Abstract—Intraoral radiographs have been taken to diagnose periapical lesions. Subsequent endodontic treatment needs to be evaluated quantitatively, that is often difficult due to various imaging factors as well as subjective visual interpretation. Therefore, we sought to establish an image analysis based quantitative model to evaluate endodontic treatments (40 effective and 43 noneffective cases). To normalize an image, the dentin area and the background were used as references. In each pair of images representing before and after treatment, the lesion area was manually selected by experts and segmented by tophat operation. Numerous features representing the effective bone healing were calculated. Using relative differences of selected features, an evaluation model was derived by logistic regression analysis. Gray level intensity and textural differences obtained from lesions significantly increased in the effectively treated cases.

The model provided the accuracy of 80.7%. Our quantitative model may be helpful to evaluate endodontic treatment in clinical settings and in animal studies.

Keywords—dental image analysis; endodontic treatment; periapical lesion; bone remodeling

I. INTRODUCTION

Bacterial infection or extraction of teeth induces inflammatory lesions that represent bone loss in the trabecular bones. Since bacterium infection due to tooth caries or cracks progresses through root canals to the root apex and inflames trabecular bone tissue close to the root apex [1], the bone resorption occurred mostly at the bone tissue close to the root apex but rarely at the one distant to the root apex. Thus, after effective endodontic treatment, the bone remodeling predominantly occurs at the original lesions but not at the tissue distant to the root apex.

Dentists may determine the effectiveness of an endodontic treatment by visual evaluation of intraoral radiographs taken before and after the treatment. However, if a dentist relies on visual interpretation only, he or she may overlook subtle changes of periapical lesions during the bone healing process [2]. Furthermore, intraoral radiographs taken during the treatment can be distorted due to various imaging factors found in X-ray devices such as irradiation angles, exposure times, and electrical voltages to the X-ray source; in the imaging device such as resolution, gain, and position relative to the X-ray source. The confounding effects of these factors may lead to a subjective evaluation of periapical lesion prognosis. Thus, we decided to seek more objective methods and establish a model for periapical bony changes by quantitative image analysis of periapical lesions.

In this study, we hypothesized that bone remodeling could be detected based on both the increased bone density (gray level intensity) and the increased complexity (texture) of the bone structure. The evidence of the bone remodeling could be used as the evaluation of the treatment. Based on the relative changes in intensity, texture, and skeletal features obtained before and after the treatment, we validated the hypothesis and constructed the quantitative model for effective endodontic treatment. The model was further tested on the images representing negative controls sampled at the area distant to the root.

II. METHODS AND MATERIALS

Fifty six patients who had trabecular bone loss due to the lesion or extraction were treated by professional dentists at Wonkwang University School of Dentistry (Iksan, Korea) and approved the use of their radiographs for the study.

Periapical X-ray images were obtained from the CCD sensor (RVG 6100 Digital Radiographic System, Carestream Health, Rochester, N.Y.) with the X-ray source (KODAK 2200 Intraoral X-ray System, Carestream Health, Rochester, N.Y.) operated at 70kV of tube voltage [3]. Eighty three sets of intraoral radiographs were obtained and annotated by experts as effectively treated ($n_{1}=40$) or ineffectively treated cases ($n_{2}=43$). Each set consisted of two radiographs representing different time points after the treatment (average treatment duration: $2.9 \pm 3.5$ months). The resolution of radiographs was set to 520 pixels/cm. To normalize the intensity distribution of each image, we set the sampling area onto the dentin of a tooth closely located to the lesion using the interactive tool that marks the region of interest (ROI) (Fig. 2.A). The modal intensity of the dentin was used as one of two reference intensity values, assuming that the dentin remains invariable in terms of bone remodeling during the treatment. Another reference intensity value was obtained from the background of radiographs. We normalized each image (Fig. 1) using the formula (1) that has been used in a previous study [4]:

$$
\text{normalized intensity} = \frac{\text{image intensity} - \text{background intensity}}{\text{dentin intensity} - \text{background intensity}}
$$
The specificity of this model was further tested using a four-fold cross validation technique. In addition, logistic regression analysis was performed to identify which features were significantly changed after the treatment.

Logistic regression analysis was performed to determine which features were significantly changed after the treatment. The following model was achieved by logistic regression analysis. Our model proposed that relative differences of average intensity of ROI, sum variance, difference entropy, and correlation of Haralick’s texture feature (indicated by Δ) images selected at the area distant from the root apex (n=75) representing negative controls based on the physiological observation that the periapical area of the tissue distant from the root apex was rarely infected.

III. RESULTS

A. Features representing bone remodeling

Intensity features such as average intensity, average trabecular bone intensity, and average bone marrow intensity of ROI were significantly increased in effectively treated cases. Some texture features such as sum average and sum variance were also increased (Wilcoxon pairwise signed rank test, n=40, p<0.001). Significantly changed features are summarized in Table II.

B. Model by four-fold cross validation test

The following model was achieved by logistic regression analysis. Our model proposed that relative differences of average intensity of ROI, sum variance, difference entropy, and correlation of Haralick’s texture feature (indicated by Δ)
were important factors in evaluating the treatment effectiveness.

\[
\text{Effect} = \frac{\exp(\eta)}{1+\exp(\eta)} \\
\eta = -0.548 + 39.97 \times \Delta \text{AIT} - 11.425 \times \Delta \text{SUMVAR} - 9.423 \times \Delta \text{DIFENTR} - 6.123 \times \Delta \text{INFCORR1} \\
\text{(AIT: Average intensity of ROI; SUMVAR: Sum variance; DIFENTR: Difference entropy; INFCORR1: Information measure of correlation 1).}
\]

We computed the performance by implementing four-fold cross validation method. Table III shows the average accuracy of 80.7%.

Furthermore, the model was applied for the verification of negative controls obtained from the periapical area distant from the root apex. Our model correctly predicted 60 out of 75 negative control images (80.0%), which was comparable to our specificity shown in Table III.

IV. CONCLUSIONS AND DISCUSSION

Our hypothesis was that the bone remodeling can be detected by the increase of bone density and the increase of the complexity of the trabecular bone. Thus, we needed to demonstrate that features calculated from the effectively treated cases indeed showed significant changes after treatment in the lesion. Increased intensity features in effectively treated cases such as average intensity, average trabecular bone intensity, and average bone marrow intensity of ROI may be associated with the increase in bone density although the presence of osteoid contents might increase these features in some cases without any increased bone mineralization. Increased texture features such as sum average and sum variance may be associated with the increase in the complexity of the bone structure although sum average and sum variance seemed to be highly correlated to the average intensity (Pearson’s analysis, \( \rho = 0.99 \) for sum average; \( \rho = 0.96 \) for sum variance, \( p < 0.01 \)). Furthermore, relative difference values of texture features such as difference entropy and information correlation type 1 played important roles in our logistic regression model, indicating the complexity of bone structure may be important in evaluating the effective treatment. Thus, we were able to show significant changes occurred during the bone healing process using the quantitative image analysis (Wilcoxon’s test).

Figure 2. Image processing procedures. (A) Original image. The lesion (solid line) and the dentin area (dotted line) are highlighted as ROIs, (B) Tophat operation, (C) Threshold at 4, (D) Trabecular skeleton, (E) Bone marrow skeleton, (F) Result of overlay.
Average intensity of ROI, sum variance, difference entropy, and correlation of Haralick’s texture feature were key descriptors in our model that evaluated the effectiveness of treatment with 80.7% accuracy (Logistic regression analysis). Our results suggest that the relative difference of bone intensity and texture features in the periapical lesion before and after treatment may be used to evaluate the effectiveness of endodontic treatment.

ACKNOWLEDGMENT

We would like to express our great appreciation to Dr. Wan Lee who prepared numerous X-ray images for this project. The correspondence should be addressed to Desok Kim, PhD and Byung-Do Lee, DDS, PhD. This work was supported partly by Ministry of Knowledge and Economy of Korea through Grid Middleware ITRC of Korea Advanced Institute of Science and Technology and partly by Wonkwang University research funds.

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