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ORIGINAL ARTICLE

Measurement accuracy of marginal bone level in digital radiographs with and without color coding

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Abstract

Objective. New radiographic techniques have made it possible to color-code intra-oral digital radiographs. The purpose of the present study was to compare the accuracy and precision of marginal bone level measurements in digital radiographs with and without color coding. ***Material and methods***. Periapical digital radiographs of 21 patients were processed with and without a color-coding algorithm. The patients had periodontal surgery immediately after exposure of radiographs, and vertical distances from the cemento-enamel junction (CEJ) to the most apical part of the marginal bone were measured clinically. The measured values were considered as a reference standard and subtracted from the corresponding radiographic vertical distance. Seven observers contributed to the radiographic measurements under the same viewing conditions. ***Results***. No statistically significant differences were found between absolute differences of vertical distances obtained from radiographs and their corresponding reference standards in the two types of radiograph. Intra- and inter-observer variability was not significant. ***Conclusion***. Color-coded digital radiographs did not provide a more favorable accuracy when assessing marginal alveolar bone levels than black-and-white radiographs and thus did not improve measurement of such levels.

Key Words: *Computer-assisted, dental, digital radiology, image processing, periodontal bone loss*

Introduction

Intra-oral radiographs are important when assessing and monitoring marginal bone levels [1]. However, radiographic assessment tends to give an underestimation of the height of the alveolar bone, especially when it is affected by inflammatory periodontal disease. With the breakthrough in digital intra-oral radiographic techniques, the manipulation and processing of images has become possible, such that their brightness and contrast can be varied. This advantage should be beneficial in alveolar bone level assessment, but several studies have revealed that underestimation of marginal bone levels is manifest in digital radiographs, too [2–7].

In theory, the human visual system is more sensitive to differences in color than to differences in gray levels in black-and-white images [8]. This is because the number of perceptible colors varying in hue, saturation and brightness far exceeds the number of perceptible shades of gray, which in fact is no more than about 100 for an observer with normal vision [9]. This implies that diagnostic information should be more perceptible in a colored than in a black-and-white radiograph, and that a color-coding method used to replace the black-and-white scale should be favorable. Thus, the aim of the present study was to compare the accuracy and precision of measured marginal bone levels in digital radiographs with and without the application of a color-coding algorithm recently introduced by Shi et al. [9]. The algorithm is applied to replace the gray scale from inherently dark to bright colors by employing dark blue, magenta, red, orange, yellow and white. Our hypothesis was that there is a significant difference between measurements in conventional black-and-white and in color-coded digital radiographs.

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Material and methods

Subjects

Twenty-one patients (ranging in age from 27 to 84 years) with a diagnosis of chronic periodontitis were included in the study. Sites and adjacent sites that could be inspected directly when a surgical flap was elevated were selected. A total of 47 sites were selected, i.e. 22 in the lower and 25 in the upper jaw.

All patients were informed about the procedure of the examination and gave their written consent. The ethics committee at Huddinge Academic Hospital, Huddinge, Sweden, approved the protocol.

Radiographs

Twenty-one periapical radiographs were exposed using the Dixi digital intraoral radiographic system (Planmeca Oy, Helsinki, Finland), which employs a CCD sensor. The dental X-ray unit employed was a FOCUS (Instrumentarium Imaging, Tuusula, Finland) operating at a nominal peak tube potential of 70 kVp and a tube current of 7 mA. To minimize geometric distortion, a paralleling technique was utilized so that the sensor was positioned parallel to the long axis of the teeth; the central ray of the X-ray beam was directed perpendicular to the sensor and the teeth.

Raw data of the digital radiographs were subsequently processed into two sets; in one set the radiographs were processed with correction for exponential attenuation at the exposure and for the response of the human visual system. This algorithm was developed on the basis of two facts: one is that the optical density of the film radiograph is a logarithmic function to exposure, the other is that the visual response of the human visual system is not linearly related to gray levels in an observed radiograph. Thus, the processing algorithm is, in fact, a combination of two algorithms: correction for attenuation and correction for visual response. By applying this combined algorithm, equal steps in object thickness will, in principle, be perceived as equal steps in brightness when a digital radiograph is viewed [10,11]. In the other set, two steps were performed before displaying the radiographs. Raw data radiographs were first processed with the algorithm of correction for attenuation and then followed by a color-coding algorithm, the color scale of which retains increasing brightness of the gray scale and adds an order of colors from inherently dark to bright, i.e. dark blue, magenta, red, orange, yellow and white. Moreover, the response of the human visual system to light intensities was taken into account [9]. Thus, the color-coded radiographs were compensated for both the exponential attenuation at the exposure of a radiograph and the visual response at the viewing. Example radiographs are shown in Figure 1.

Assessment of radiographs

All digital radiographs were displayed on a cathode-ray tube monitor (Nokia 447 PRO; Nokia, Salo, Finland). Prior to viewing, brightness and contrast of the monitor were optimized and pre-set by the investigators using the Nokia Screen Test 1.0. The resolution of the monitor was 1024×768 pixels.

Seven observers experienced in radiographic diagnosis of periodontal bone loss evaluated the test radiographs, but only five assessed all sets. The observers were asked to measure the vertical distance from the cemento-enamel junction (CEJ) to the most apical part of the marginal bone. If the CEJ had been destroyed by restorative treatment, the apical margin of the restoration was used as the landmark. Before the evaluations, each observer was given verbal and written instructions about vertical distance measuring. Measurements were taken in a room with dimmed light with the Program DentalEye (DentalEye AB, Spånga,

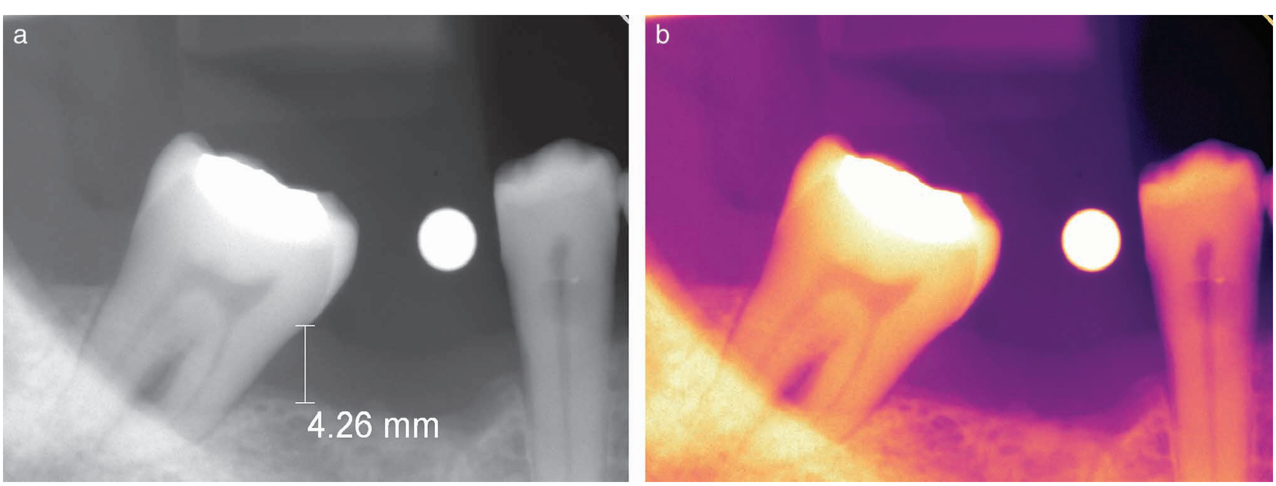

Figure 1. Example of black-and-white (a) and color-coded (b) digital radiographs. A measurement value is indicated in (a).

Sweden), with which linear measurements were made with a mouse-driven on screen cursor. To prevent tiredness, each observer measured only one set of radiographs at one viewing session. For analyzing intra-observer variability, one set of radiographs was re-assessed by one observer 4 weeks later.

Open bone measurement

The patients were operated on immediately after exposure of the baseline radiographs. One investigator (P.E.E.) measured the vertical distance from the CEJ to the most apical level of the marginal bone under complete visual control after that the flaps were raised. The pocket probe used for measurements (UNC 15; Hu-Friedy Manufacturing Inc., Chicago, Ill., USA) was positioned at the bottom level of a pocket. Readings were taken to the nearest millimeter at the CEJ. When the CEJ had been destroyed by restorative treatment, the apical margin of the restoration was used as the landmark.

The clinical measurements were subsequently used as the reference standards and subtracted by the vertical distance from the radiographs. The calculation of differences (D) was expressed as $D = D_S - D_R$, where D_S is a measurement performed clinically during the surgical procedure and D_R a measurement obtained in a radiograph. These calculated absolute differences were employed for statistical analysis. To study the tendency of over- or underestimation in different tooth sites, net differences were also plotted with plus and minus signs (Figure 2). A value with a plus sign is an underestimation of bone level compared to the reference standard, while a value with a minus sign indicates an overestimation.

Statistical analysis

The data from the five observers who completed assessments were used to analyze the accuracy of the respective modality. When analyzing inter-observer variability, the data from the other two observers, who only assessed one set of radiographs, were included as well.

A paired *t*-test was employed for analyzing the effect on measurements of modality, jaw and tooth site. Inter-observer variability was tested using a one-way ANOVA with observers as the independent variable. Intra-observer variability was tested using the paired *t*-test. To analyze the relation between absolute differences and reference standards, linear regression analysis was employed.

Results

Figure 2 shows net mean differences between radiographic measurements and the corresponding reference standards. The values below and above zero represent over- and underestimation, respectively.

Mean absolute differences of measurements obtained during surgery and in radiographs, together with standard deviations as a function of tooth site, are illustrated in Figure 3. Mean differences for the incisor region are higher than those for other regions, i.e. the region of canine, premolar and molar. A significant impact of tooth site on measurements was observed when assessing bone levels in the incisor region ($p < 0.001$), but no significant differences were found for other regions. The difference between measurements of vertical distances in the upper and lower jaw was not significant.

Figure 4 demonstrates the relation of absolute differences and reference standards. A regression

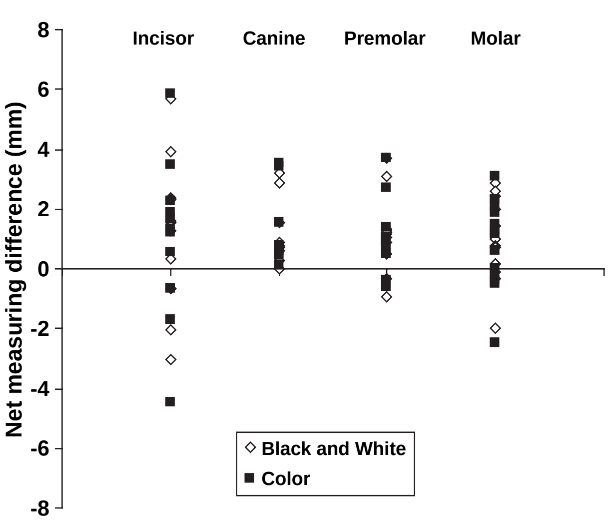

Figure 2. Net measurement differences. The values below zero are for overestimation and those above zero for underestimation.

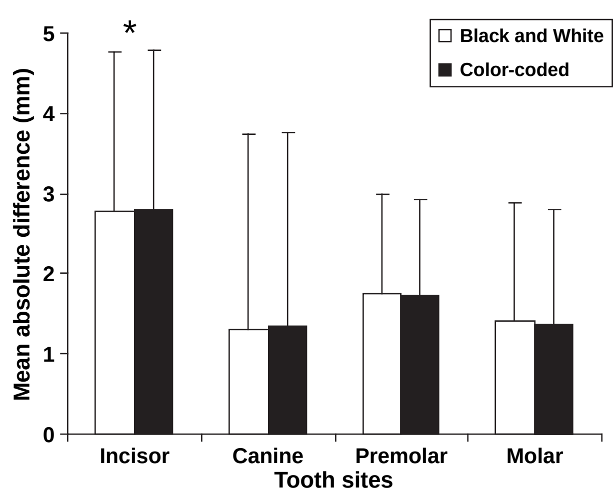

Figure 3. Mean absolute measurement differences and standard deviations for different tooth sites. An asterisk indicates a significant difference compared to the other tooth sites.

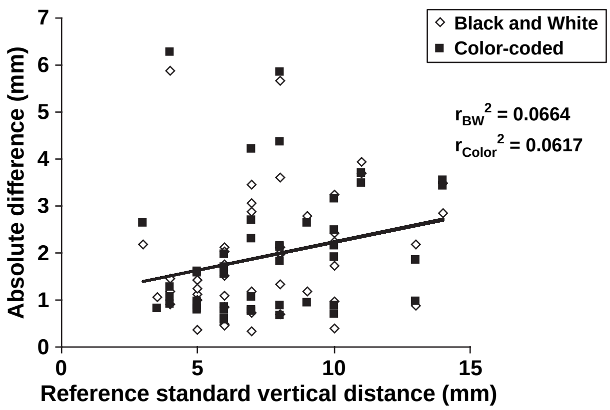

Figure 4. Relation between absolute values of distance differences and clinical reference standards.

analysis gave a r^2 value of 0.0664 for black-and-white and 0.0617 for color-coded radiographs.

No significant difference was found for intra-observer variability ($p = 0.294$). The inter-observer analysis indicated that there was no significant difference among observers except that the measurements of one of the observers were significantly different from those of the other four ($p = 0.049$).

Discussion

The color-coding algorithm was developed in an attempt to improve the perception of digital image characteristics, since, in theory, the number of perceptible colors far exceeds the number of perceptible shades of gray [8,9]. Compared to other approaches to the construction of a color scale, the algorithms used to construct the color scale employed in this study were more advanced. They were featured in three parts. First, the continuous increasing brightness in the gray scale was maintained. Second, colors ranging from inherently dark to inherently bright were added by employing dark blue, magenta, red, orange, yellow and white. Each color in the color scale was constructed by mixing all three primary colors, i.e. red, green, and blue, to prevent a too marked saturation. Third, the response of the human visual system was taken into account. This is non-linear relative to object thickness when a radiograph of an exposed object is viewed [9]. Digital radiographs that are color-coded in this way should in theory keep the advantage of a black-and-white radiograph and add the merits of colors.

It has been demonstrated that colored film radiographs "contain more information than conventional radiographs" [12]. To display digital radiographs with characteristics as similar as possible to film radiographs, the radiographs employed in this study for color coding were processed to compensate for the exponential attenuation at the exposure, which contributes to the radiographic contrast of an exposed object. This compensation largely corrects the display of radiographs so that equal steps in object thickness are perceived as approximately equal steps in brightness [10].

Considering the above, an improvement was expected regarding the accuracy of bone level measurements in color-coded radiographs. The present study, however, shows that there is no significant difference between measurements in color-coded and black-and-white radiographs. Although this concurs with previous studies in which the perception of small contrast details and the diagnostic accuracy of caries were not improved in color-coded radiographs [13,14], the radiographs employed in these two studies were not corrected for exponential attenuation at exposure. The results of this work indicate that the present type of color coding does not provide extra-perceptible diagnostic information over conventional black-and-white radiography. On the other hand, they imply that color-coding radiographs with the presently employed color-coding method may not end in loss of diagnostic information, which to a greater or lesser extent is the case with all color-coding methods that we have found in the literature.

Figure 2 shows net differences of marginal bone level measurements obtained in radiographs and during surgery. There are more values below zero for the incisor region than for the other regions, thus indicating that bone level was more frequently overestimated in the region of the incisors than in the other regions. However, the tendency towards underestimation of marginal bone levels for all tooth sites is also indicated by the results of measurements as illustrated in Figure 2. This coincides with previous studies [2–7].

The effect of the severity of marginal bone loss on the accuracy of linear measurements was also analyzed. The regression between mean absolute differences and clinical reference standards obtained during surgery was low, indicating that the severity of marginal bone loss is not a factor that affects measurement accuracy (Figure 4). This is in contrast to a study by Pepelassi & Diamanti-Kipioti [15] indicating that radiographic measurements of bone levels deviated most from reference standards in cases of severe bone loss, and may be due to the fact that the number of patients employed in the present study was relatively small.

Previous studies have demonstrated that neither the upper nor the lower jaw influences the accuracy of measurements [5,16]. This was confirmed in the present study, but one further finding was disclosed, namely that there is a significant difference between measurements taken in different regions, i.e. at different tooth sites. Measurement accuracy in the region of the incisors is lower than in any other region when measuring vertical distance from the CEJ to the most apical level of the marginal bone. This may be caused by the mathematical method used to present the difference. In the present study, absolute differences of vertical distances were employed for the statistical analysis. This was done intentionally to obviate cancellation of positive and negative values when calculating mean of differences and, therefore, to prevent subsequent reduction in actual differences and irrelevant explanations [17].

Although we did not study the subjective impression of the two types of radiograph, the observers commented that marginal bone levels were easier to locate in color-coded than in black-and-white radiographs. For the eye, the color-coded radiographs were more comfortable than the black-and-white radiographs.

In conclusion, color-coding digital radiographs with such a color scale that brightness, hue and saturation, as well as the response of the human visual system to light intensities, are taken into account does not affect the accuracy and precision of measurements of marginal alveolar bone levels, neither positively nor negatively, compared to measurements in black-and-white radiographs. Thus, for this purpose the presently employed color-coding method may be used to replace the conventional black-and-white scale in digital radiographs.

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