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Digital imaging of patterns of dental wear to diagnose bruxism in children

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Summary. *Objective.* The aim of this study was to evaluate and compare the area, perimeter, and form (D factor and fractal dimension) of the dental wear among bruxist and nonbruxist children with mixed dentition in order to determine if the dental wear may be used as criteria to diagnose bruxism.
Methods. The children were 8 to 11 years old and were classified as bruxist or nonbruxist, according to anxiety level and temporomandibular disorders. Dental casts of the upper arch were obtained for the bruxist ($n = 24$) and the control ($n = 29$) group. The dental wear was measured in digital format and processed automatically. The complete and pathological dental wear was compared between the two groups, using the Student's t-test and Mann–Whitney test.
Results. Statistically significant differences were observed between the two groups, with a higher area, perimeter, and more irregular form of the pathological dental wear among the bruxist group. Regarding complete dental wear, differences were only significant for the D factor (an un-dimensional quantitative parameter which produces a relation between the area and the perimeter of an object).
Conclusion. Digital imaging of dental wear may be used as criteria to diagnose bruxism in children with mixed dentition after making an analysis of the area, perimeter, and irregularity of the form of pathological dental wear.

Introduction

There is still no agreement regarding the definition and diagnosis of bruxism [1]. It has been defined as a parafunctional activity, carried out during the day and/or night [2] that consists of nonfunctional contact of the teeth and that includes clenching or grinding in a nonvoluntary form, rhythmical or spasmodic. It is associated with habits such as nail biting or tongue thrust against the teeth [3]. It also has been defined as nocturnal nonmasticatory movements of the mandible that can cause occlusal trauma [3].

Most authors suggest bruxism to have a multifactorial aetiology [1,4–6]. Basically, two groups of aetiological factors can be distinguished, peripheral (morphological) factors and central (pathophysiological and psychological) factors. Among the emotional features, anxiety has been the factor most often studied in children [6].

The effects of bruxism on teeth depends on several factors: type and severity of the parafunction, localization of the teeth, position of the teeth within the arch, intermaxillary relations, number of teeth, cusp heights, mobility, and interdental contacts [7,8]. Dental wear can be caused by digestive problems [4,9] and physiological masticatory functions [8,10]. Dental wear of natural teeth depends on variables such as structure and hardness of the dental enamel, charge applied to the contact surfaces, saliva, and duration of the contact [10,11].

Physiological abrasion occurs during normal function such as mastication and affects the canine ridges, supporting cusps, the molar fossae, and pits [12].

Most studies that measure the dental wear in bruxist subjects base their diagnosis of bruxism on a visual examination of dental wear [13,14] without making clear differentiation between physiological or pathological wear with reliable tools, such as digital systems. This is despite evidence that shows that pathological dental wear is located most often in the cutting cusps (buccal cusps of upper premolars and molars and lingual cusps of the lower premolars and molars), canine cusps, and/or incisors [12]. The dental wear produced by bruxism is characterized by a plane surface with a central zone that sometimes reaches

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the dentine, surrounded by enamel zones [7]. Waltimo *et al.* [15] found that the most common dental facets are the ones with horizontal form that indicate a grinding pattern rather than a clenching pattern of bruxism. Negoro and Briggs [14] reported differences between the dental wear of bruxist and nonbruxist subjects using the visual examination of the dental wear.

One reason why studies have been confined to visual examination is that the measurement of the dental wear has been difficult. Controlled clinical trials in humans that include study of this feature are limited because there are technical difficulties regarding the precise quantification of the intraoral wear and because it is very difficult to control the variables that affect the oral environment [7].

Some quantitative methods, however, have been implemented in order to measure dental wear. Visual evaluation of the number of wear facets [13,14], the number of teeth involved and the area and the amount of teeth or restorative material affected have also been measured [16]. Sophisticated *in vitro* methods based on image processing have also been applied [17], such as stereophotometry [18,19], interferometry, microscopy, 3-D topography, and mechanical sensors [20].

For image analysis, different parameters such as the evaluation of the area, perimeter, factor of the form (D factor), and fractal dimension [20–22] have been used for different tasks.

The D factor is an undimensional quantitative parameter, which produces a relation between the area and perimeter of an object. It helps to compare two objects with differences in the scale of measurement. When the form of the object that is being measured is very complex, the value of the D factor must be low.

The fractal dimension describes complex forms and structural patterns in the images and allows a characterization of properties as roughness. It is accepted that a higher fractal dimension corresponds to a more complex form.

The fractal dimension has been used to analyse properties of materials [20,22] on medical and dental images [23–26] such as periapical, panoramic X-rays [27], mammographies [28], Computarized Tomography (TAC), and magnetic resonance imaging (MRI) [25,29] in order to facilitate the diagnosis of gingivitis, periodontitis [30], and osteoporosis [31–33]. It has never previously been used to diagnose bruxism or to measure dental wear.

The aim of this investigation was to use digital imaging to evaluate and compare the area, perimeter, and form of the dental wear in bruxist and nonbruxist children with mixed dentition and to determine if the dental wear can be used as diagnostic criteria for bruxism.

Materials and methods

Clinical evaluation

One hundred and eighty-eight children from the Montessori School of Medellín, Colombia, 8 to 11 years old with good general health were evaluated. For all subjects, informed consent from the school and their parents was obtained before the start of the study.

From the 188 children initially evaluated, 53 individuals were randomly selected and included in the study. The following inclusion criteria were used for selection: absence of skeletal facial dysplasias, mixed dentition, bilateral molar and canine angle class I, absence of premature contacts and deflexions, and presence of dental wear. The subjects were divided in a group of bruxist and a control group, based on occurrence of nocturnal audible grinding sounds of the teeth reported by the parents, anxiety level, measured with Conner's Parents and Teacher's Rating Scales (CPRS and CTRS) [34], and the presence of signs of pathology in the temporomandibular joint (TMJ), according to the Bernal and Tsamtsouris [35] test. Both tests have been used to diagnose bruxism [6]. Those that related grinding signs of the teeth, more than 0·75% of anxiety level, according to Conners, and two or more signs of pathology in the TMJ according to Bernal and Tsamtsouris test were included in the bruxist group ($n = 24$). The remaining subjects were assigned to the control group ($n = 29$).

Dental casts of the upper arch were obtained for each child using a standardized technique. On the casts, all the dental wear present in the teeth (primary and permanent teeth) was drawn by the same trained investigator with black paint (Bisq-Satin OS 476® for stone). The teeth that did not have dental wear were not drawn. The examiner error was less than 5%.

Three days later, the dental wear was filmed through a 5-mm-wide nonreflective glass and with a standardized distance of 20 cm between the model and the camera. The digital image of each model was then obtained using an acquisition video system constituted by a CCD sensor, connected to an acquisition card IMAQ-PCI-1408 (National Instruments, Austin, TX, USA) in a PC IBM, controlled by software devel-

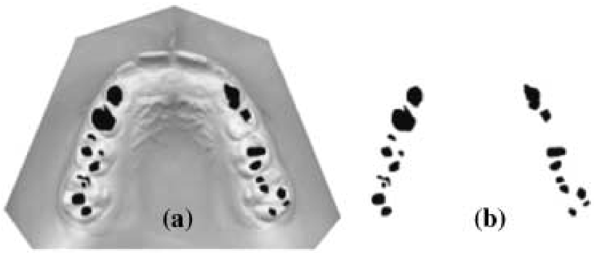

Fig. 1. Transformation of the image. (a) Original image of the dental cast. (b) Transformation of the image to a binary format.

oped in LabView 5·1 (National Instruments) and Matlab 5·3 (MathWorks, Inc., Natick, MA, USA).

The system made an analogical preprocess phase in order to enhance the contrast of the image. Afterwards, the image was converted from a greyscale to a binary format (two-dimensional matrix of 0s 'black pixels' to detect the background and 1s 'white pixels' for the dental wear facet), before applying a digital morphological processing that included algorithms to preprocess the image before the detection of boundaries (Figs 1, 2).

The area and perimeter of the dental wear were calculated to evaluate the size of the wear: From these the form factor (D factor) and fractal dimension were estimated to evaluate its form. All the measurements were obtained for complete dental wear (total dental wear present in the dental cast of the upper arch), and then the system identified the pathological dental wear (wear present in the cutting cusps; buccal cusps of the upper molars, and lingual cusps of the lower molars, canine cusps, and incisors).

Area, perimeter, and the D factor were calculated using software developed in Matlab 5·3. For the D factor, the following relation was used:

$$Dfactor = \frac{\sqrt{a}}{p} \text{ where:}$$

a is area [mm²] and p the perimeter [mm]

The form factor (D factor) is an undimensional measurement, but is based on the area and the perimeter, essentially converting the irregular form of a tooth wear facet to a more regular form for measurement purposes.

To evaluate the fractal dimension, the analytical method [29] provided in the version for the IBM PC

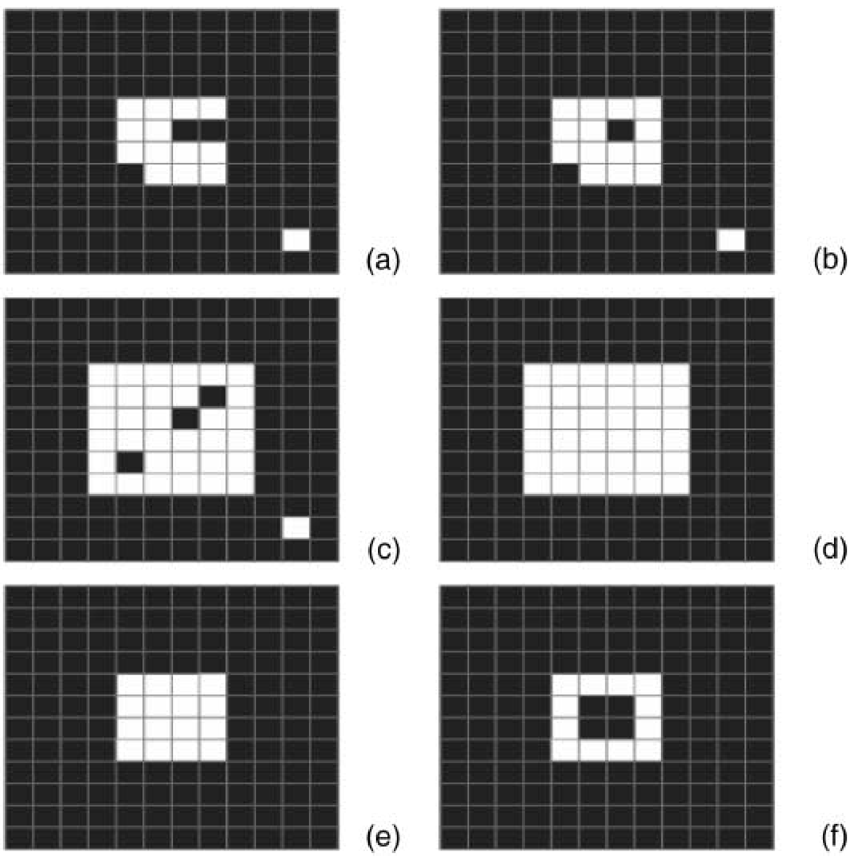

Fig. 2. Morphological image processing. (a) Theoretical original image of a dental wear facet with defined geometry (white is the dental wear facet and black is the background). (b) Closing strategy: removal of isolated background pixels (black). (c) Dilatation strategy: addition of pixels to the boundaries of the facet. (d) Opening strategy: removal of isolated white pixels from the exterior of the facet image. (e) Erosion strategy: removal of pixels that had been added in the dilation process. (f) Detection of boundaries.

Table 1. Distribution of age in the bruxist and nonbruxist group.

Mean age (Years)	Bruxist *n*	Nonbruxist *n*
8	2	2
9	11	12
10	9	15
11	2	0
Total	24	29

of the Image Fractal (NIH, Bethesda, MD, USA) was used. This algorithm estimates how much of the available space (total image) is taken up by the fractal structure (dental wear facet). First, an arbitrary length is placed over the structure to be measured. Then, the system counts how many times that length is filled by the fractal structure. The process is then repeated with a length half the size of the previous one. The data from several counts are tabulated and plotted on a log–log plot. A linear regression is automatically carried out to find the best fit and the slope of the regression line is used to calculate the fractal index (s). The fractal dimension (FD) was calculated, using the following relation:

$$FD = 1 - S \text{ where: } \frac{FD \textit{ is the fractal dimension}}{S \textit{ is the fractal index}}$$

Statistical analysis

Univariate and bivariate analyses were performed for each variable, using frequencies and mean values. The bivariate analysis was carried out using distribution two-tailed Student's *t*-test or Mann–Whitney test, depending on the normality of distribution of the variables. Distributions were tested using the Smirnoff–Kolmogorov test.

Afterwards, a multivariate analysis using logistic regression and the Stepwise Forward Likelihood Ratio method was performed.

Results

Univariate analysis

Six female subjects were evaluated in the bruxist group and 12 in the nonbruxist group. Among male subjects, 18 were bruxist and 17 regarded as nonbruxist, presenting proportions of 6 : 18 female : male in the test, and 12 : 17 in the control group. The individuals in both groups were between 8 and 11 years old. The mean age for subjects in the bruxist group was 9·46 (SD 0·77) and for the nonbruxist group was 9·44 (SD 0·63) (Table 1).

Bivariate analysis

In terms of age, the groups of bruxist and nonbruxist children were comparable and there were no statistically significant differences between the groups.

The four outcome measurements of dental wear were compared between the bruxist and nonbruxist groups (Table 2). There was a statistically significant difference for the form of the dental wear (D factor) when quantifying the complete dental wear in the two groups ($P = 0{\cdot}034$). Comparing the pathological dental wear (cutting cusps), there were statistically significant differences (*P*-values of 0·013, 0·019, and 0·013, respectively) in the area, the perimeter, and D factor, with all three measurements being higher for the subjects in the bruxist group.

When the fractal dimensions were compared between the bruxist and the nonbruxist group, there was a statistical significant difference between the two groups for pathological dental wear (*P*-value = 0·02).

Table 2. Comparison of dental wear between bruxist and nonbruxist children.

	Bruxist ($n = 24$)		Nonbruxist ($n = 29$)		Difference
	Media	Standard deviation	Media	Standard deviation	*P*-value
Dental wear					
Complete dental wear					
Area	59·8	36·2	54·3	34·2	0·57
Perimeter	112·3	50·1	96·51	46·3	0·23
D factor	14·6	2·8	13·1	2·8	0·034
Pathological dental wear					
Area	9·5	7·2	6	4·5	0·013
Perimeter	51·1	31·5	33·5	23·5	0·019
Fractal dimension	1·29	0·73	0·75	0·35	0·02
D factor	16·02	5	12·8	5·0	0·013

Table 3. Results of the multivariate analysis with logistic regression.

Independent variable	Beta	OR Exp (Beta)	IC 95% L.S. (OR)	IC 95% L.S. (OR)	*P*-value
Fractal dimension of the pathological dental wear	1·5605	4·7	0·74	0·18	0·0359
Irregularity of the complete dental wear (FD)	–0·2678	0·7650	–0·1811	0·1277	0·1059
Irregularity of the pathological dental wear (FD)	0·1280	1·1366	0·07	0·09	0·0360
Constant	0·5047				0·52

Multivariate analysis

For those variables where *P*-values were less than 0·25 in the bivariate analysis, a multivariate analysis using logistic regression was performed (Table 3). The variables included in this second analysis were: the D factor (form factor) of the complete dental wear and the area, perimeter, D factor of the dental wear located in the cutting cusps (pathological wear), and the fractal dimension of the pathological dental wear. The multivariate analysis was carried out using the method Stepwise Forward Likelihood Ratio, with a cut-off point of 0·5.

In the final model, the Nagelkerke coefficient (measurement obtained with the logistic regression to determine the reliability of the variables included in the model to explain the phenomenon (bruxism)), presented a value of 0·37, which showed that 37% of the differences between groups could be explained by the variables: D factor for the complete dental wear and the fractal dimension for pathological dental wear. The chi-squared value was 17·374 with a *P*-value of 0·0006. The adjustment test of Hosmer–Lemershow (measurement to determine if the model, conformed by the variables included in the multivariated analysis is flexible or rigid. The more flexible the model, the better it is to explain the phenomenon) gave a statistical value for the chi-squared of 7·36 with a *P*-value of 0·28, suggesting that the model was flexible and that the variables contained in it adequately explained the findings of this investigation.

The concordance of the model between the observed and the predicted values was 66·04%, suggesting effectiveness of the model in predicting the diagnosis.

From the two covariables included in the final model, the odds ratio of the fractal dimension and the D factor of the pathological dental wear were 4·7 and 1·13, respectively, showing a positive association with signs of bruxism (Table 3). These findings were statistically significant ($P = 0·035$ and 0·036, respectively). The odds ratio of the irregularity of the complete dental wear (FD) suggests a negative association with the presence of bruxism but this result was not a statistically significance ($P = 0·10$).

Discussion

The aim of this investigation was to evaluate and compare the area, perimeter, form factor (D-Factor), and fractal dimension of the dental wear in bruxist and nonbruxist children with mixed dentition and to determine if dental wear measured in this way can be used as a diagnostic criteria for bruxism.

The dental wear of the upper arch of bruxist and nonbruxist subjects was filmed and analysed by means of a specialized software, where the area, perimeter, D factor, and fractal dimension were calculated digitally. The measurements where then compared between the two groups.

Bruxism is considered to be a parafunctional behaviour that has a multifactorial aetiology [1,5,36–38]. In this investigation, dental wear was shown to be a pathognomonic sign of bruxism; however, it must be not taken as the only sign in order to diagnose this parafunctional activity. There are no specific measurement methods or criteria to diagnose bruxism, but there are some that, when combined, may help to detect this parafunctional habit. For example, pathological dental wear may be present as a result of other causes, such as malocclusions, presence of premature contacts, etc. That is why in this study, children with malocclusions were excluded. Anxiety level or signs of temporomandibular disorders are also not specific signs of bruxism by themselves, but when sounds of dental grinding [14] are reported, high anxiety levels [6] and temporomandibular disorders [5] are also likely to be present, there are therefore more than two associated factors associated with bruxism that allow clinicians to diagnose a subject as bruxist. There is clearly a possibility of misdiagnosing or overdiagnosing a subject as bruxist. Dental wear and the audible sounds of teeth are similarly only signs of grinding, not of clenching that also could be present.

Most studies about bruxism are not clear regarding the measurement of the dental wear, most are limited and describe only simple differences, showing the most affected group as the one that presents 'atypical dental wear' [13,14]. Only in some of those studies, if possible to determine from the methodology, whether the form and/or the extent of the dental wear was measured.

Regarding the form of the dental wear, Linqvist [39] found a positive correlation among the atypical dental wear and bruxism. The way in which the differentiation of each facet between typical or atypical was made, however, is unclear. In this study, after digital mapping of dental wear, the form of the complete and the pathological wear appeared to be more irregular for the bruxist children, with the difference between groups proving statistically significant. This finding may be a result of the irregular movements of the mandible during nonmasticatory function, producing irregular forms of dental wear in the bruxist group.

Some complex microstructures are poorly defined by relatively simple measurements using Euclidian geometry (area and perimeter). There are digital methods, however, to calculate the area of the dental wear [40]. Measurements using non-Euclidian geometry (D factor and fractal dimension) allow numeric estimations of form without concerning the grade of irregularity. This type of geometry was used, as it is impossible to classify the dental wear in geometrical figures, such as ellipses, circles, or other common figures.

Shu-Zu and Hellawell [20] showed the potential of fractal dimensions applied to images produced by metallographic characterization. To evaluate irregular forms, it is common to express an aspect of the form or distribution in terms of the relation between the surface and the volume. The D factor of the dental wear can be obtained, evaluating each facet bidimensionally, making an approximation to its perimeter and area and expressing it as a number without dimension. The main advantage of this type of relation without dimension is that it is a form of normalization of images that does not depend on the magnification of the images by microscopy. Its calculation depends on the measurement of the area and perimeter of the structure.

Vanderas and Manetas [2] reported that dental wear can be measured objectively. That is not, however, indicative of the actual level of bruxism in the patient, as dental wear is a permanent sign. Patients who have recently started bruxing do not present dental wear, in contrast with those with longstanding bruxing behaviour but who have stopped bruxing recently, will always present dental wear in their permanent dentition.

The fractal dimension can be a complementary diagnostic method as it is not affected by the region evaluated or the projection in the image acquisition. Because of this property, it has been used to determine periodontal conditions [30,39], osteoporosis [41], caries, and restorative treatment of teeth [42,43]. Its use in determining dental wear is still controversial because there is currently insufficient information in the literature to support it, other methods have been used to measure wear but direct comparison with results using the fractal dimension is not possible.

The gender make-up of both groups in this study (bruxist and nonbruxist children) was different and numbers in each were relatively small, so comparisons regarding sex were not possible. Other studies [44–46] have presented homogeneous gender distribution in the study group, so the variable was controlled when tooth wear was studied and no comparisons were reported between males and females. Other reports in adults [47] have revealed the influence of age, gender, bite force, self-reported teeth clenching/grinding, and number of daily meals/snacks to have significant correlations with maxillary tooth wear.

Moslemi [48] concluded after studying 3744 subjects aged 4–15 years (1786 girls and 1958 boys) in Tehran, Iran, that boys had their permanent teeth erupt by the age of 99 months (8·3 years), whereas the corresponding age in the girls was 96 months (8·0 years). If this result is extrapolated to the findings in the present investigation, the impact of the difference in eruption dates between genders in the two groups seems too small to be likely to have a great effect in the dental wear of the permanent teeth.

The results of this study showed that the main difference between the dental wear found in bruxist and nonbruxist children is the irregularity of form of wear facets, especially in considering dental wear as a whole.

Results of this study suggest that dental wear measured through digital imaging can be used as diagnostic criteria of bruxism in children if objective measurements and differentiation of the pathological and physiological wear is obtained; if only visual inspection is used to identify bruxist children through dental wear, many patients could be overtreated.

What this paper adds

- Bruxism is a common parafunction, which is difficult to diagnose.
- The visual inspection of the dental wear is the most common tool of paediatric dentists to detect bruxism in children, although it is not a reliable tool.

Why this paper is important to paediatric dentists

- This study allows the clinician to support the diagnosis of bruxism on a more detailed, easy to use and reliable tool.

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