Evaluating Occlusal Caries Using a Non-Destructive Micro-CT Examination

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Abstract: This study used micro-computed tomography (Micro-CT) to evaluate occlusal dental caries non-destructively. Twenty-seven extracted molar teeth were scanned using Micro-CT, and 3-D images were reconstructed from the data. The extent of caries was evaluated from images extracted at various angles, and recorded as 2-D images. To assess the validity of Micro-CT, six teeth were randomly selected and cut approximately 100-µm-thick sections in the same plane as that evaluated using Micro-CT. The specimens were examined histologically and with contact microradiograms (CMR). The fine structure was observed using Micro-CT. The Micro-CT image was equivalent to the histological examination or CMR. In all, 78 measuring points in all of the teeth were analyzed using KaVo DIAGNOdent, a laser-based caries-detection device. Spearman's rank correlation coefficient between the DIAGNOdent score and the extent of caries was 0.70, and suggested a good correlation between DIAGNOdent and Micro-CT for examining occlusal caries. The sensitivity and specificity were calculated for DIAGNOdent using Micro-CT as the ‘gold standard’. The sensitivity and specificity for enamel caries were 0.74 and 1.00, respectively. The values for dentin caries were 0.64 (sensitivity) and 0.91 (specificity). These results were similar to those of recent studies using histological examination as the gold standard. We concluded that Micro-CT is useful for non-destructive examination in the evaluation of occlusal caries.

Key Words: Caries detection, DIAGNOdent, Non-destructive examination, Micro-CT

Introduction

Clinically, accurate, reliable diagnosis is important in the early detection of caries. In addition, it is very important to monitor the progression of caries over time and to promote remineralization with minimal intervention. However, it is difficult to detect caries on occlusal surfaces, especially dentinal caries beneath an intact enamel surface 1-3).

Recently, several methods of detecting caries have been introduced and evaluated, including the electrical caries monitor 4-7), digital imaging fibro-optic transillumination 8), quantitative laser/light-induced fluorescence 9-11), and DIAGNOdent (KaVo, Biberach, Germany). DIAGNOdent, a non-invasive system for detecting and quantifying caries, has been the focus of attention 12-16).

A number of studies have evaluated several of these methods; however, the ‘gold standards’ used to evaluate the extent of caries were based on destructive analysis, such as histological examination. Histological sectioning causes tissue loss and irreversible sample destruction. For non-destructive examination, dental X-ray analysis or traditional medical computed tomography (CT) is used. Unfortunately, their resolution is low and not sufficient for evaluating the size of caries lesions properly. Recent reports have found that Micro-CT is suitable for the analysis of biogenic hard tissues, such as bone and teeth, and can observe fine structures 17-19).

Therefore, we evaluated occlusal caries using a non-destructive Micro-CT examination and assessed the validity of Micro-CT as a ‘gold standard’ for detecting occlusal caries.

Materials and Methods

1. Teeth

The material comprised 27 extracted molar teeth that were stored in 10% neutral buffered formalin solution. The teeth were...
retrieved from the formalin solution, cleaned with a toothbrush and polishing paste, rinsed in copious water, and dried with compressed air for about 10 seconds with a three-way syringe. Each of the occlusal surfaces was photographed. Then, two to five measuring points per tooth were chosen (total: 78 measuring points), and marked on the photographs of the occlusal surfaces.

2. Examination for the extent of caries in teeth

The teeth were examined non-destructively using Micro-CT. The scanning procedure was performed using a Micro-CT system (SMX-130CT, Shimadzu Corporation, Kyoto, Japan) under the following conditions: 60 kV; 60 µA; pixel matrix, 512 × 512; slice thickness, 28 µm. Then, 3-D images were reconstructed from the data. The extent of caries at each measuring point was evaluated using images extracted from various angles. The maximum extent of caries was recorded as a 2-D image.

Then, six teeth were randomly selected and cut approximately 100-µm-thick sections in the plane evaluated by Micro-CT. A histological examination was performed using a stereomicroscope. Contact microradiograms (CMR) (Softex Co., Ltd., Tokyo, Japan) were exposed at 7 kV and 2 mA for 20 min using Fuji Film FR. After developing, the films were examined under a stereomicroscope.

The extent of caries on the sliced images obtained from the Micro-CT, histological examination, and CMR was scored on the following scale: 0 = sound; 1 = enamel caries limited to the outer half of the enamel; 2 = caries extending into the inner half of the enamel, but not to the dentino-enamel junction; 3 = caries penetrating the dentino-enamel junction, but limited to the outer half of the dentine; 4 = caries involving the inner half of the dentine.

Figure 1 shows representative two-dimensional images observed with Micro-CT in the same plane as the histological examination and CMR. In the other five specimens, images equivalent to the histological examination or CMR were obtained using Micro-CT. That is, the extent of caries progression diagnosed with Micro-CT was the same as that revealed by the results of the histological examination and CMR in all six specimens.

2. Examination using laser fluorescence device

DIAGNOdent was used with the tapered conical tip designated by the manufacturer for use on occlusal pits. A single examiner performed the measurements. First, the DIAGNOdent was calibrated in accordance with the manufacturer’s instructions. The tip of the instrument was placed on the measuring points perpendicular to the long axis of the tooth and was rotated 360 degrees. The highest value, which ranged from 0 to 99, was recorded. The measuring points were analyzed three times and averaged to give the DIAGNOdent score.

Spearman’s rank correlation coefficient was used to calculate the correlation coefficient between the DIAGNOdent score and Micro-CT examination. The sensitivity and specificity were calculated for DIAGNOdent using Micro-CT as the ‘gold standard’.

Results

1. Examination for the extent of caries in teeth

Table 1. The extent of caries determined by Micro-CT: number of enamel and dentinal caries prevalence

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound</td>
<td>5</td>
<td>6.4</td>
</tr>
<tr>
<td>Enamel caries</td>
<td>59</td>
<td>75.6</td>
</tr>
<tr>
<td>Dentinal caries</td>
<td>14</td>
<td>18.0</td>
</tr>
<tr>
<td>Total</td>
<td>78</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2. Cut-off point, sensitivity and specificity of DIAGNOdent for enamel caries and dentin caries

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>cut-off point</th>
<th>sensitivity</th>
<th>specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel caries</td>
<td>6.93</td>
<td>0.74</td>
<td>1.00</td>
</tr>
<tr>
<td>Dentin caries</td>
<td>25.87</td>
<td>0.64</td>
<td>0.91</td>
</tr>
</tbody>
</table>

The Cut-off point for enamel and dentinal caries were obtained from figure 3. The sensitivity and specificity for enamel and dentin caries were determined by cut-off point of the outer half of enamel and the outer half of dentin.
the DIAGNOdent scores are summarized in Table 1 and Figure 2. At scores between 20-29, the frequencies of enamel and dentinal caries were similar. Below these values, enamel caries predominated, while above these values dentinal caries prevailed.

Spearman’s rank correlation coefficient between the DIAGNOdent score and the extent of caries was 0.70, and suggested a good correlation between DIAGNOdent and Micro-CT for examining occlusal caries. Figure 3 shows the relationships
of between the results of Micro-CT examination and DIAGNOdent score. Exponential functions were used to plot the curves. The cut-off point for enamel caries and dentinal caries were determined from figure 3, in order to calculate the sensitivity and specificity. The cut-off point, and the sensitivity and specificity of DIAGNOdent for enamel caries and dentinal caries are shown in table 2.

Discussion

Generally, histological examination is used as the gold standard when inspecting the extent of caries. A histological examination can observe the extent of caries accurately using a stereomicroscope and microradiography, but the specimens must be sectioned to perform the examination, which can alter the structure of dentinal tissues. In addition, sectioning may not be appropriate if the specimens need to be used for other experiments. Another disadvantage is that assessments using this method observe only the cut surface of the sections, and it is difficult to assess three-dimensional images of caries lesions. Even with three-dimensional reconstruction using serial images, the reproducibility of the reconstruction is low, owing to the limited number of sections cut when the specimens are sliced. Although dental X-ray analysis can observe the extent of caries non-destructively, the analysis is not sufficient for use as a gold standard because the resolution is low. By contrast, Micro-CT is suitable for observing biogenic hard tissues, such as bone and teeth.

Caries involve complex three-dimensional extensions and form various structures. Therefore, Micro-CT is considered more suitable for evaluating caries than X-ray analysis, which produces two-dimensional images and makes observations from only one direction, or a histological examination, which observes only the cut surface of sections.

The Micro-CT system consists of the main imaging apparatus and a computer that performs the calculations. Three-dimensional reconstruction is performed using a maximum of 512 two-dimensional images processed using a three-dimensional image-processing program (TRI/3D-Bone, Ratoc System Engineering Co., Ltd). In this study, Micro-CT was compared with histological examination and CMR. Representative two-dimensional images obtained using Micro-CT, histological examination, and CMR are shown in Figure 1. It is difficult to apply a traditional medical CT device to the stomatognathic system because of the wide scan-pitch and low resolution. However, since Micro-CT can be observed from defined viewpoints, with a precision equivalent to that of a stereoscopic microscope, it can acquire morphological information without destroying specimens. Furthermore, Micro-CT can obtain a picture with a minimal penumbra by moving the object, because it can move the position of the specimen stage and the part examined. The fine structure observed by Micro-CT is equivalent to the results of histological examination or CMR.

In this study, DIAGNOdent was evaluated using Micro-CT as the gold standard. Various studies have compared DIAGNOdent and other caries diagnostic methods using histological examination and CMR as the gold standard. Our results are similar to those of recent studies.

With the development of the concept of minimal intervention, prevention has become an important part of dentistry. Many studies have examined remineralization. Such in vitro studies require non-destructive examination, to enable continuous observation. We conclude that Micro-CT constitutes a useful appraisal method when continuous observation is difficult, but necessary.

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