84 | 0.043 | 0.349 | |
| Occlusal contact area ($mm^2$) | 83 | 0.365 | <0.001 | 0.045 (0.02–0.07) |
| Maximum bite force ($N$) | 83 | 0.290 | 0.004 | |

[a]Pearson coefficient.
[b]Adjusted $R^2=0.123$.

to use for a single night, consistent with the conclusions of other authors [21, 27]. Although most studies photographed or scanned the worn BruxChecker placed on a plaster model [20, 21, 23, 24, 27, 37], reliability is higher when scanned by transillumination without the model, probably because light reflections might simulate nonpeeled surfaces or mask peeled surfaces [19]. The main disadvantage of transillumination is that some peeled areas could be masked by the buccal surfaces of the BruxChecker, especially in the anterior and canine teeth; however, it should be remembered that detection can be checked in the original image as an intermediate intensity of colour. Another limitation may be the need for specialised equipment, such as a scanner with transillumination capabilities and specific software, which are not readily available in many dental practices. However, smartphone applications could be developed to quantify the peeled area of the

BruxChecker from captured images. Considering the hours of use or the hours asleep with the BruxChecker and estimates of the peeling rate after the third night of use did not improve the reliability of the BruxChecker. The reliability of the peeled area also did not depend on whether it was measured in absolute or relative values with respect to the total occlusal surface area. However, it is preferable to express the peeled area as a percentage of the occlusal surface to minimise the effect of tooth size, especially between sexes [27]. The presence of perforation in the occlusal surface of the BruxChecker after three nights of use revealed substantial agreement in the test–retest analysis (Cohen's kappa, 0.78).

The present study indicated that approximately half of the participants peeled the red dye on more than 10% of the total occlusal surface (equivalent to 84 $mm^2$) after three nights of using the BruxChecker. These represent reference values obtained from a young adult population and are consistent with reports from other studies after adjusting for sex and the number of nights using the BruxChecker [21, 26]. The finding that approximately half of the individuals perforated the BruxChecker after three nights of use supports the use of this criterion as indicating the presence of sleep bruxism [25]. Considering the present results and reported criteria for the presence of sleep bruxism as the correlation between the number of phasic-type bruxism episodes and the peeled area of the BruxChecker and BruxChecker perforation [21, 25], we propose that individuals with $>100\,mm^2$ (11.7%) peeled or with perforation of the BruxChecker after three nights use could be considered suspected bruxers. Given the present results and a reported prevalence of definitive polysomnography-assessed sleep bruxism of about 8% in the general population [10], we propose that individuals who peel $>150\,mm^2$ (17.0%) after three nights and perforate the BruxChecker could be considered frequent or severe bruxers. However, a larger and more representative sample of the general population is needed to validate these cut-off values.

Extension of the peeled area on the BruxChecker was positively associated with self-reported grinding during sleep. Thus, tooth wear, occlusal contact area, and maximum bite force assessed with the BruxChecker may be valid for quantitatively assessing the dental consequences of grinding during sleep, especially the force and extension data. However, the present study did not show construct validity, and further research will be needed to confirm this hypothesis. Interestingly, the ability to perforate the BruxChecker was not associated with any of these characteristics (i.e., grinding during sleep, tooth wear, occlusal contact area, maximum bite force) but was strongly associated with the extension of the area peeled, which suggests that BruxChecker perforation might reflect other aspects of sleep bruxism (i.e., the frequency and/or duration of mandibular movements). The aspect of sleep bruxism that truly reflects the ability to perforate the BruxChecker could be elucidated in a well-controlled study assessing masticatory muscle activity with electromyographic monitoring during sleep while using oral appliances with sensors [38].

The BruxChecker is a valid and reliable instrument for quantifying the grinding type of sleep bruxism at the dental level, and it would be valuable in future studies to assess the association between this type of bruxism and negative outcomes, such as tooth wear, restoration failure, occlusal trauma and tooth migration [4, 5]. However, bruxism has been associated with positive health outcomes [15], suggesting that the BruxChecker could also be useful to predict positive consequences of sleep bruxism [26]. In the present study, the occlusal contact area and maximum bite force correlated positively with the peeled area. Because these are key measures of masticatory performance and asymmetry in dentate populations [39–42], the occlusal peeled area in the BruxChecker could be positively associated with the masticatory function of the individual. Further studies are needed to demonstrate this relationship.

When sleep bruxism is assessed by questionnaire, the prevalence of frequent sleep bruxism has been estimated at 13% [9], being higher in women aged 18–35 years and associated with mechanical tooth wear, stress and muscle pain [8, 11, 13, 43, 44]. However, the prevalence of definitive sleep bruxism assessed by polysomnography is about 8% and is not associated with age or sex, and half of the people who report sleep bruxism by questionnaire are not confirmed by polysomnography [10]. Therefore, the best way to assess sleep bruxism is to combine subjective, clinical, and instrumental data [7, 17]. When a clinician assesses sleep bruxism to evaluate the risk of tooth wear or dental restoration failure, it is recommended that the duration and intensity of masticatory muscle activity be determined by ambulatory electromyography and tooth contact evaluation [18]. In this scenario, the BruxChecker could provide complementary information about not only the intensity and extension of sleep bruxism at the dental level but also the occlusal pattern of grinding activities during sleep. In addition, the BruxChecker may play an important role in increasing patient awareness of this sleep disorder.

This is the first study with a sufficient sample size to determine the test–retest reliability of the BruxChecker system and provide reference values in a young adult population. However, we recognise some limitations. First, few males participated, most participants were young, and the recruitment of dental students likely reduced the power to detect gender differences, limiting the representativeness of the sample for the general population [45]. Second, electromyography activity of the masticatory muscles was not recorded while using the BruxChecker, preventing us from establishing an association between clenching/grinding types and the observed perforation or peeling areas. Third, the BruxChecker seems to be effective in quantifying the grinding type of sleep bruxism but it could not detect its clenching type. In addition, the grinding patterns reflected in the BruxChecker were not assessed or compared to the physiological jaw movements of participants. These issues should be addressed in future research.

## 5 | Conclusions

The BruxChecker system demonstrates excellent reliability in measuring the occlusal peeled area in dental students and, based on the extent of this area, may serve as a quantitative tool for assessing the grinding component of sleep bruxism at the dental level. The highest reliability was achieved using the BruxChecker for two or three consecutive nights and scanning by transillumination. This study proposes reference values for absolute and relative peeled areas after using the BruxChecker for three nights.

The best agreement between the peeled area and BruxScreen was in the self-reported grinding during sleep and tooth wear domains. The best predictors of peeled areas were the occlusal contact area in ICP and, to a lesser extent, the maximum bite force.

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### Author Contributions

Mireia Ustrell-Barral contributed to the conception, design, data acquisition, analysis, and interpretation, and drafted and critically revised the manuscript. Carla Zamora-Olave, Laura Khoury-Ribas, and Bernat Rovira-Lastra contributed to the design, data interpretation, and critical revision of the manuscript. Jordi Martinez-Gomis contributed to the conception, design, data acquisition, data analysis, and interpretation, and drafted and critically revised the manuscript. All authors approved this version of the manuscript.


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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/joor.13959.

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**Supporting Information**

Additional supporting information can be found online in the Supporting Information section.

## Appendix 1

**TABLE A1** | Test–retest reliability and measurement error of different variables that quantify sleep Bruxism at the dental level assessed by different methods.

| Bruxchecker outcomes | | Peeling/perforating | Plaster Model/transillumination/visual | Area/rate/teeth | Relative (%)/absolute ($mm^2$)/number/no-yes | Nights used, *N* | *N* | ICC (95% CI) | SDD |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BC-GAM1p | Peeling | Plaster model | Area | % | 1 | 73 | 0.814 (0.719–0.879) | 0.68% |
| 2 | BC-GAM2p | Peeling | Plaster model | Area | % | 2 | 68 | 0.902 (0.845–0.938) | 0.59% |
| 3 | BC-GAM3p | Peeling | Plaster model | Area | % | 3 | 81 | 0.894 (0.840–0.930) | 0.65% |
| 4 | BC-GAM1m | Peeling | Plaster model | Area | $mm^2$ | 1 | 73 | 0.818 (0.726–0.882) | 5.95 $mm^2$ |
| 5 | BC-GAM2m | Peeling | Plaster model | Area | $mm^2$ | 2 | 68 | 0.903 (0.847–0.939) | 5.27 $mm^2$ |
| 6 | BC-GAM3m | Peeling | Plaster model | Area | $mm^2$ | 3 | 81 | 0.896 (0.843–0.932) | 5.70 $mm^2$ |
| 7 | BC-GAM3p_hU | Peeling | Plaster model | Rate (h use) | %/h | 3 | 81 | 0.826 (0.742–0.884) | 0.040%/h |
| 8 | BC-GAM3p_hS | Peeling | Plaster model | Rate (h sleep) | %/h | 3 | 81 | 0.831 (0.750–0.888) | 0.043%/h |
| 9 | BC-GAM3m_hU | Peeling | Plaster model | Rate (h use) | $mm^2$/h | 3 | 81 | 0.827 (0.744–0.885) | 0.355 $mm^2$/h |
| 10 | BC-GAM3m_hS | Peeling | Plaster model | Rate (h sleep) | $mm^2$/h | 3 | 81 | 0.834 (0.753–0.890) | 0.381 $mm^2$/h |
| 11 | BC-GAT1p | Peeling | Transillumination | Area | % | 1 | 73 | 0.839 (0.755–0.896) | 0.70% |
| 12 | BC-GAT2p | Peeling | Transillumination | Area | % | 2 | 68 | 0.918 (0.871–0.949) | 0.58% |
| 13 | BC-GAT3p | Peeling | Transillumination | Area | % | 3 | 81 | 0.929 (0.891–0.954) | 0.54% |
| 14 | BC-GAT1m | Peeling | Transillumination | Area | $mm^2$ | 1 | 73 | 0.847 (0.767–0.901) | 6.02 $mm^2$ |
| 15 | BC-GAT2m | Peeling | Transillumination | Area | $mm^2$ | 2 | 68 | 0.921 (0.875–0.950) | 5.16 $mm^2$ |
| 16 | BC-GAT3m | Peeling | Transillumination | Area | $mm^2$ | 3 | 81 | 0.928 (0.891–0.953) | 4.80 $mm^2$ |
| 17 | BC-GAT3p_hU | Peeling | Transillumination | Rate (h use) | %/h | 3 | 81 | 0.848 (0.774–0.900) | 0.039%/h |
| 18 | BC-GAT3p_hS | Peeling | Transillumination | Rate (h sleep) | %/h | 3 | 81 | 0.843 (0.766–0.896) | 0.043%/h |
| 19 | BC-GAT3m_hU | Peeling | Transillumination | Rate (h use) | $mm^2$/h | 3 | 81 | 0.850 (0.776–0.900) | 0.345 $mm^2$/h |
| 20 | BC-GAT3m_hS | Peeling | Transillumination | Rate (h sleep) | $mm^2$/h | 3 | 81 | 0.846 (0.770–0.898) | 0.381 $mm^2$/h |
| 21 | BC-PAT3p | Perforating | Transillumination | Area | % | 3 | 81 | 0.714 (0.588–0.806) | 0.13% |
| 22 | BC-PAT3m | Perforating | Transillumination | Area | $mm^2$ | 3 | 81 | 0.726 (0.604–0.814) | 1.11 $mm^2$ |
| 23 | BC-PVT3 | Perforating | Visual | Teeth | number | 3 | 81 | 0.566 (0.448–0.684)[a] | |
| 24 | BC-PVD3 | Perforating | Visual | | no-yes | 3 | 81 | 0.777 (0.640–0.914)[b] | |

*Note:* Model two-way random; type absolute agreement; single measures.
Abbreviations: ICC, intraclass correlation coefficient; SDD, smallest detectable difference.
[a]Weighted Kappa (linear weighting for agreement).
[b]Cohen Kappa.