Oral Radiology (2023) 39:117–124
https://doi.org/10.1007/s11282-022-00612-3

ORIGINAL ARTICLE

Evaluation of mandibular bone density in bruxers: the value of panoramic radiographs

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Received: 4 February 2022 / Accepted: 3 April 2022 / Published online: 19 April 2022

Abstract

Objectives This study aimed to establish a difference in mandibular bone density between bruxer and non-bruxer patients, based on panoramic radiographs.

Methods Panoramic radiographs of bruxer and non-bruxer patients were analyzed with ImageJ®. Several radiological determinants were studied on the patients' panoramic radiographs: gray values of cancellous bone and cortical bone, and bony exostoses at the mandibular angle.

Results Thirty-seven bruxers and forty-seven non-bruxers were included in the study.
A statistically significant difference ($p < 0.05$) was noted in the cancellous to cortical bone ratios of bruxers and non-bruxers: the density of cancellous bone was greater in bruxers than in non-bruxers.
The number of bony exostoses at the mandibular angle was significantly higher in bruxers ($p < 0.05$).

Conclusions This study obtained radiological determinants of bruxism from panoramic radiographs. Further studies are needed to supplement this preliminary approach, especially via the analysis of three-dimensional imaging to overcome the limitations of panoramic radiography.

Keywords Bone density · Bruxism · Exostoses · Mandible · Panoramic radiograph

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Introduction

In 2018, an international consensus defined bruxism as "a repetitive masticatory muscle activity characterized as forcefully maintaining a certain mandibular position and thrusting as forcefully moving the mandible in a forward or lateral direction—both activities without the necessary presence of tooth contact" resulting from non-nutritive, repetitive, involuntary, mostly unconscious manducatory motor activities [1]. Long considered solely a parafunction, the notion of bruxism has gradually evolved into a concept of a biological continuum [2]. Indeed, in people with no specific pathology, bruxism should no longer be considered as pathologic, but rather a muscular behavior that can have different etiologies, and which can be harmful or harmless, or even protective in relation to specific health determinants [3]. Thus, it is when it is excessive, i.e., when it weakens dental structures or when it constitutes a sign of an underlying pathology (significant anxiety, ventilation problems), that bruxism requires management [4]. It can occur during sleep or while awake [5]. Epidemiological data relating to bruxism are fairly variable due to the difficulties encountered in its diagnosis and the methodologies detailed in the different studies published in the literature that are sometimes difficult to compare [3]. However, recent data estimate that sleep bruxism affects 15% of the adult population, while the prevalence of awake bruxism has been estimated at between 22 and 30% in adults [6].

Different mandibular movements may be reported during episodes of bruxism, which generate dental contact: grinding, clenching, tapping, and jiggling [7]. The consequences of these repeated contacts, commonly referred to as "attrition", are not limited to dental tissue [8]. Indeed, these movements can also have consequences for the periodontium, which consists of the gums, the cementum, the alveolar ligament, and alveolar bone, corresponding to all the tissues that support the tooth [9] and contribute to its degradation, but also its reinforcement [10]. Thus, application of these loads is likely to induce an architectural modification of bone tissue [11]. This was formulated as early as 1892 in Wolff's law, which states that bone can adapt its external cortical structure and its internal trabecular structure according to the loads to which it is subjected [12]. Thus, bone exhibits opposing reactions to the repeated application of these forces. Further, bone variability in humans depends on two characteristics: an innate, genetically inherited element, and an acquired behavioral element, of which bruxism is a component [8, 13].

Thus, the remodeling of bone, its variations in volume and density, result in part from the adaptation of bone to the forces to which it is subjected [11]. Therefore, it was legitimate to think that bone would adapt to specific muscular behaviors of the manducatory apparatus, such as bruxism.

The main objective of this study was to establish a difference in mandibular bone density between patients with bruxism and non-bruxer patients. This was achieved by identifying determinants (bone density value, presence of bony exostoses at the mandibular angle) that constitute objective criteria for the diagnosis of bruxism, which to the author's knowledge, have not to date been established.

Materials and methods

Examining the characteristics of bone in living subjects requires the use of medical imaging [14, 15]. The dental practitioner must justify the use of panoramic radiographs, which are taken very frequently by dentists [16]. In France, the recommendations laid down by the HAS (Haute Autorité de Santé) establish that this justification, which is the primary basic principle in the protection of patients against ionizing radiation, determines the choice of imaging technique. Thus, panoramic radiography is indicated for "periodontal diseases, pathological, pre-surgical and traumatological diagnosis, implant diagnosis, new patients, edentulous patients, analysis of the stage of dentition, analysis of temporomandibular joints and analysis of sinuses in dentate adults" [17].

Participants

This cross-sectional study was based on all usable panoramic radiographs (accessible panoramic radiographs, in patients with at least one pair of posterior antagonist teeth on the right and left sides, with no prosthesis requiring removal during radiological acquisition and no blurring resulting from movement during radiological acquisition) taken in adult patients seen in a "function-dysfunction" consultation in the "Oral Rehabilitation" Department, Odontology Department, Timone Hospital, AP-HM (Assistance Publique—Hôpitaux de Marseille), France, diagnosed as bruxers or non-bruxers with a self-report questionnaire and a clinical examination, by three specialized, calibrated hospital practitioners over a three year period (January 2018–January 2021). Information regarding date of birth, gender, and bruxer or non-bruxer status was collected for each patient from electronic medical records.

Non-inclusion criteria involved patients with partial edentulism, those with panoramic radiographs taken elsewhere than in the odontology department, or those with unusable panoramic radiographs (due to patient movement during radiological acquisition, for example), as well as patients with bone pathologies such as bone metastases, those undergoing radiotherapy and chemotherapy, those suffering from osteoporosis or being monitored for hormone deficiency (parathyroid hormone and calcitonin), or with a history of mandibular fractures.

The authorization of the Data Protection Officer of the AP-HM was obtained for the collection and processing of data, which were anonymized (registered in the RGPD-Ap-hm registry under number 2020-149).

Patient panoramic radiographs

The sample size required for this study was calculated for a 90% confidence interval, and a 10% margin of error. No study has been conducted on this protocol, so an arbitrary standard deviation of 0.5 was used.

All patient panoramic radiographs were taken with the same X-ray machine: Planmeca ProMax®3D Mid (Planmeca OY, Helsinki, Finland), with known acquisition parameters (68 kV, 8mAs, and 22 s exposure time), by the same operator.

Analysis: use of ImageJ software

All panoramic radiographs were analyzed with the medical imaging analysis software, ImageJ (version 1.46r) (https://

imagej.nih.gov/ij/). ImageJ software, developed by the National Institute of Health, Bethesda, MD, USA, is recognized as a reliable tool for the analysis of radiological examinations [14].

All panoramic radiographs were exported with 256 Gy levels, 2529 ×1152 pixels, and a resolution of 279 DPI, in a digital format (JPEG) compatible with ImageJ software.

The radiographs were evaluated by two blinded assessors. Inter-evaluator reproducibility was tested using 25 panoramic radiographs randomly selected from the sample. It was checked that there were no significant differences between data obtained on the right and left sides. An intra-examiner concordance test was conducted for both assessors, in addition to an inter-rater test to measure the agreement between the two.

Recording of radiological determinants on patient images

Several parameters were studied on each panoramic radiograph:

- A gray value for cortical bone and a gray value for cancellous bone, with assignment of a gray value between 0 and 255, without unit.

A specific region of interest located directly below the first mandibular premolar was defined for the analysis of these radiographs (Fig. 1).

Cancellous bone and cortical bone are not homogeneous tissues, as evidenced by their histological composition. As a result, the grayscale values obtained in the regions of interest, although limited to several tens of pixels, could vary significantly. To overcome this potential bias in this study, and to obtain reliable and reproducible gray values, it was necessary to use an average gray level value, which was provided by the histogram of the region of interest.

These gray values were combined in a ratio: cancellous bone gray value to cortical bone gray value (without unit). This ratio allowed a relative evaluation of bone density to be obtained for each panoramic radiograph, avoiding the possibility that any variations in gray levels related to image reconstruction (resulting in the projection and superimposition of anatomical structures) might affect the gray values obtained.

- The presence or absence of bony exostoses at the mandibular angle (Figs. 2a and 2b).

Statistical analyses

Analyses were performed using R software (version 4.0.3), available at: https://www.r-project.org.

Feasibility study on 25 panoramic radiographs randomly selected from the sample: inter-evaluator reproducibility

To check evaluator reliability (intra-operator variability) and method reproducibility (inter-operator variability), a concordance test was performed on the values obtained for the ratio of cancellous bone to cortical bone (gray values, quantitative variable) with the Bland–Altman test, and on the presence of bony exostoses at the mandibular angle (qualitative variable) with Cohen's Kappa.

A comparison of the results of the ratio of the cancellous bone gray value to the cortical bone gray value obtained for each panoramic radiograph on the left and right sides was also made (Wilcoxon test).

Analysis of the sample (panoramic radiographs of 84 patients)

After results had been obtained indicating good inter-evaluator concordance, an analysis was carried out on the whole sample ($n = 84$).

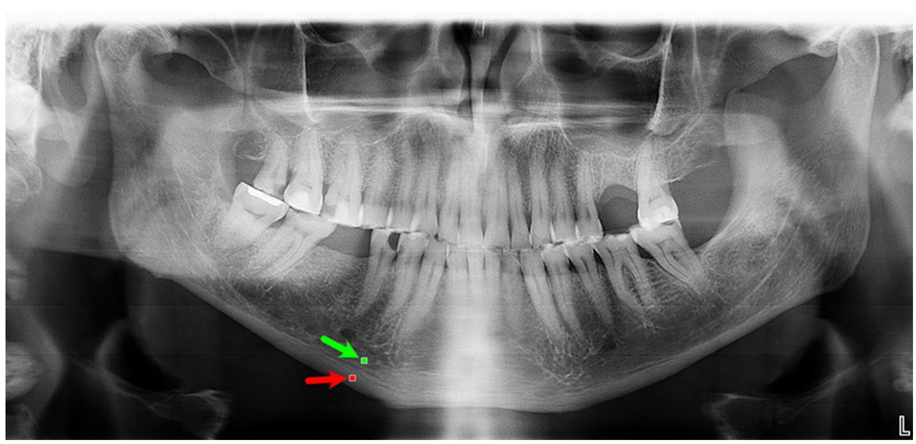

Fig. 1 Selection of the region of interest for cortical bone (red arrow) and cancellous bone (green arrow)

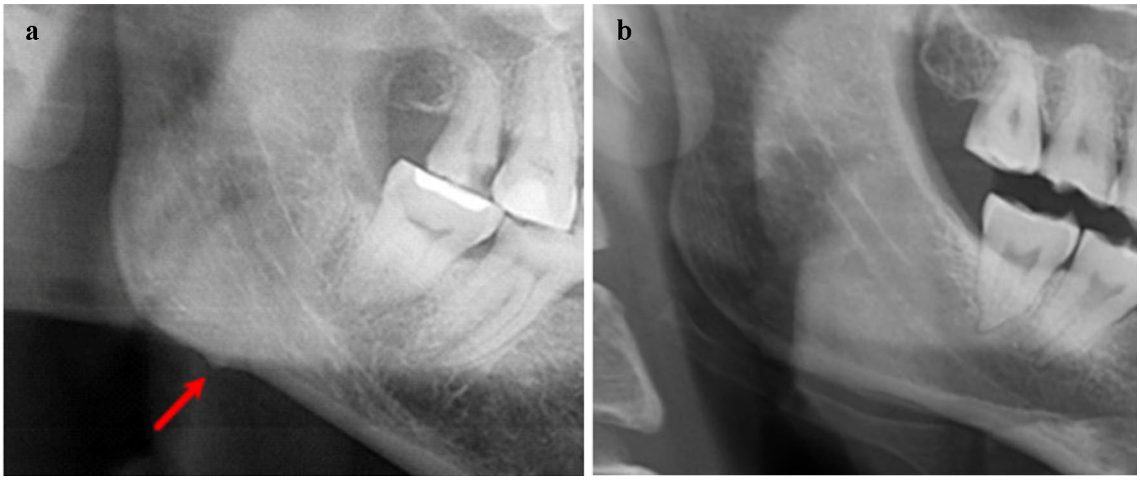

Fig. 2 **a** Evaluation of the presence of bony exostoses at the mandibular angle (red arrow). **b** Absence of bony exostoses at the mandibular angle

Inter-evaluator reproducibility To check the reproducibility of the method on the whole sample, a concordance test was performed on the values obtained for the ratio of cancellous bone to cortical bone (gray values, quantitative variable) with the Bland–Altman test, and on the presence of bony exostoses at the mandibular angle (qualitative variable) with Cohen's Kappa.

Analysis of the sample The ratios of cancellous bone gray values to cortical bone gray values for the bruxer and non-bruxer groups on the right and left sides were evaluated with a Welch's *t* test.

The presence or absence of bony exostoses at the mandibular angle in the bruxer and non-bruxer groups on the right and left sides was evaluated with a Chi-square test.

Results

The sample size required for this study was 67 panoramic radiographs, for a 90% confidence interval, and a 10% margin of error.

Eighty-four panoramic radiographs representing the 84 patients meeting the inclusion criteria were evaluated for this study (37 bruxers and 47 non-bruxers), as shown in Table 1.

The mean age of bruxer patients was 48 years, with a range of 19–84 years, and a standard deviation of 18.2 years.

The mean age of non-bruxer patients was 46 years, with a range of 19 78 years, and a standard deviation of 14.5 years.

Feasibility study conducted on 25 panoramic radiographs: inter-evaluator reproducibility

There was no statistically significant difference between the ratios measured for cancellous bone gray values to cortical bone gray values on the left and right sides for both evaluators (Wilcoxon test, $p = 0.78$ for evaluator 1 and $p = 0.96$ for evaluator 2).

Table 1 Distribution of patients by status, gender, and age

	Status		Total
	Bruxer	Non-bruxer	
Male			
< 45 years old	6	6	29
> 45 years old	9	8	
Female			
< 45 years old	11	18	55
> 45 years old	12	14	
Total	37	47	84

There was good concordance of the ratios of cancellous bone values to cortical bone values obtained for each panoramic radiograph by the two operators (Bland–Altman tests).

Concordance for the presence or absence of mandibular angle bony exostoses was obtained with excellent reproducibility (Cohen's Kappa coefficient = 0.76).

Analysis of the sample (panoramic radiographs of 84 patients)

As method reproducibility was able to be verified following the results obtained from the 25 panoramic radiographs by the two evaluators, the measurement series was performed on all 84 panoramic radiographs in the sample, on the right and left side of each panoramic radiograph, by the two evaluators.

Inter-evaluator reproducibility

There was a good concordance of the ratios of cancellous bone values to cortical bone values obtained for each panoramic radiograph by the two operators (Bland–Altman tests) (Fig. 3).

Concordance for the presence or absence of bony exostoses at the mandibular angle was obtained with good reproducibility (Cohen's Kappa coefficient = 0.67).

Analysis of the sample

Values were obtained by averaging the values obtained by the two evaluators. These values are assembled in Table 2.

The average gray values obtained for cortical bone and cancellous bone are assembled in Table 3.

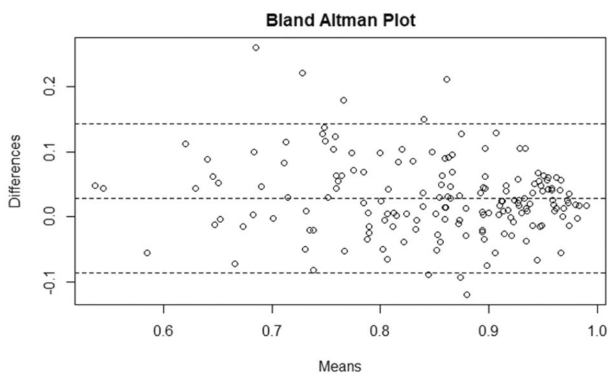

Fig. 3 Good concordance of the ratios of cancellous bone values to cortical bone values obtained for each of the 84 panoramic radiographs, by the two evaluators

Table 3 Means of gray values obtained for cortical and cancellous bone, on the right and left side by averaging the values obtained by the two evaluators

	Cancellous bone, right side	Cortical bone, right side	Cancellous bone, left side	Cortical bone, left side
Non-bruxers	96.23	119.81	92.15	114.25
Bruxers	112.57	122.02	107.81	116.09

The ratio of cancellous bone gray values to cortical bone gray values for bruxer and non-bruxer groups showed a statistically significant difference for the right side (Welch's *t* test, $p = 2.3.10^{-16}$) and for the left side (Welch's *t* test, $p = 2.2.10^{-16}$).

The distribution of cancellous bone to cortical bone ratio values is shown in Fig. 4 for the right side.

Results obtained for the presence or absence of bony exostoses at the mandibular angle in bruxers and non-bruxers showed a statistically significant difference on the right side (Chi-square test, $p = 1.9.10^{-13}$) (Fig. 5) and on the left side (Chi-square test, $p = 6.32.10^{-14}$).

More than 80% of bruxers had bony exostoses, while these were present in a maximum of 25% of non-bruxers (Table 2).

Discussion

The main objective of this study was to establish a difference in mandibular bone density between bruxer and non-bruxer patients on the basis of panoramic radiographs. For this purpose, the ratio of cancellous bone to cortical bone density, in gray values, was evaluated in panoramic radiographs of

Table 2 Measurements made for the 84 panoramic radiographs by averaging the values obtained by the two evaluators

	Right side				Left side			
	Cancellous bone	Cortical bone	Ratio	Exostosis	Cancellous bone	Cortical bone	Ratio	Exostosis
Non-bruxers ($n = 47$)								
Mean	96.23	119.81	0.78	12 (25.5%)	92.15	114.25	0.78	8 (17%)
Median	102.31	116.175	0.87		104.45	116.17	0.87	
Standard deviation	34.38	33.89	0.10		34.52	33.97	0.10	
Min	32.3	53.36	0.55		27.16	46.83	0.51	
Max	185.670	197.781	0.97		172.07	188.25	0.98	
Bruxers ($n = 37$)								
Mean	112.57	122.02	0.91	31 (83.7%)	107.81	116.09	0.92	30 (81%)
Median	103.02	116.40	0.87		102.69	116.25	0.87	
Standard deviation	33.73	33.72	0.09		33.65	33.67	0.09	
Min	46.08	59.75	0.73		48.88	53.25	0.73	
Max	199.62	208.12	0.99		171.01	188.66	0.99	

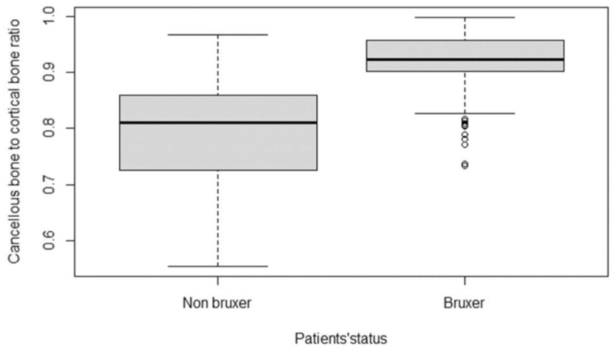

Fig. 4 Ratio of cancellous bone gray values to cortical bone gray values on the right side

Fig. 5 Presence or absence of bony exostoses at the mandibular angle examined according to the bruxer or non-bruxer status of patients, right side

bruxer and non-bruxer patients, as well as the presence of bony exostoses at the mandibular angle.

The sample size required for this study was 67, calculated for a 90% confidence interval, and a 10% margin of error. As no study has been conducted on this protocol, an arbitrary standard deviation of 0.5 was used. The number of panoramic radiographs included in the study was increased by 20% to consider the prevalence of bruxism, estimated to be 15%–30% of adults according to the studies [6], and to have enough panoramic radiographs to meet statistical requirements. All forms of bruxism (awake or sleep bruxism, grinding or clenching), were included without differentiation in this study. Indeed, the sample size for each subgroup was too small to be statistically relevant. This aspect should be investigated in a future study, to determine, for instance, if grinders have a denser bone than clenchers.

The first evaluation performed on 25 panoramic radiographs checked that the two evaluators were well calibrated and had acquired competence in the measurement method. The evaluation by the two examiners of the whole sample (84 panoramic radiographs) increased the power of the study and confirmed the validity of the results.

A statistically significant difference was recorded between bruxers and non-bruxers for this ratio, which had a higher value in bruxers, related to a higher density value for cancellous bone than in the non-bruxer group.

A statistically significant difference was recorded between bruxers and non-bruxers for the presence of bony exostoses at the mandibular angle in favor of bruxers.

The characteristics of mandibular bone, particularly its density, have been the subject of numerous investigations over the last few decades. Indeed, they interest various fields, from dentistry with, for example, the surgical planning of implants [15] and its follow-up [16] to rheumatology, with the diagnosis of osteoporosis [17–20]. Although three-dimensional examination, using CBCT (Cone Beam Computed Tomography), is commonly accepted as the gold standard for analysis of the characteristics of mandibular bone tissue in dentistry, it is also a radiological examination that is subject to the principles of justification and optimization of the use of ionizing radiation. Indeed, in France, the HAS recommends using CBCT for "well-selected clinical indications, either for the diagnosis of pathologies and for a pre-operative assessment, in endodontics, oral and implant surgery or even periodontal surgery, when the study of soft tissues is not required" [21]. It also specifies that "CBCT cannot replace other imaging examinations if it does not improve patient management and if its dosimetric value is not demonstrated" [21].

Panoramic radiographs were used in this study. This type of two-dimensional radiographic image represents an imaging technique that is used by dentists on a daily basis [22]. Thus, it was the high frequency at which this radiological examination is performed, its accessibility to patients, its irradiation level, which is lower than that of CBCT, not indicated to date in the study of the etiology of bruxism, that directed the selection of this type of imaging examination.

This is the first study to investigate the relationship between radiological determinants that aim to assess mandibular bone density using grayscale values and bruxism. Indeed, the purpose of this work was to evaluate whether the analysis of patients' panoramic radiographs could help in the diagnosis of bruxism [6].

To meet these objectives, this study was divided into two parts, mainly to analyze two different types of data: the ratio of cancellous bone density to cortical bone density, and the presence of bony exostoses, commonly associated with bruxism, at the mandibular angle.

For assessment of the ratio of cancellous bone density to cortical bone density, a specific region of interest was chosen in line with the first premolar, as its definition is little impacted by radiological reconstruction processes, by the presence of anatomical elements likely to cause a one-off variation in bone density (mental foramen, submandibular gland), or by the projection of anatomical elements (hyoid bone, space between the back of the tongue and the soft palate), which would distort the values of the bone densities obtained [19].

The results showed a significant difference between the values obtained for patients diagnosed as bruxers and non-bruxers, with a higher ratio of cancellous bone gray values to cortical bone gray values in the bruxer group. This result showed that the discrepancy between the density of cortical bone and cancellous bone in bruxer patients was reduced because the cancellous bone had a higher density value. This study has shown that differences in bone density could be observed between bruxers and non-bruxers.

However, it should be noted that the distribution range of gray values measured on patients' panoramic radiographs was very wide [(27.16–208.12]). This was due to the limitations of panoramic radiography itself, e.g., in image reconstruction, which results in the projection and superimposition of anatomical structures that may impede the proper reading of these examinations. Through CBCT, three-dimensional imaging could represent a solution to overcome the limitations of panoramic radiographs.

Conversely, the results showed a statistically significant difference for the presence of bony exostoses at the mandibular angle, supporting a positive correlation between the presence of bony exostoses and bruxism. These results are consistent with other studies in bruxers, such as that published by Isman in 2021 [23]. The location of these bony exostoses at the mandibular angle corresponds to the insertion site of the masseter muscle [24, 25]. A higher level of activity of these masticatory muscles, linked to bruxism, would thus explain the localized development of these bony outgrowths.

The authors chose to use imaging processing software, ImageJ®, that is recognized by the scientific community, and not to apply any pre-processing step to the panoramic radiographs studied prior to data acquisition to minimize the risk of inducing bias in data collection by working in gray values with the “Histogram” tool offered by ImageJ®. Other studies have offered different study protocols to exploit panoramic images of bruxer patients and to propose a diagnostic aid. Thus, recently, Gulec et al. [26] used fractal analysis, and Padmaja Satheeswarakumar et al. [27] evaluated changes in the mandibular surface of the condylar and coronoid processes in bruxer and non-bruxer patients. Isman [23] used six radiographic indices to measure distances of interest on mandibular bone. These studies are valuable because of their methodology but require corroboration by further studies. In addition, some of these studies require more complex and time-consuming processing of panoramic radiographs than does the methodology presented in this study, which could impede its daily use by dentists.

Thus, this preliminary study made it possible to obtain radiological elements that could contribute to the diagnosis of bruxism by being associated with the various approaches that have already been developed in the literature (report of bruxism by the patient, clinical examination, paraclinical examinations such as electromyography (EMG), or polysomnography) [1].

Future studies could be performed with a larger number of patients to refine the results, especially according to age group. Occlusal overload could also be evaluated to determine whether there is a correlation between the force applied to bone and the variation in bone density recorded. Finally, these radiological results show that three-dimensional analysis (CBCT) should provide more information on the diagnosis of bruxism.

Based on the examination of panoramic radiographs, this preliminary study has shown an association between bruxism and bone development in the mandible, with a greater cancellous bone density and the presence of bony exostoses at the mandibular angle in the bruxer patient.

Further studies of bone tissue changes in bruxer patients, including a larger number of participants, would help to clarify the value of medical imaging in the diagnosis of bruxism. In addition, it would be beneficial to use three-dimensional imaging, such as CBCT, to overcome some of the limitations of panoramic radiographs in this protocol.

Funding Not applicable.

Declarations

Conflict of interest The authors declared that they have no conflict of interest.

Ethics approval This article does not contain any studies with human or animal subjects performed by the any of the authors. RGPD-APHM registry #2020-149.

Informed consent Not applicable.

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