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Criteria for a Diagnosis of Caries through the DIAGNOdent

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ABSTRACT

Objective: The aim of this study was to investigate the correlation between the demineralization depth measured by dental computed tomography (CT) and the measured value from a non-destructive dental caries diagnosis with a laser. Methods: Optimal cut-off points were obtained for enamel and dentin caries, from the measured levels from a dental caries diagnosis with a laser, to investigate the clinical usefulness of a diagnosis using a laser. Using human teeth, the demineralization depth was measured and the caries were diagnosed by a dental caries diagnosis with a laser. Results: The optimal cut-off point was investigated for accuracy, sensitivity, and specificity, which were calculated from the results. These results demonstrated the correlation between the measured values and demineralization depth in both the pit and fissure caries and smooth surface caries. The optimal cut-off points were found to be 16–21 in the fissure caries and 9–11 in the smooth surface caries.

INTRODUCTION

Caries treatment has mainly been performed by restoring lesions after they have been identified. Recently, preventive treatment is being emphasized, and should be required to find any dental caries and arrest their progress at an early stage. Explorations and diagnoses of dental caries are important for various treatments. Caries is clinically diagnosed by inspection, palpation, and radiography, for example. However, there are some reports in which inspection, palpation, and radiography are subject to the sensations and experiences of an operator, so that the reliability of the diagnosis is low.1–3 Furthermore, there are many problems to such approaches, including exposure to x-ray photography, the remineralization layer being broken by the probes used, and lesions becoming contaminated by bacteria on the probes used.4,5

Recently, a dental caries diagnostic unit—DIAGNOdent—employing a semiconductor laser was developed. This unit irradiates teeth and detects fluorescence generated by carious enamel and dentin. Consequently, it evaluates the scope and degree of dental caries in a noninvasive and objective manner. Reports on the DIAGNOdent show favorable repeatability of caries detections and diagnoses6–8 and significant accuracy9–11 compared to conventional methods for examination.

Recently, dental computed tomography (CT) devices have been developed. As reported by Daasstelaar et al.,12,13 dental CT is optimal for diagnosing and examining hard tissue and surrounding tissues of the cephalic and cervical regions, including jaws, teeth, and oral mucosa, in three dimensions. The device is now beginning to be applied in clinical settings. Dental CT devices can image lesions from any given angles, and they have higher resolution compared to conventional dental x-ray. Therefore, reliability is significantly higher when diagnosing lesions.

Against this background, this study was designed to clarify the effectiveness of DIAGNOdent for dental caries detection in comparison with a dental CT that was clinically applied. Dental caries was diagnosed, and the depth of demineralization was measured with a dental CT scanner. Then, the relationship between the demineralization depth and the DIAGNOdent measurement value was examined. We discuss the clinical utility of DIAGNOdent for diagnosing dental caries by using the
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optimum cut-off point of the DIAGNOdent measurement value to separate the enamel caries from dentin caries obtained for accuracy, sensibility, and specificity.

METHODS

Subject teeth

Subject teeth included fresh human extracted teeth that were diagnosed as requiring extraction. Fifty-one teeth (56 tooth surfaces), identified to be enamel caries and dentin caries by inspection, were used with the consent of the Ethics Committee of Tokyo Dental College. After extraction, dental calculi and deposits on the tooth surface were removed from the subject teeth with hand scalers, and the teeth were measured with the DIAGNOdent.

Principle of the DIAGNOdent

The DIAGNOdent takes advantage of the fact that dental caries generates fluorescent reflections that no healthy tooth generates when irradiated with a laser having a wavelength of 620–670 nm. The output of the built-in laser is 1 mW or less (class 2 laser device). It emits a red laser light with a wavelength of 655 nm via an excited semiconductor. The tooth surface is irradiated through the source light-guiding fiber in the center of the cable. The reflected light-guiding fiber receives the laser light that is reflected by tooth structures. The reflected light is compared to that of sound tooth structures and digitized after analysis. Before any measurement, a calibration is performed by two methods: tooth structures are visually inspected to be sound, and the attached calibrator is used. The measured values are displayed on the screen by calibration in the range of 0–99. The probes include tip A (for fissure caries) and tip B (for smooth surface caries).

Measurement with the DIAGNOdent

The laser caries diagnosis device used in this study was DIAGNOdent (model 2095, serial no. B379875; Kavo). Before measurement, the tooth surfaces were air-blown and dried as much as possible. The device was calibrated with sound tooth structures as needed. Tips A and B were used for fissure caries and smooth surface caries, respectively. The measurement was performed with the tip making contact at a right angle to the tooth surface. The teeth were measured three times at the maximum value, from which the DIAGNOdent values were obtained through their average. After the measurement, the subject teeth were immediately stored in a 10% neutral buffered formalin fixative.

Dental CT scanner photography

The dental CT scanner used in this study was the 3DX MULTI-IMAGE MICRO CT (J. Morita MFG. Corp.; referred to as “3DX” hereinafter). The specifications of the 3DX included a focal spot size of 0.5 mm × 0.5 mm, x-ray tube voltage of 60–80 kV, x-ray tube current of 1–10 mA, and a shooting time of 17 sec. The imaging area was a column-shaped three-dimensional image with a diameter of 40 mm and a height of 30 mm. In this study, radiographs were taken at conditions that included an x-ray tube voltage of 60 kV, x-ray tube current of 1.0 mA, and slice thickness of 0.5 mm, which were appropriate for discriminating the enamel, dentin, and hypocalcified layers. Data after shooting were converted to three dimensions with the Dimension 8100 (Dell Computer Corp., Intel® Pentium IV 1.8 GHz cpu, main memory of 512 MB) and 3DX Integrated Information System software (J. Morita MFG. Corp.), and analyzed. The low-density layers in the radiographic images were defined as dental caries. The direct distance of an area whose image concentration was different from healthy tooth structures was used for the demineralization depth (referred to as “3DX depth” hereinafter) (Fig. 1).

FIG. 1. Measurement by 3DX. The low-density layers in the radiographic images were defined as dental caries. The direct distance of an area whose image concentration was different from healthy tooth structures was used for the demineralization depth.
Diagnostic capability of DIAGNOdent values

In order to discuss the characteristics of diagnosing performance and reliability of the DIAGNOdent measurement values, test teeth were classified into caries index I (group C1) and caries index II (group C2) based on the images obtained by 3DX. Additionally, a given DIAGNOdent measurement value was adopted as optimum cutoff points (referred to as “COP” hereinafter). For example, if COP was set to a DIAGNOdent measurement value of 10, it was expressed as COP = 10. The cases of caries index I with DIAGNOdent measurement values higher than COP were classified into the FC1 group, and the cases of caries index II with DIAGNOdent measurement values higher than COP were classified into the TC2 group. Likewise, the cases of caries index I with DIAGNOdent measurement values lower than COP were classified into the TC1 group, and the cases of caries index II with DIAGNOdent measurement values lower than COP were classified into the FC2 group. Then, the number of test teeth were analyzed (Table 1).

As a result, accuracy = (TC2 + TC1)/(ALL), sensitivity = TC2/(TC2 + FC2), specificity = TC1/(TC1 + FC1), enamel caries predictive value = TC1/(TC1 + FC2), and dentin caries predictive value = TC2/(TC2 + FC1) were statistically tested (Table 2). Further, the relationship between the sensitivity and specificity (i.e., examination accuracy) was analyzed by using ROCKIT (Charles E. Metz, The University of Chicago) in accordance with ROC curve and Az value (area under the curve).

Statistical analysis

Correlations between the demineralization depth and the DIAGNOdent values were analyzed by Pearson’s correlation coefficient. $p < 0.05$ was considered to be statistically significant.

RESULTS

DIAGNOdent values and 3DX depth

Figures 2 and 3 show the Pearson’s correlation coefficient and regression line of the DIAGNOdent values and 3DX depth.

Fissure caries. The DIAGNOdent values included a minimum value of 4 and a maximum value of 45, with an average of 22. The 3DX depth deviated from 0.28 to 3.38 mm. The average was 1.31 mm. The correlation coefficient between the DIAGNOdent value and 3DX depth was $r = 0.651$, with regression line $y = 0.0423x + 0.370$. It was tested by the $t$-distribution. A correlation was observed at a significance level of 5%. Figure 4 shows a 3DX image of fissure caries.

### TABLE 1. 3DX AND DIAGNOdent: CONTINGENCY TABLE (2 × 2)

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<th>Enamel caries by 3DX</th>
<th>Dentin caries by 3DX</th>
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<tr>
<td>Diagnodent &lt; COP</td>
<td>TC1</td>
<td>FC2</td>
</tr>
<tr>
<td>Diagnodent &gt; COP</td>
<td>FC1</td>
<td>TC2</td>
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### TABLE 2. 3DX AND DIAGNOdent for Evaluation

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<tr>
<th></th>
<th>Accuracy</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Enamel caries predictive value</th>
<th>Dentin caries predictive value</th>
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<td></td>
<td>(TC2 + TC1)/(ALL)</td>
<td>TC2/(TC2 + FC2)</td>
<td>TC1/(TC1 + FC1)</td>
<td>TC1/(TC1 + FC2)</td>
<td>TC2/(TC2 + FC1)</td>
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![FIG. 2. Correlation between the DIAGNOdent value and 3DX depth (fissure caries).]
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Smooth surface caries. The DIAGNOdent values included a minimum value of 3 and maximum value of 42, with an average value of 22.48. The 3DX depth was 0.20–1.89 mm, with an average of 1.056 mm. The correlation coefficient between the DIAGNOdent value and 3DX depth was $r = 0.772$, with regression line $y = 0.0323x + 0.330$. It was also tested by the $t$-distribution. A correlation was observed at a significance level of 5%.

![Diagram](image1)

**FIG. 3.** Correlation between the DIAGNOdent value and 3DX depth (smooth surface caries). The DIAGNOdent values included a minimum value of 3 and maximum value of 42, with an average value of 22.48. The 3DX depth was 0.20–1.89 mm, with an average of 1.056 mm. The correlation coefficient between the DIAGNOdent value and 3DX depth was $r = 0.772$, with regression line $y = 0.0323x + 0.330$. It was also tested by the $t$-distribution. A correlation was observed at a significance level of 5%. Figure 5 shows a 3DX image of smooth surface caries.

![Image](image2)

**FIG. 4.** Fissure caries (3DX image). DIAGNOdent value of 44, and 3DX depth of 1.75 mm.
Caries diagnosis by 3DX

Caries diagnostic capability by the DIAGNOdent value. Figures 6–8 show the results of the ROC curve, accuracy, sensibility, and specificity for fissure caries and smooth surface caries. Figures 9 and 10 show the results of the fissure caries or smooth surface caries predictive value.

**ROC curve.** The ROC curve showed fissure caries of $Az = 0.721$, and smooth surface caries of $Az = 0.912$ (Fig. 6).

**Accuracy, sensibility, and specificity.** The accuracy of the fissure caries diagnosis was 0.48 (minimum value) and 0.71 (maximum value) (Figs. 7 and 8). The maximum value of the accuracy corresponded to the scope of COP = 16–21 and 30–35. The accuracy for the smooth surface caries was 0.24 (minimum value) and 0.92 (maximum value). The maximum values of the accuracy were COP = 9 and 11.

**Fissure caries or smooth surface caries predictive value.** The hitting ratio of the DIAGNOdent value = 15 for the enamel caries predictive value is 0.73 (Figs. 9 and 10). The hitting ratio of the DIAGNOdent value = 22 for the dentin caries predictive value is 0.75. Therefore, with regard to fissure caries, DIAGNOdent values smaller than 16 and larger than 21 fall under enamel caries and dentin caries, respectively.

The hitting ratio of the DIAGNOdent value = 8 for the enamel caries predictive value is 1.00. The hitting ratio of the DIAGNOdent value = 12 for the dentin caries predictive value is 0.94. Therefore, with regard to smooth surface caries, DI-
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AGNOdent values smaller than 9 and larger than 11 fall under enamel caries and dentin caries.

DISCUSSION

Presently, DIAGNOdent is being tested on occlusal and smooth surfaces compared with visual inspection, histology, radiography, and quantitative light-induced fluorescence. In this study, we evaluated the usefulness of the DIAGNOdent in the detection of dental caries of occlusal or smooth surfaces defined by the 3DX.

Performance of 3DX

In this study, the minimum measurement value of caries was 0.20 mm. The 3DX provided results with a higher accuracy than the intraoral roentgenograph. Therefore, it is believed that the 3DX can collect enough information for diagnosing dental caries.

Characteristics and effectiveness of caries diagnoses using DIAGNOdent

Correlations between the DIAGNOdent values and demineralization depth. In caries treatments, information about the

FIG. 7.  Accuracy, sensibility, and specificity for fissure caries. The accuracy for fissure caries is highest (0.72) in the range of COP = 16–21 and 30–35. The sensitivity and specificity both show higher values with COP = 16–21. Meanwhile, the accuracy of caries detection is reduced because the sensibility is low with COP = 30–35.

FIG. 8.  Accuracy, sensibility, and specificity for smooth surface caries. The accuracy is highest (0.92) with the COP = 9 and 11 in the smooth surface caries.
degree of progression of caries and the caries activity obtained from diagnoses is important. This is true especially because the caries depth relates to the determination of clinical diagnoses and is an important diagnostic tool for therapeutic strategies of caries.

Anttonen reported that the junction between the enamel caries and dentin caries was DIAGNOdent = 30. Lussi reported that the healthy tooth structure or the primary caries limited to half of the enamel had a score of 0–4, when the caries had expanded to the entire enamel layer it had a score of 4–10, when the dentine caries expanded to half of the dentine it had a score of 10–18, and when the caries expanded to the pulp it had a score of 18 or more in vitro. Furthermore, Lussi reported that caries with a score of 0–13 might require no specific treatment, a score of 14–20 should receive preventive therapies, a score of 21–29 should receive preventive therapies or restorations, and restorations were recommended for a score of 30 or more.

Thus, there have been many different reports about the correlation between the DIAGNOdent values and the progress of dental caries, or the standard of dental caries removal. These different views seem to have resulted in different interpreta-
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Fluctuation factors of the DIAGNOdent value. Based on the Az value, it was suggested that this was a better diagnostic method for smooth surface caries. It is believed that the incidence angle of the laser during the measurement, anatomic complicated morphology of the tooth and deposits on the tooth surfaces related to the low correlation coefficient, efficiency and Az value of the fissure caries. Furthermore, it is said that the measured values are changed by the effects of incidence angles in measurements. It is believed that this is because the laser can not reach the caries existing in fissures and enough diffused fluorescent reflections can not be collected, resulting in reduced DIAGNOdent values. Meanwhile, it has been reported that the DIAGNOdent values get larger when measured with unremoved deposits such as dental calculi. As shown above, special consideration is required with respect to anatomic morphology for the DIAGNOdent value of fissure caries.

DIAGNOdent value and clinical diagnosis of caries

In general diagnoses of caries detection, a higher accuracy means better diagnostic capability. A diagnostic method with higher sensitivity rarely misses lesions and, furthermore, rarely mistakes a healthy part for a lesion. As one of the purposes of this study was to find the optimal cut-off point between the enamel caries and the dentin caries, we made accuracy an important point by defining both sensitivity and specificity with high values. Therefore, the maximum accuracy had priority as a diagnostic criterion of caries. Conditions where both the sensitivity and specificity had higher numeric values were adopted.

The accuracy for fissure caries is highest (0.72) in the range of COP = 16–21 and 30–35. The sensitivity and specificity both show higher values with COP = 16–21. Meanwhile, the accuracy of caries detection is reduced because the sensitivity is low with COP = 30–35. Furthermore, the hitting ratio of the DIAGNOdent value = 15 for the enamel caries predictive value is 0.73 (Fig. 9). The hitting ratio of the DIAGNOdent value = 22 for the dentin caries predictive value is 0.75. Therefore, with regard to fissure caries, DIAGNOdent values smaller than 16 and larger than 21 fall under enamel caries and dentin caries, respectively.

The accuracy is highest (0.92) with the COP = 9 and 11 in the smooth surface caries. The hitting ratio of the DIAGNOdent value = 8 for the enamel caries predictive value is 1.00. The hitting ratio of the DIAGNOdent value = 12 for the dentin caries predictive value is 0.94 (Fig. 10). Therefore, with regard to smooth surface caries, DIAGNOdent values smaller than 9 and larger than 11 fall under enamel caries and dentin caries, respectively. If the measurement value is in the range of the COP, caries should be fully examined, and making comparisons with other diagnostic methods may be important.

CONCLUSION

The purpose of this study was to examine the correlation between the DIAGNOdent value and the demineralization depth, and further, to investigate the optimum cut-off point between the enamel caries and dentin caries. The following results were obtained by discussing the correlation between the DIAGNOdent value and the demineralization depth obtained by 3DX and their respective caries diagnoses.

1. A correlation was observed between the DIAGNOdent value and the demineralization depth at a significance level of 5% for both the fissure caries and smooth surface caries. By this, it was suggested that there was a correlation between the DIAGNOdent value and the demineralization depth.
2. A measurement value of 16–21 was suggested as being the optimum cut-off point of the DIAGNOdent value for fissure caries. Meanwhile, a measurement value of 9–11 was suggested as the optimum cut-off point of the DIAGNOdent for smooth surface caries.

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