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Quantification of White Spot Lesions around Orthodontic Brackets with Image Analysis

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ABSTRACT

Objective: To investigate the use of image analysis for diagnosis and quantification of artificial white spot lesions on digital photographs before and after removal of orthodontic brackets.

Materials and Methods: Enamel demineralization was artificially induced on the labial surface of 20 teeth bonded with orthodontic brackets. Standardized digital photographs were taken at angles of 90° and 110° to the labial surface, before and after bracket removal. All images were analyzed by two observers using image-processing software, and the area of the white spot lesion was calculated. Reproducibility was assessed by the Pearson correlation coefficient for interobserver reliability and by the paired *t*-test for differences between observers. Differences between the known and the measured demineralization area were tested using the *t*-test. Differences between both stages and angles were assessed by application of the paired *t*-test.

Results: Reproducibility was very good for all measurements. For the photographs taken at an angle of 110°, there was a statistically significant but clinically irrelevant difference between the observers. The difference between the surface measured and the true surface was dependent on the stages and angles but was always <1 mm^2.

Conclusion: Image analysis is a reproducible and reliable method for quantification of artificial enamel demineralization around orthodontic brackets.

KEY WORDS: Orthodontics, Demineralization, Diagnosis, Orthodontic brackets, Image analysis.

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INTRODUCTION Return to TOC

The appearance of enamel demineralization areas or white spot lesions is a side effect of orthodontic treatment and a much reported feature in the literature. The white spot lesion has been associated with prolonged accumulation of bacterial plaque on the enamel surfaces adjacent to fixed appliances,[1] followed by acid production and loss of calcified tooth substance. Gorelick and colleagues[2] reported a 49.6% incidence among patients treated with bonded orthodontic attachments. White spot lesions have the potential to develop within 4 weeks of

the initiation of the orthodontic treatment[3,4] and can lead to frank cavitation if not arrested. The characteristic altered tooth surface may present an esthetic problem even more than 5 years after treatment.[5] It has been generally accepted that the combined application of fluoride regimes, oral hygiene instructions, and dietary control can contribute greatly to the inhibition of demineralization during fixed-appliance treatment.[6–8] Nevertheless, early diagnosis of white spot lesions by the clinician is a matter of great importance.

Clinical detection has been carried out primarily by means of traditional methods such as visual inspection after air drying and tactile examination by dental probing. However, the subjectivity, lack of reproducibility, and prerequisite of the presence of a significantly advanced lesion have led to the introduction of several optical devices during the past decades: the optical caries monitor,[9] quantitative laser and light-induced fluorescence (QLF I, II; Inspektor Research Systems BV, Amsterdam, The Netherlands),[10,11] digital imaging with fiber optic transillumination (Electro-Optical Sciences, Inc, Irvington, NY),[12] and laser fluorescence (DIAGNODent; KaVo, Biberach, Germany).[13]

So far, these methods have been tested mainly in vitro studies, while the related clinical investigations are rare and not based on orthodontic patients in active treatment with fixed appliances. Moreover, the clinical value is reduced by the high cost and complexity of the procedures. On the other hand, quantification of demineralized areas by a relatively simple and inexpensive photographic technique is another option. In their study, Benson et al[14] concluded that this method is more reproducible than direct assessment with the naked eye. Recently, the measurement of white spot lesions from conventional photographic images using computerized image analysis was suggested for the clinical setting.[15] The reproducibility of this method has been confirmed by various study protocols,[15–17] and the accuracy has also been proved when carried out on digital images.[18] Regarding the technical details, several authors have cautioned against alteration in the angle at which the camera is placed relative to the buccal surface of the tooth[15] and reflected light,[14–19] as these might give false readings of the area of interest.

To our knowledge, researchers have never attempted to measure enamel demineralization before and after removal of orthodontic brackets on digital images by means of image analysis. Therefore, the aim of this study was to investigate the potential for detection and quantification of artificially induced white spot lesions using the computer analysis of digital photographs.

MATERIALS AND METHODS Return to TOC

Tooth Preparation

Twenty permanent maxillary central incisors, with macroscopically labial surfaces free of stain, caries, enamel defects, or restorations, were selected by two investigators from a pool of previously extracted teeth. The teeth were pumiced gently, embedded in a plastic tube filled with plaster (Figure 1a), randomly numbered, and stored in distilled water. As a control, the teeth were photographed by one of the operators before any intervention. Identical standard edgewise brackets with a slot size 0.018 × 0.025 inches (ORMCO, Orange, Calif) were bonded with 3M Transbond XT light cure adhesive (3M Unitek) to simulate the clinical conditions (Figure 1b). No etching gel was used to prevent enamel demineralization increment and bond strengthening, which could have resulted in difficult bracket removal and altered tooth surface appearance. Round buttons (GAC International, Bohemia, NY) were bonded with 3M Transbond Plus light cure bond adhesive (3M Unitek) on the cervical third of the labial surface, and the crowns were coated with an acid-resistant varnish.

After the button removal, a small window was left on the incisor surface. The teeth were placed separately in a demineralization solution (20% formic acid, 5% trisodium citrate/pH 2.2) for 15 minutes.[20] To ensure equal acid potency for all teeth, a fresh solution was used for each tooth. Following completion of the demineralization process, the incisors were washed cautiously in distilled water and the varnish removed with acetone before washed anew in distilled water. Consequently, each tooth displayed an artificial enamel lesion of known size (stage I; Figure 1c). Finally, the teeth were debonded, and any adhesive remnants were separated with a scaler (stage II; Figure 1d).

Photographic Technique

Two incisor stages were determined for the monitoring of the white spot lesion:

stage I: bonded teeth, after demineralization exposure (Figure 1c) and

stage II: debonded teeth, after demineralization exposure (Figure 1d).

In our study, the incisors were photographed perpendicular to the labial surface and at angle of 20° below the perpendicular.[15] For the images obtained at 110°, a base was used that tilted the plastic tube to the required angle. Moreover, a red-brownish background was included in the study setting to imitate the oral environment. All the photographs were taken with a Nikon D1x camera (Nikon Corporation, Tokyo, Japan) with a 105 mm/2.8 AF Micro Nikkor lens and Nikon SB-29s Macro flash. The camera was set to manual with an aperture of f9 and a shutter speed of 1/125 of a second. The image quality was set as fine and ISO sensitivity 200. All images were saved as Joint Photographic Experts Group (JPEG) files suitable for manipulation with the image analysis software. To standardize the photographic procedure in relation to the distance and angle of camera-tooth, a special setting was constructed (Figure 2).

Image Analysis

The JPEG images of stages I and II were imported into image analysis software (Image J version 1.33u for Windows XP, US National Institutes of Health, Bethesda, Md) and converted to 8-bit gray-scale images. Image J is an image-processing program that can calculate area and pixel value statistics of user-defined selections. During the analysis, images were magnified up to 75%, and after the 10-mm distance had been defined on the ruler of the photographic setting, the scale was adjusted to pixels/mm for size accordance. The image analysis software was set to calculate the area. The outline of the induced white spot lesion was traced by means of the freehand preselection tool and the computer mouse. In case of doubt about the investigators' assessment, the respective images of the teeth before initiation of any intervention were rechecked. All measurements were carried out by two observers in random order with a 5-minute interval in between series of four images and repeated after 1 week.

Statistical Analysis

All statistics were carried out in SPSS 12.0.1 for Windows (SPSS Inc, Chicago, Ill). The intraobserver reliability was studied on eight randomly selected incisors for stages I and II. Each of the observers measured the demineralization areas three times. Intraobserver performance was expressed by the reliability coefficient, which is calculated by determining the Pearson correlation coefficient, and the measurement error, calculated as the square root of the mean variance over the three series of surfaces measured. These analyses were done for both observers separately.

Two observers performed all measurements. To describe the interobserver performance again, the reliability coefficient was calculated. To look for differences between observers, the paired *t*-test was applied. This was carried out separately for both angles and incisor stages.

To find the difference between the surface measured by using digital photographs and the true surface of the button, the diameter of the button was measured using a digital caliper, and its was surface calculated. Then, the difference between the demineralization surface on the tooth and the surface of the button was assessed by the *t*-test. This was done for both stages, both angles, and both observers separately.

To find the difference between the two stages for both angles, a paired *t*-test was applied. In this analysis, the average of the surfaces measured by both observers was used.

RESULTS Return to TOC

General

Of 20 photographed incisors, the images of one tooth were excluded from statistical analysis because of the quality of the picture. Therefore, the statistical analysis was performed on 76 images of bonded and debonded teeth after the demineralization procedure.

Intraobserver Reliability

For the intraobserver measurements, the reliability coefficient varied between .987 and .988 for observer 1 and between .907 and .928 for observer 2. The measurement error was .071 mm^2 for observer 1 and .147 mm^2 for observer 2.

Interobserver Reliability

For the teeth photographed perpendicular to the labial surface, the reliability coefficients between the two observers for both stages were .946 and .945, respectively. The differences detected with a paired-sample test between the measurements of the two observers, on bonded (P = .061) as well as debonded teeth (P = .065), were statistically not significant (Table 1).

For the photographs taken at angle of 110°, the reliability coefficients were .922 and .964, respectively. A paired-sample test showed a statistically significant difference between the measured areas of observer 1 and observer 2 on images of stage I and II (P values are, respectively, .028 and <.001). The areas measured by observer 1 were statistically smaller than those measured by observer 2, but the difference was very small (Table 1).

Comparison of Measurements to True Surface Area

At 90°, the *t*-test for both observers and both stages showed a statistically nonsignificant difference between the measured area on the photographs of bonded teeth and the true size of the white spot lesion. For observer 1, this difference was 0.60 mm^2, and for observer 2, it was 0.73 mm^2 (Table 2). The range for these differences can be read from the 95% confidence interval. At both stages, the difference in the best case is virtually 0, and in the worst case, it approaches clinical significance (1 mm^2). At 110°, no statistically significant differences were found.

Comparison of Stages I and II

To find the difference between the two stages for both angles, the average of the surfaces measured by both observers was used. The difference detected with the paired-sample test between the two averages for 90° and 110° was not significant (P = .099 and .231, respectively; Table 3).

DISCUSSION Return to TOC

This in vitro study was designed to examine the potential for diagnosis and measurement of enamel demineralization lesions around orthodontic brackets by means of the combined use of digital photography and image analysis. Until now, there has been evidence about the reproducibility of measurements performed on scanned photographic slides[16,17] and digital images[18] by computer-assisted analysis of the slides. The use of a digital camera, as suggested by Benson et al,[15] can be advantageous in terms of reducing the variation in image production and time consumed. It is known that enamel demineralization can be quantified by the determination of either the size of the white spot lesion or the amount of mineral loss, as represented by optical properties such as luminance.

A review of the available literature shows that most relevant articles recorded proportional rather than absolute measurements of luminance or size.[17–19,21] Because of the additional need for gray-scale (luminance) calibration and the subsequent discrepancies in the clinical environment, absolute area measurements were elected in the present study. Determination of absolute sizes necessitates the calibration of the image. A ruler fixed in the photographic setting of the study served as an internal standard of image calibration. In our investigation, the perimeter of the white spot lesion was drawn by means of the computer mouse, a procedure that might increase random error. The use of an optical mouse as proposed by Kanthathas and colleagues[19] might eliminate possible tracing errors. However, regardless of all the additional measures taken, the visual assessment by the naked eye always entails a certain degree of subjectivity.

The results of this study for the measurements at 90° showed that both observers were highly compatible. This held true for measurements carried out on bonded and debonded teeth. However, the measured area of the artificially applied demineralization was constantly and significantly larger than the true button surface. Furthermore, the comparison of the measurements at 110° revealed that one observer measured a statistically significantly larger demineralized area than the other observer did.

Nevertheless, the magnitude of this difference appeared to be so small that the clinical relevance is negligible. As the presence of a bracket might hamper the measurement of the demineralization area due to reflection of the metal, we measured the area before and after debonding. The enamel demineralization area measured on teeth at an angle of 110° before and after removal of the bracket was equal to the true surface area. These results are in agreement with those of previous studies that investigated the reproducibility of the application of image analysis for assessment of enamel demineralization on scanned photographic slides of teeth with brackets[17] and without brackets.[15,16]

Based on our results, we can add that the presence of brackets did not influence the results. This is of clinical importance as the clinician will be able to accurately detect the presence of white spot lesions during the orthodontic treatment and, more important, to monitor their progress after taking the necessary preventive measures. Still, it must be kept in mind that the technique was applied for maxillary central incisors and may need to be modified for posterior teeth when carried out in the clinical environment. It should be also taken into consideration that our experimental design was based on the assumption that the entire exposed enamel surface will be uniformly demineralized. Moreover, this in vitro study shows that the angle of camera positioning might not be so critical for the images produced, providing the angulation does not exceed 20° below or above the perpendicular to the labial surface. This parameter may facilitate the application of the method in the orthodontic practice. Future studies should illustrate the aspects of lighting conditions and replication of camera positioning in the clinical environment.

CONCLUSIONS Return to TOC

- The quantification of white spot lesions around orthodontic brackets by means of image analysis of digitally photographed teeth is a reproducible and accurate method.
- Under standardized lighting conditions and camera positioning, this method may be a useful tool for early diagnosis of enamel demineralization during orthodontic treatment.

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TABLES Return to TOC

Table 1. Paired-Sample Statistics Regarding Interobserver Perfor mance for Both Stages and Both Angles (mm^2)

	Stage	Reliability Coefficient	*P* Value	Mean Difference	95% Confidence Interval of Difference
90°	I	.946	.061	0.13	−0.01, 0.26
	II	.945	.065	0.14	−0.01, 0.28
110°	I	.922	.028	0.21	0.03, 0.39
	II	.964	<.001	0.27	0.16, 0.38

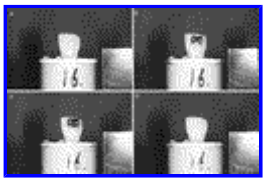
Table 2. Difference Between the Surface Measured by Digital Pho tographs and the True Surface (mm^2)

	Stage	*P* Value	Mean Difference	95% Confidence Interval of Difference
Observer 1				
90°	I	.007	0.60	0.19, 1.01
	II	.011	0.60	0.15, 1.04
110°	I	.440	−0.17	−0.63, 0.29
	II	.151	−0.30	−0.70, 0.12
Observer 2				
90°	I	.002	0.73	0.32, 1.13
	II	.001	0.73	0.36, 1.14
110°	I	.879	0.03	−0.41, 0.48
	II	.907	−0.02	−0.44, 0.39

Table 3. Results of the Paired *t*-Test for the Comparison of Aver age Measurements of Both Observers Between the Two Angles

	P Value	Mean Difference	95% Confidence Interval of Difference
90°	.099	−0.06	−0.13, 0.01
110°	.231	0.07	−0.05, 0.18

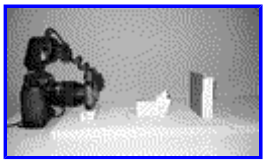
FIGURES Return to TOC



Click on thumbnail for full-sized image.

Figure 1. Photographs of a sample tooth (a) before bracket placement, (b) after bracket placement, (c) after demineralization procedure

and before bracket removal, and (d) after demineralization and bracket removal



Click on thumbnail for full-sized image.

Figure 2. The photograph setting used in the present study

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