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Evaluation of the effects of different bracket types on the detection of interproximal enamel caries using periapical radiography

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Abstract

Aim: During orthodontic treatment, dental materials can affect the imaging of caries lesions. Material density and X-ray beam attenuation play important roles in this imaging. This study aims to evaluate the artifacts that are caused by brackets made of different materials and affect the visibility of International Caries Detection and Assessment System (ICDAS) code 5 caries.

Methodology: One premolar tooth with ICDAS code 5 caries was examined. Eight periapical radiographs were taken: one without a bracket and seven with different types of brackets (composite with metal slot, self-ligating ceramic, monocrystalline ceramic, polycrystalline ceramic, zirconium, self-ligating stainless steel, and conventional stainless steel). The gray values of the caries region were evaluated using Fiji software (version 1.53f, National Institutes of Health, USA) on periapical radiographs.

Results: Conventional stainless steel and self-ligating stainless steel brackets increased the radiopacity of the outer half of the enamel (E1). When these brackets were present, the gray values changed by -13.63633 (p = .026) and -16.38967 (p = .006), respectively. There was no statistically significant difference in column B due to the brackets. However, numerically, the gray value changes were similar to those in column A.

Conclusion: Orthodontic brackets affect the evaluation of periapical images. Ceramic brackets provide more advantages than stainless steel brackets for radiographic imaging.

Keywords: Periapical radiography, enamel caries, radiographic effect, orthodontic brackets, caries radiopacity, gray value evaluation

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Introduction

It is known that during fixed orthodontic treatment, when oral hygiene procedures are not properly followed, the risk of caries formation increases due to increased food retention. Non-cavitated interproximal caries below the interproximal contact of the teeth may not be easily visualized during a clinical examination. It is important to diagnose dental caries as early as possible to implement a conservative and appropriate treatment plan, reduce treatment costs, and save time. Various diagnostic methods, such as visual analysis, laser fluorescence, electronic caries monitor, and radiography, can be used for the early detection of caries; among all of the methods (1), bitewing and periapical (parallel technique) radiography are the most recommended for detecting interproximal caries (2).

In addition, enamel caries may not be visible on radiographs until approximately 30–40% demineralization occurs (3). However, when periapical or bitewing radiographs are taken from teeth with orthodontic brackets, the diagnosis of caries may be challenging, because the bracket or archwire is superimposed on caries, because brackets can lead to the presence of beam-hardening artifacts and the Mach band effect around metallic objects (3, 4). Mach band effect is an optical illusion induced by the retina's intrinsic edge amplification, which results in a darker edge of a dark object near to a bright object, and vice versa. Photodensitometric tracing can be used to verify that the apparent change is an optical illusion, since it will provide a constant reading with no changes at the afflicted area (5). Generally, previous studies evaluated the artifacts caused by orthodontic materials on cone-beam computed tomography (CBCT) (4) and magnetic resonance (MR) images (6). In one study, the effects of the combination of three different brackets and two archwires on the visibility of interproximal caries in periapical radiographs were investigated (7). To the best of the authors' knowledge, there has been a very limited number of studies about the artifacts caused by orthodontic brackets on periapical images. Unlike other studies, in terms of standardization, the current study was designed on a tooth that was selected based on the International Caries Detection and Assessment System (ICDAS) classification recommended by the American Dental Association (ADA) (8). According to the ICDAS classification, teeth with advanced (code 5 and code 6) caries are likely to become visible on X-ray films and require restoration. In patients undergoing orthodontic treatment, the material of the bracket may affect the detection of the size and border of caries and may even completely mask the presence of caries in the image. In addition, depending on the angle of the X-ray, the probability of the brackets being superimposed on the dentin is high. For this reason, it is important to conduct a careful evaluation of interproximal enamel in teeth with brackets (1, 9).

This study aims to evaluate the artifacts that are caused by brackets made of different materials and affect the visibility of ICDAS code 5 caries. The null hypothesis is that the presence of brackets does not affect the detection of interproximal caries.

Materials and Methods

The study was carried out at İstanbul Medeniyet University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology. One upper first premolar tooth with ICDAS code 5 ("advanced caries" according to the ADA caries classification system) non-cavitated caries was used. Six measurements were performed on eight periapical images with different types of orthodontic brackets. All procedures followed were in accordance with the ethical standards of the responsible committee (institutional and national) and with the Helsinki Declaration of 1964 and later versions. The study protocol was approved by the İstanbul Medeniyet University Göztepe Education and Research Hospital Clinical Research Ethic Committee, with 2022/556 approval number.

Image Acquisition

Radiographic images of one premolar tooth were taken by following certain standards. These radiography standards were as follows:

- For imaging, a new, unused photostimulable phosphor plate (PSP) (Carestream Size 2) was used, and the phosphor plate was scanned using the Carestream 7200 scanner (CS 7200) (Carestream Dental, Atlanta). All radiographs were taken at the Oral and Maxillofacial Radiology Clinic.

- Images were obtained using a Planmeca ProX™ (Planmeca®, Helsinki, Finland). All radiographs were taken at 70 kVp, 5 mA, and 0.03 sec with a parallel technique. For this purpose, a shelf was fixed perpendicularly to the wall (Fig. 1).



Figure 1. The imaging plane on the wall

- On the shelf, a rectangular frame was drawn around the margins of the phosphor plate to ensure that each exposure had the same position, and the cone was oriented perpendicular to the phosphor plate at a distance of 10 cm. The tooth and an aluminum step wedge were placed on the cover of the phosphor plate with transparent double-sided tape and were not moved at all in subsequent periapical X-rays.

- To evaluate the effects of the brackets, eight radiographs (one for a tooth with no bracket and seven for the same tooth with seven different brackets) were taken in the same way. The seven different brackets were as follows: a metal-slotted composite bracket, a self-ligating ceramic bracket, a polycrystalline ceramic bracket, a monocrystalline ceramic bracket, a zirconium bracket, a self-ligating stainless steel bracket, and a conventional stainless steel bracket. Brackets were placed on the tooth by the orthodontist with a transfer guide, without disturbing the position or angle of the tooth. The adhesive paste Transbond XT (3M Unitek, Monrovia, CA, USA) was used for bonding without LED curing in this way the tooth surface was cleaned easily with no enamel loss.

- The radiopacity of a caries lesion is quantified by the International Organization for Standardization (ISO) and the American National Standards Institute/American Dental Association, using a pure aluminum (98% purity) step wedge as a reference (10). An 11-step aluminum step-wedge is placed next to the tooth for radiographic image (0–255 gray values) calibration of the gray value with each take. The base of the radiographic image was determined as “black = 0,” and the sign on the film was determined as “white = 255.” The steps of the aluminum step wedge were ordered between white (255) and black (0) values.

Image Evaluation

For a standard evaluation, horizontal and vertical grid lines were digitally drawn at 0.5 mm intervals on the non-bracketed tooth to determine the extent of the caries lesion on a PowerPoint slide (Fig. 2).

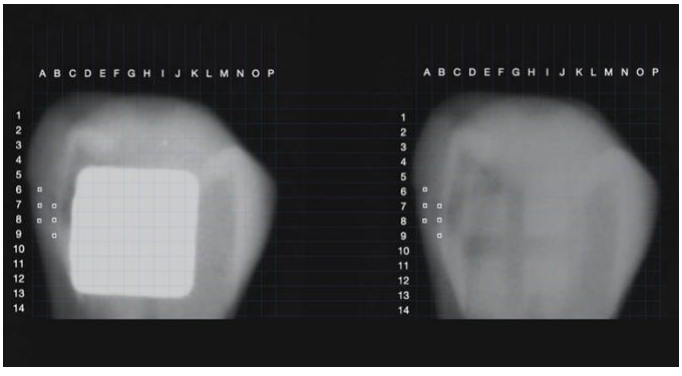


Figure 2. Reference grid lines (left: zirconium bracket; right: polycrystalline ceramic bracket; dots: enamel caries lesion)

After the determination of grid squares, which included radiolucency, the images of brackets were overlapped with the same grid template. Five columns (A, B, C, D, E) showed the radiolucency of caries on the left side of the tooth. However, in some images, the brackets were superposed to columns C, D, and E, which were dentin caries. These three columns were excluded from the evaluation so that they would not misdirect the study, and the evaluation was conducted on enamel caries. Three lines squares on columns A and B showing radiolucency were measured for eight images after calibration of each take. Each image was saved in JPEG format with the grid lines for further evaluation.

The radiographic images were imported to open-source Fiji software (version 1.53f, National Institutes of Health, USA) by two operators (BA, GK). These operators were unaware of which image belonged to which type of bracket. The image was transformed to 8-bit. Before measuring the gray values, optical calibration was applied to all images with the help of an aluminum step wedge, as written in the instruction manual (https://imagej.nih.gov/ij/docs/examples/calibration/). Every 11 steps of the aluminum step wedge and the mean gray value of the background were measured, and numerical values were obtained. The rectangular selection tool was selected, and the region of interest (ROI) covered as much as one step without overlapping another step. Then, the background, which did not include any parts of the step wedge or the tooth, was measured. The results comprised 13 measurements. The Calibrate function was used under the Analyze tab, and the results were automatically entered into the left column. The expected gray values were manually entered into the second column at 21.25 gray value intervals, equally divided between 0 and 255. The value of the background region corresponded to a gray value of 0. The Rodbard function was selected from the pop-up menu, and the gray value was entered into the Unit field. Subsequently, the software generated and displayed a calibration curve (Fig. 3). After the calibration was complete, the measurements inside the grids were taken to evaluate the effect/artifact of the brackets on caries.

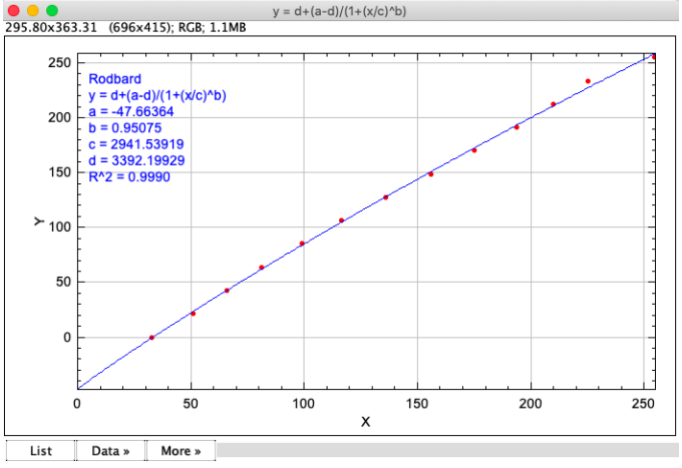


Figure 3. Calibration curve

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows/Macintosh, Version 22.0 (IBM Corp., Armonk, NY, USA). The normality test of the collected outcomes was confirmed to follow normal distribution by using the Shapiro-Wilk test ($p > 0.05$).

The tooth with ICDAS code 5 caries without brackets was regarded as the reference. Changes in radiographic images after attaching the brackets to this tooth were verified by determining how much the gray value of caries differed from that of the reference image. Therefore, a one-way analysis of variance (ANOVA) followed by a Tukey HSD post hoc test was used for intergroup comparison of the seven bracket types. Finally, to evaluate the reproducibility of the six measurement values (A6, A7, A8, B7, B8, B9), 4 images were randomly chosen, and the measurements for each bracket were repeated after 2 weeks; $p \leq 0.05$ was considered statistically significant.

Results

The measured ICC was 0.892–0.972, indicating excellent intraexaminer reliability. Enamel caries was examined in two halves, as in the case study (7). E1 represents the outer half of the enamel, and E2 represents the inner half. Measurements were taken from 3 square rows in column A for E1 and from 3 square rows in column B for E2. First, squares, where caries were detected in the tooth, were measured separately—without brackets and with seven different brackets (composite with metal slot, self-ligating ceramic, monocrystalline ceramic, polycrystalline ceramic, zirconium, self-ligating stainless steel, and conventional stainless steel). Gray values of 6 squares that showed enamel caries lesions were measured separately, and numerical gray values ranging between 0 and 255 were obtained. A score of 0 showed the most radiolucent area (black), and a score of 255 showed the most radiopaque area (white).

For some brackets, a statistically significant change in gray value was observed in column A. Conventional stainless steel and self-ligating stainless steel brackets caused an increase in radiopacity. The gray value changed respectively −13.63633 ($p = 0.026$), and −16.38967 ($p = 0.006$) in column A, which represents the E1 enamel caries lesion (Table 1).

Although there is not a statistically significant difference between composite with metal slot and zirconium brackets, they caused the closest change to stainless steel brackets among other brackets respectively, −7.29767 ($p = 0.488$) and −8.66967 ($p = 0.294$) (Table 1).

There was no statistically significant difference in column B due to the brackets. However, numerically, the gray value changes are similar to those in column A. The statistically insignificant change in column B of the brackets mentioned for column A is as follows: conventional stainless steel −14.216 ($p = 0.338$), self-ligating stainless steel −15.057 ($p = 0.402$), zirconium −7.52733 ($p = 0.931$), and composite with metal slot −8.947 ($p = 0.853$) (Table 1).

Table 1. Effects of different bracket types on the radiolucency of the enamel caries lesion.

Caries Column	Bracket Type (1)	Bracket Type (2)	Mean Difference (MD) (1-2)	SD	p	95% Confidence Interval	
						Lower Bound	Upper Bound
A	No bracket	Composite (with metal slot)	-7.29767	3.57910	.488	-19.6891	5.0937
		Ceramic (self-ligating)	-4.62967	3.57910	.889	-17.0211	7.7617
		Polycrystalline ceramic	-1.32567	3.57910	.998	-13.7171	11.0657
		Monocrystalline ceramic	-2.86033	3.57910	.991	-15.2517	9.5311
		Zirconium	-8.66967	3.57910	.294	-21.0611	3.7217
		Stainless steel (self-ligating)	**-16.38967***	3.57910	**.006***	-28.7811	-3.9983
		Stainless steel (conventional)	**-13.63633***	3.57910	**.026***	-26.0277	-1.2449
B	No bracket	Composite (with metal slot)	-8.94700	6.47395	.853	-31.3608	13.4668
		Ceramic (self-ligating)	-6.21200	6.47395	.974	-28.6258	16.2018
		Polycrystalline ceramic	-1.63333	6.47395	.997	-24.0471	20.7804
		Monocrystalline ceramic	-.71233	6.47395	.998	-23.1261	21.7014
		Zirconium	-7.52733	6.47395	.931	-29.9411	14.8864
		Stainless steel (self-ligating)	-15.05700	6.47395	.338	-37.4708	7.3568
		Stainless steel (conventional)	-14.21600	6.47395	.402	-36.6298	8.1978

Abbreviations: SD-standard deviation; MD-mean deviation. Values are means (95% confidence interval); *$p < 0.05$; *P* values were derived from an analysis of variances (ANOVA) with a Tukey HSD post-hoc test; a Shapiro-Wilk test was employed to test the normality.

Discussion

In studies about caries lesions, artificially created cavities and caries lesions to simulate caries have more distinct margins than natural caries lesions do (11), so artificially created caries are likelier to be detected on X-rays (12). Therefore, in the present study, we aimed to find the most realistic results by using a tooth with a natural interproximal caries lesion.

The formation of dental caries is essentially a demineralization process leading to changes in density within the enamel or dentin and is therefore detectable through radiographic imaging. Intraoral radiography is vital for caries diagnosis and management, although it is not a sensitive method for early caries detection (1). Small lesions—ICDAS codes 3-4—are better examined clinically, as radiography plays a small role in the detection of these lesions (13). Therefore, to perform a good assessment, the study was carried out on ICDAS Code 5 (advanced) non-cavitated caries.

During fixed orthodontic treatment, it is not always possible to determine dentin caries and caries extension to the pulp because of the radiopaque orthodontic brackets and beam-hardening artifact and the Mach band effect around them (3, 4). Therefore, it would be useful to evaluate caries by focusing on interproximal enamel.

A similar study evaluating interproximal enamel caries reported that stainless steel, ceramic, and acryl brackets without arch wire did not affect the caries diagnosis (4). However, in the present study, it was concluded that conventional and self-ligating stainless steel brackets increased the radiopacity of the interproximal enamel caries. This difference might be due to the difference in evaluation methods. In the aforementioned study (4), a subjective and visual evaluation was conducted by the examiners, whereas in the present study, the gray value was evaluated objectively using software.

Intraoral radiographs can be obtained in two ways: conventionally and digitally. While analog films are used in conventional radiography, charge-coupled devices (digital sensors) and phosphor plates are used in digital radiography. These three receptors' sensitivity and specificity in detecting enamel and dentin caries are as follows: 55% and 100% (analog films), 45% and 100% (charge-coupled devices), and 55% and 100% (phosphor plates) (14). The sensitivity and specificity of phosphor plates is equal to that of analog films, and the sensitivity and specificity of both phosphor plates and analog films in detecting enamel are better than that of charge-coupled devices (14, 15).

When the detection was only made for enamel caries, the sensitivity was low for all three. Although there is no difference between all the receptors, the phosphor plates with 70 kVp and 0.03-second exposure time had the highest sensitivity for enamel lesions. Besides the advantages of phosphor plates, extensive usage of phosphor plates is a disadvantage that causes unwanted lines and marks on subsequent radiographic images (16). For this reason, a new and unused phosphor plate was used in the present study, and exposure was standardized to 70 kVp and 0.03 sec.

Since there is no similar study, we discuss the data in itself. Self-ligating and conventional stainless steel brackets increased the radiopacity of interproximal enamel lesions according to objective software evaluation results. The amount of both increments was similar. The main concern for us was why conventional and self-ligating stainless steel brackets created a difference in radiopacity while other brackets did not. The reason for this may be the differences in the size, design, and, hence, density of the bracket. Those factors may affect the direction, pattern, and amount of the X-ray beam. According to radiation physics, the X-ray that interacts with the matter undergoes transmission or attenuation (scatter or absorbed). Attenuation is the reduction of the intensity of an X-ray beam during the transmission through matter. The reduction may result in absorption or deflection (scatter) of some X-ray beams (17). Additionally, scattered X-rays may be seen in three ways: forward, backward, and side (18). The backscatter is the reflection to the back, and the side scatter is the reflection to the environment, they do not reach the film and do not affect the image. However, the forward scatter contributes to image formation. The radiographic image comes out with transmitted and forward scattered X-rays. Since the absorbed beam cannot fall on the film, it does not affect image formation. The amount of scattered and absorbed X-rays also depends on the density of the material (Fig. 4). Since the brackets are located between the tooth and the X-ray source, they are the first structures that the beam interacts with. This can affect the amount of absorbed, transmitted, and forward scatter of an unbracketed tooth. Stainless steel brackets have a denser structure than all other brackets. Denser materials may cause an increase in the amount of absorbed radiation (attenuation) and a decrease in the amount of forward scatter. This may be the reason why a more radiopaque image is obtained in these denser brackets (19). When we look at the results table, the zirconium bracket with the closest density to the metal and the composite bracket with the metal slot also caused statistically nonsignificant numerical increments more than the other brackets.

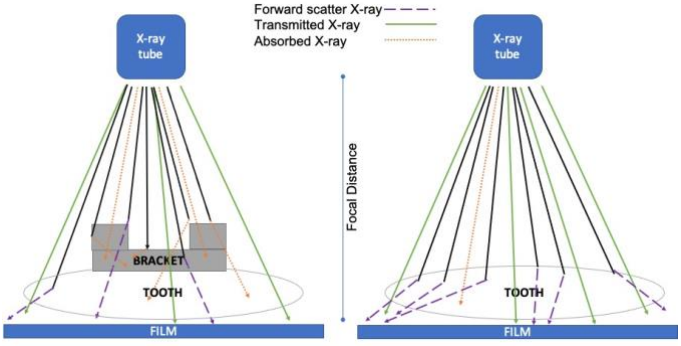


Figure 4. Scattering types

The visual perception of the radiographic image is subjective and affected by the experience of the operators, room light, and monitor resolution. When all conditions are ideal, the human eye can perceive 60 different gray tones. Considering that the gray tones vary between '0-255', the eye can detect approximately every 4 gray value changes (20). From this point of view, it might be said that composite and zirconium brackets with metal slots caused the differences in 2 gray tones, self-ligating stainless steel 4, and conventional stainless steel brackets 3 gray tones. These changes are similar for column B. Numerically, the changes caused by self-ligating stainless steel, conventional stainless steel, zirconium, and metal slotted composite brackets were −15.057, −14.216, −7.52733, and −8.947, respectively. These changes are close to the changes in column A. However, there was no statistically significant result because the gray value of this region was high. When we evaluate in terms of gray tone here, a similar result is obtained with column A.

The ceramic self-ligating bracket, on the other hand, caused a change that was less than but similar to the change caused by the aforementioned brackets due to the metal cover part. Isman et al. determined that the diagnostic performance of periapical radiography in detecting caries on stainless steel brackets with steel wire and steel brackets with Ni-Ti wire groups was very low (4). However, insufficiency was in the direction of radiolucency, not radiopacity. The same study reported higher sensitivity and fewer specificity values because the beam hardening led to false positive interpretations by both observers in their image examinations. There is disagreement regarding the modality of difference between Isman et al.'s and the present study. Beam hardening occurs in dense materials (21). Therefore, we cannot discuss beam hardening in our study; our assessment was made via attenuation, not beam hardening.

The present study concluded that stainless steel brackets caused an increase in radiopacity according to objective measurement of gray values. Wires were not combined with the bracket due to being able to evaluate the pure bracket effect. The absence of wire addition also plays a role in the different results. The evaluation was conducted objectively with the help of software (Fiji). Sensitivity and specificity evaluation could not be performed, as there is no information about specific gray values indicating caries lesions.

Additionally, since the enamel–dentin thickness and caries borders are different for each tooth, the attenuation pattern may change. To eliminate this issue in the present study, one tooth sample was used to observe X-ray behavior. Although it was reported that stainless steel brackets created a difference in both studies, we think that subjective and objective findings should be evaluated together in visual image examination. This is the main limitation of these two studies.

Conclusion

Orthodontic materials affect the quality of radiographic images. The position of the object and the direction of the X-ray are important issues for superposed shade in an image. Generally, materials do not superpose the interproximal enamel. Therefore, interproximal enamel evaluation is important in caries detection. However, it should not be forgotten that dense materials such as stainless steel brackets may affect the radiopacity of enamel lesions. In this manner, ceramic brackets provide a significant advantage. The main limitation of this study is its lack of sensitivity and specificity evaluation. Making a correlation between subjective and objective values may be beneficial for the results.

Disclosures

Acknowledgments: This study was carried out at İstanbul Medeniyet University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology.

Ethical Approval: Ethics committee approval was received for this study from İstanbul Medeniyet University, Göztepe Education and Research Hospital Clinical Research Ethics Committee, in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2022/556.

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Author Contributions: Conception – G.K.; Design – G.K., B.A.; Supervision – B.A.; Materials – G.K.; Data Collection and/or Processing – A.F.K.; Analysis and/or Interpretation – G.K.; Literature Review – B.A., A.F.K.; Writer –G.K.; Critical Review – Ö.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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