Abstract: This study evaluated the effectiveness of swept-source optical coherence tomography (ss-OCT) for detecting calculus and root cementum during periodontal therapy. Optical coherence tomography (OCT) images were taken before and after removal of subgingival calculus from extracted teeth and compared with non-decalcified histological sections. Porcine gingival sheets of various thicknesses were applied to the root surfaces of extracted teeth with calculus and OCT images were taken. OCT images were also taken before and after scaling and root planing (SRP) in human patients. In vitro, calculus was clearly detected as a white-gray amorphous structure on the root surface, which disappeared after removal. Cementum was identified as a thin, dark-gray layer. The calculus could not be clearly observed when soft tissues were present on the root surface. Clinically, supragingival calculus and cementum could be detected clearly with OCT, and subgingival calculus in the buccal cervical area of the anterior and premolar teeth was identified, which disappeared after SRP. Digital processing of the original OCT images was useful for clarifying the calculus. In conclusion, ss-OCT showed potential as a periodontal diagnostic tool for detecting cementum and subgingival calculus, although the practical applications of subgingival imaging remain limited.

Keywords: diagnosis; optical coherence tomography; periodontitis; ss-OCT; subgingival calculus.

Introduction

Periodontitis is an infectious, chronic, inflammatory, and tissue-destructive disease that affects periodontal soft and hard tissues. During initial periodontal treatment, mechanical debridement of the periodontally compromised root surface is usually performed to eliminate calcified deposits as well as bacteria and their endotoxins from the cementum to restore the biological compatibility of the diseased root surfaces (1).

Currently, subgingival calculus is most commonly detected through manual periodontal probing utilizing
tactile feedback during examination. Manual detection is occasionally difficult and is mainly dependent on the clinician’s experience and ability. Smith et al. (2) reported that the intra-examiner agreement of subgingival calculus detection was 54.2% for exploratory probing of the root surface in periodontal pockets. Therefore, development of a reliable and objective method to detect subgingival calculus is necessary. Several novel methods have recently been developed to facilitate dental calculus detection (3), including fiber-optic endoscopy (4,5), spectro-optical technology (6-8), and laser-induced autofluorescence (9-11). However, these new technologies are not yet widely employed in the clinic due to a lack of convenience compared to conventional manual probing.

It was previously reported that the presence of adequate remaining cementum after scaling and root planing may be advantageous for periodontal wound healing (12), particularly with regard to tissue attachment and regeneration. The cementum contains various proteins that enhance tissue regeneration (13) and modulate growth and mineral-associated factors during periodontal regeneration (14). Thus, cementum preservation has been recently recommended, and observation of the cementum has become critical during root debridement. Visualization of the cementum layer may also help prevent excessive removal of the cementum and subsequent dentin exposure. However, there are currently no suitable methods for cementum evaluation in dental clinics. Therefore, the development of a novel, non-invasive, and objective imaging system for calculus and cementum observation is required.

Optical coherence tomography (OCT) is a high-resolution, non-destructive optical imaging technique for creating cross-sectional images of hard and soft tissues (15). It was first utilized as a biological imaging system in 1991 (16). The system has since become well-established and widely developed in medicine, especially in the field of ophthalmology (17). In the field of dentistry, there are many reports on the utilization of OCT for tooth and periodontium imaging (18-22). In 1998, Colston et al. (18) first reported the potential application of OCT for visualizing periodontal tissues in vivo and clearly revealed its potential to depict epithelium, connective tissue, and alveolar bone, although the image acquisition time was very long (45 s). Also in 1998, Feldchtein et al. (19) described the OCT imaging of periodontal tissues including the hard palate, soft palate, and vestibular alveolar mucosa with a short image acquisition time of 2-3 s. More recently, Hsieh et al. (21) reported that so-called “swept source” OCT (ss-OCT) imaging of dental calculus in vitro enabled almost real-time imaging, and Lee et al. (20) observed the cementum in OCT images in vitro using polarization-sensitive OCT. Additionally, Park et al. (22) visualized dental calculus ex vivo via OCT images in dogs, and Kao et al. (23) utilized miniature endoscopic OCT for subgingival calculus detection in the clinic.

Despite these recent advances, detailed investigation of subgingival calculus and root cementum via OCT in vitro and in vivo is still insufficient, and only low-quality images have been reported (20-25). In particular, the evaluation of OCT images of cementum is very limited. Optical limits of resolution are dependent on the wavelength and swept band source width, and have not improved substantially in the last few decades, but fewer motion artifacts and high signal-to-noise ratios have enabled the acquisition of fine sectional images. Furthermore, the recently-developed ss-OCT has faster imaging time delay than other OCT systems, resulting in a typical sensitivity advantage of 20-30 dB over previous domain OCT systems (26). Advances in technology over the years have resulted in OCT images that are of better quality and can be acquired much faster than those acquired via previous OCT systems.

The purpose of the current study was to evaluate the present status and the potential of ss-OCT as a tool for detecting subgingival calculus and root cementum in vitro and in the clinic.

**Materials and Methods**

**OCT system**

Two kinds of ss-OCT systems (Santec IV-2000, Santec, Komaki, Japan; Prototype 2, Panasonic Health Care, Ehime, Japan) employing frequency (Fourier) domain techniques with a tunable light source were used (Fig. 1). The center wavelengths and bandwidths of the scanning lasers were 1,310 nm/100 nm for IV-2000, and 1,330 nm/100 nm for the Prototype 2. The IV-2000 system consists of a high-speed scanning frequency-swept external cavity laser and interferometer unit, a scanning probe, and a personal computer (Fig. 1E). The illumination power of the sample arm is 0.8 mW, and the power of the reference arm is 0.6 μW. A balance detector is utilized for interference detection, and a data acquisition card is used for computer-photodetector interfacing. The system incorporates a hand-held probe to set appropriate distances from the samples (Fig. 1C, D). The output power is <5 mW, which is within the safety limit for class I laser instruments as defined by the American National Standards Institute. The electric signal acquisition rate is 100 MS/s.

Experimental data were collected and analyzed using image analysis software (ImageJ version 1.47V; Wayne

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The light beam from the laser source was projected onto the sample and the area of interest was scanned using the hand-held probe. Backscattered light relaying information about the microstructure of the sample was collected, returned to the system, digitized on a time-scale, and analyzed in the Fourier domain to reveal the depth of the sample.

Sample collection
In the present study, periodontally-involved teeth with subgingival calculus were used. These teeth had been extracted from patients who visited the Tokyo Medical and Dental University (TMDU) Dental Hospital due to advanced periodontitis, after obtaining informed consent. After extraction, the teeth were stored in water at 4°C.

Calculus and cementum detection via OCT in vitro
Six extracted teeth with subgingival calculus and without apparent caries lesions or defects on the root surface were utilized. The teeth were divided into an ultrasonic scaler group \( (n = 3) \) and a hand curette/scaler group \( (n = 3) \).

In order to evaluate OCT images of fundamental anatomical structures and subgingival calculus, an OCT image parallel to the apico-coronal axis of the tooth was taken before scaling. Each sample was fixed on a three-dimensional translation stage. OCT imaging was performed by scanning the root surface including the visible calculus, the cementenamel junction (CEJ), and other characteristic structures used as landmarks, with the probe fixed in a stand. After OCT acquisition, an experienced periodontist (S.O.) removed the subgingival calculus using an ultrasonic scaler (Varios 750, Nakanishi, Kanuma, Japan) or a hand curette (mini-Five SAS7/8R, Hu-friedy, Chicago, IL, USA). When the hand curette was used, root planing was also performed. After subgingival calculus removal, OCT imaging was conducted again at the same position.

After the experiment, the crown and apex of the teeth were dissected and notches were made in both the coronal and apical ends of the samples indicating the scanning line for OCT evaluation. For preparation of the non-decalcified specimens, the teeth were fixed in formalin solution, dehydrated in serial concentrations of ethanol, then embedded in methyl methacrylate resin. After 3 weeks of polymerization at 35°C, the resin blocks were trimmed and cut. For each tooth, based on the notches prepared for section analysis, one mesiodistal section parallel to the long axis of the tooth was carefully prepared with a micro-cutting machine (BS-3000, EXAKT, Norderstedt, Germany). The thickness of the section was then reduced to approximately 20-25 μm via polishing with a micro-grinding machine (MG-400, EXAKT). The histological section was stained with toluidine blue. All histological sections were analyzed under a light microscope (Eclipse E800, Nikon Inc., Tokyo, Japan) equipped with a computerized image analysis system (Image-pro Plus, Media Cybernetics, L.P., Silver Spring, MD, USA).

Influence of gingival soft tissue over calculus on the OCT image in vitro
In order to examine the influence of soft tissue overlying the calculus on OCT imaging, rectangular porcine gingival sheets of approximately \( 10 \times 10 \) mm were prepared from the mandible of a pig that had been sacrificed for alimentary purposes. Four gingival sheets of different thicknesses were carefully prepared by slicing the connective tissue surface using a scalpel. Gingival sheet thickness was measured using a digital vernier caliper without applying pressure to the tissue surface.
The prepared sheets were then kept in a moist condition until they were imaged via OCT. First, the site of the tooth root surface with a band of calculus suitable for scanning was identified. The teeth and probe were then fixed. OCT images were taken before and after placing the gingival sheets of various thicknesses on the root surface.

**Calculus and cementum detection via OCT in human patients**

*Supragingival calculus and root cementum detection*

A patient who was receiving periodontal treatment at the Dental Hospital of TMDU Department of Periodontics provided informed consent to participate in this part of the study. OCT images of a tooth with supragingival calculus were taken before and after scaling.

*Subgingival calculus detection*

Five patients provided informed consent to participate in this study. In total, eight teeth with rough root surfaces as determined via pocket probing on the buccal side were selected. Subgingival scaling and root planing were performed using a hand curette by one experienced periodontist (A.A.). OCT images were taken before and after root debridement to evaluate the subgingival root surface. The scanning site was confined to the midbuccal region of each tooth in the horizontal direction and parallel to the tooth axis in the vertical direction.

One examiner (A.A.) evaluated the OCT images of the cervical area. The presence of a white-gray mass area on the root surface, which is considered to reflect subgingival calculus, was rated as A, B, or C based on the degree of intensity and clarity of the white-gray area. “A” was recorded when there was an identifiable gray mass area under the gingiva, “B” was recorded if a gray mass area could be seen but the image was not clear, and “C” was recorded if there was no discernible gray mass area.

In addition, the horizontal distance from the gingival surface to the surface site as well as the deepest site of the calculus were measured at the center point between the upper and lower ends of the calculus, to obtain an estimation of the capacity to detect calculus depth in human gingiva. The depth length was dubbed the “optical path length,” and the actual length was calculated by dividing it by the refractive indices of human gingiva and calculus.

**Modification of OCT images for clarification of calculus detection**

To clarify the presence of calculus in OCT images, a two-tone effect was applied to the original OCT images via image analysis software (ImageJ). The threshold of the tone was determined manually and was set as low as possible to reveal the internal gingival structure. A tracing tool was then utilized in the center point of the mass depicted below the gingiva to outline the mass. The tracing tool was set with no tolerance, meaning that the outlined area consisted only of adjacent dots. These experiments were approved by the Ethics Committee of the TMDU Faculty of Dentistry (No. 527 and 777).

**Results**

*Calculus and cementum detection via OCT in vitro*

Photographs, OCT images, and photomicrographs of histological sections of the root surfaces of extracted teeth with the same magnification before and after root debridement with a curette (A-E) or an ultrasonic scaler (F-J). Red lines indicate the sites where OCT images were taken. A, D, F, I. Photographs of the root surface before and after calculus removal. B, G. OCT images before root debridement. The roots exhibited rugged surfaces with white-gray protrusions. C, H. OCT images of root surfaces after root debridement. The white-gray amorphous structures disappeared and the root surface exhibited a smooth appearance and a remaining cementum layer. The image of the dark-gray cementum layer underlying the removed calculus was obtained after debridement. E, J. A histological section stained with toluidine blue after root debridement derived from the same location as the OCT examination. The cementum is clearly depicted as a thin, darkly stained layer on the root surface. En: enamel, De: dentin, CEJ: cementoenamel junction, SbC: subgingival calculus, Ce: cementum.

Fig. 2  Representative photographs, OCT images, and photomicrographs of histological sections of the root surfaces of extracted teeth with the same magnification before and after root debridement with a curette (A-E) or an ultrasonic scaler (F-J). Red lines indicate the sites where OCT images were taken. A, D, F, I. Photographs of the root surface before and after calculus removal. B, G. OCT images before root debridement. The roots exhibited rugged surfaces with white-gray protrusions. C, H. OCT images of root surfaces after root debridement. The white-gray amorphous structures disappeared and the root surface exhibited a smooth appearance and a remaining cementum layer. The image of the dark-gray cementum layer underlying the removed calculus was obtained after debridement. E, J. A histological section stained with toluidine blue after root debridement derived from the same location as the OCT examination. The cementum is clearly depicted as a thin, darkly stained layer on the root surface. En: enamel, De: dentin, CEJ: cementoenamel junction, SbC: subgingival calculus, Ce: cementum.
The OCT images of extracted teeth clearly revealed fundamental anatomical structures including enamel, dentin, cementum, and the CEJ or dentinoenamel junction. In vitro, calculus was clearly identifiable as a bright-gray or white-gray amorphous structure, and cementum was identifiable as a thin dark-gray layer that was darker than the underlying dentin (Fig. 2B, G). Before scaling, the OCT images of the root surfaces depicted rugged surfaces with whitish protrusions and smooth surfaces with cementum (Fig. 2B, G). Internal structures below the calculus could be detected in some cases (Fig. 2G), but not in others (Fig. 2B). After scaling, the whitish structures disappeared and the root surfaces appeared smooth (Fig. 2C, H). The cementum layer under the calculus was not visible before scaling due to the optical noise produced by the calculus; however, the layer could be visualized after scaling (Fig. 2C, H). A thin dark-gray layer on the OCT image (Fig. 2C, H) coincided with the cementum layer visible in the histological sections (Fig. 2E, J). On root surfaces treated with a curette and those treated with an ultrasonic scaler, the cementum layer was mostly present except in the cervical area; however, the curette-treated surfaces generally exhibited less thick cementum and broader exposure of dentin. One of the curette-treated root surfaces exhibited marked exposure of dentin, suggesting that the root planing procedure may have resulted in the loss of cementum. In cases subjected to ultrasonic scaling, exposure of dentin was limited to the cervical area.

Influence of gingival tissue over the calculus on OCT imaging in vitro

Before the adaptation of porcine gingiva, a clear and distinct white/gray-colored protruding structure was evident on the root surface (Fig. 3A, B). Upon coverage of the root surface by gingival soft tissue, the calculus image became unclear, and it became progressively more unclear with increased gingival thickness. After the adaptation of a gingival sheet with a thickness of 0.38 mm, the whitish protrusions became unclear but were still visible (Fig. 3C). At a thickness of 0.50 mm, the protrusions were slightly visible (Fig. 3D), but at thicknesses of 0.81 mm and 1.40 mm, the protruding structures could no longer be detected (Fig. 3E, F, respectively).

Calculus and cementum detection via OCT in human patients

Figure 4 shows a representative OCT image of cervical periodontal tissues with subgingival calculus. Figures 4B-E represent the corresponding original A-scan data for each position in Fig. 4A. The A-scan is a graph of depth (mm) and signal intensity (dB) at a single point on the surface. The signal intensity is expressed as a gray-scale shade in the B-scan (OCT image) using a look-up table. The border between white and black in signal intensity was set at approximately 8 dB. The two-dimensional OCT image is composed of the A-scan data for every point on the scanned line. The evaluation was made based on the existence of a white layer with
strong intensity between the root surface and the gingiva surface.

At the position labeled No. 1 in Fig. 4A, cementum was observed as a relatively dark area surrounded by white lines, indicating the surfaces of cementum and dentin (Fig. 4B). At the position labeled No. 2, gingiva, root surface, and cementum were observed (Fig. 4A, C). At the position labeled No. 3, calculus was observed as a white-gray structure on the root surface, and cementum was not visible due to light attenuation during gingival penetration (Fig. 4A, D). At the position labeled No. 4, only gingival tissue was observed and the root surface was not visible (Fig. 4A, E).

Figure 5 shows representative OCT images of a tooth’s cervical area before and after treatment (scaling alone or scaling and root planing). Gray structures similar to those visualized in the in vitro experiments were detected in human patients via OCT imaging (Fig. 5).

**Supragingival calculus and cementum detection**

Figure 5A is a representative OCT image of supragingival calculus. Clinical photographs and OCT images with the same magnification were aligned in the same position. Before debridement, a white-gray mass area was clearly identifiable on the OCT image, and a dark-gray cementum layer was visible on the exposed root surface. After supragingival debridement, the white-gray mass area disappeared and the underlying dark-gray cementum layer was clearly visible on the treated root surface.
424

Subgingival calculus and cementum detection

Among the eight anterior and premolar sites evaluated in the five patients, subgingival calculus was detected at seven sites via OCT. Subgingival cementum was occasionally detected in the marginal area. Calculus removed during debridement was confirmed at 6 of the 7 OCT-positive sites (Table 1).

![Figure 5B](image1)

**Table 1** Evaluation of subgingival calculus using OCT images

<table>
<thead>
<tr>
<th>Case number</th>
<th>Patient</th>
<th>Tooth number</th>
<th>Root surface roughness</th>
<th>Presence of removed calculus</th>
<th>OCT evaluation</th>
<th>Imaging depth to calculus</th>
<th>Imaging depth to root</th>
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</thead>
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<tr>
<td>1</td>
<td>1</td>
<td>13</td>
<td>+</td>
<td>+</td>
<td>A</td>
<td>0.51</td>
<td>0.66</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>13</td>
<td>+</td>
<td>+</td>
<td>A</td>
<td>0.88</td>
<td>0.98</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>12</td>
<td>+</td>
<td>+</td>
<td>A</td>
<td>0.76</td>
<td>0.98</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>23</td>
<td>+</td>
<td>+</td>
<td>B</td>
<td>0.58</td>
<td>0.67</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>43</td>
<td>+</td>
<td>+</td>
<td>B</td>
<td>1.07</td>
<td>1.15</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>23</td>
<td>±</td>
<td>+</td>
<td>C</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>24</td>
<td>+</td>
<td>–</td>
<td>B</td>
<td>1.02</td>
<td>1.21</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>43</td>
<td>+</td>
<td>+</td>
<td>A</td>
<td>0.79</td>
<td>0.89</td>
</tr>
</tbody>
</table>

“Presence of removed calculus” refers to the detection of removed calculus during debridement: “+” indicates that it was clearly observed; “±” indicates that debris was removed, but calculus was not detected; and “–” indicates that no solid substance was removed. A, Calculus was clearly detected as a white-gray substance; B, A white-gray substance was imaged but not clearly detected; C, Not detected; OCT, optical coherence tomography.

![Fig. 6](image2)

Subgingival calculus was detected. The exposed root surface was apparent in the coronal area, indicating gingival recession. A gray structure was clearly visible on the root surface in the supragingival area, as was cementum. The gray structure disappeared after debridement.

Imaging depth was determined by measuring the horizontal distance from the surface or the deepest site of the calculus to the gingival surface. The actual depth was calculated by dividing the original value by the refractive index of human gingiva at a wavelength of 1,330 nm (1.397 ± 0.008) (27) and the refractive index of calculus at a wavelength of 1,310 nm (2.097 ± 0.094) (21). The actual imaging depths calculated were 0.80 ± 0.20 mm (mean ± SD, n = 7; range, 0.51 to 1.07 mm) to the surface.
of the calculus and 0.93 ± 0.20 mm (mean ± SD, n = 7; range, 0.66 to 1.21 mm) to the deepest point of the calculus (Table 1; Fig. 6B-D, a).

Modification of OCT images for clarification of calculus

After the modification of original OCT images via two-tone processing, the presence of calculus became more distinct (Fig. 6A-D, c) compared to the original gray mass images (Fig. 6A-D, a). Two-tone processing was conducted manually using a threshold method based on the brightness value. The threshold value was set at the lowest value at which the internal structure of gingiva could be identified (brightness value = 40.5 ± 8.2 [mean ± SD, n = 4] of a maximum of 255). Cementum also became clearer (Fig. 6A, e) after two-tone processing compared to the original image (Fig. 6A, b). Auto-outlining enhanced the visualization of calculus (Fig. 6A-D, d).

Discussion

In general terms, an OCT system determines the signal level derived from a reflected light source, and translates the signal into a gray-scale image via a look-up table. Using the backscattered light, the characteristics of the object are determined based on its refractive index and internal reflection. Meng et al. (28) reported that the respective refractive indices of enamel, dentin, and cementum were 1.63, 1.54, and 1.58. These differences in refractive indices result in a strong reflection at the boundary of two different adjacent tissues. The boundary line is depicted as a white line, making it easy to distinguish different adjacent tissues.

In the current OCT study, tissue structures appeared from whiter to darker in the following order: calculus, dentin, enamel, and cementum. A whiter structure in an OCT image indicates increased reflection of light from the tissue, and less transparency. The image of internal enamel structures is monotone, while that of dentin is shaded. Hariri et al. (29) reported the difference between the absorption of enamel and dentin in 1,310-nm OCT images. They reported that the appearance of enamel was monotone, but that of dentin differed according to the orientation of dentinal tubules.

Lee et al. (20) previously reported that cementum appears as a transparent layer under polarization-sensitive OCT. In contrast, in the present study, cementum was depicted as a thin dark-gray layer surrounded by two white lines, indicating strong reflections from the surface of the cementum and from the boundary between the cementum and dentin.

Calculus, which has an internally heterogeneous structure, appears whiter than other periodontal tissues in OCT images. Hsieh et al. (21) reported that calculus exhibited a stronger signal intensity in OCT images than other periodontal tissues, and appeared whiter. Calculus is much less transparent than other periodontal structures, and sometimes light cannot penetrate through it. Therefore, as observed in the present study, images of structures beneath calculus may not be clearly constructed via OCT in vitro, and what is seen is either a black image resulting from a lack of information, or a white-gray image resulting from halation created by a strong reflection of light scattered by calculus.

In the present study, ss-OCT was employed and generated clearer and more detailed OCT images of calculus than those presented in previous reports (21). The intense white-gray image of calculus disappeared after the removal of the calculus in vitro, and the underlying structures, such as the root cementum and dentin, became clearly evident in the OCT images. We compared these OCT images with histological sections and found considerable correspondence between the OCT images and histological sections.

When calculus on the root surface was covered with a porcine gingiva sheet, the OCT image became unclear due to the strong light-scattering effect of gingival tissue, even though the calculus was still observed as a whitisht structure. In the present study, subgingival calculus was still slightly detectable under a gingival thickness of 0.50 mm or less; however, the structure could not be recognized when the thickness was increased to 0.81 mm and above. Hsieh et al. (21) reported that the upper limit of gingival thickness for calculus detection was 0.80 mm in their in vitro study, which incorporated porcine gingiva. However, in the current in vivo study, the mean imaging depth to the subgingival calculus through the gingiva was 0.80 mm on average, and the maximal value was 1.07 mm. The difference between the imaging depth capability in vitro and in vivo may be attributable to differences in the optical characteristics of dead porcine and live human gingival tissues.

In the present study, supragingival calculus was clearly visible in OCT images taken in the clinic. Subgingival calculus could be identified in vivo as a blurred gray structure on the root surface under gingival tissue, and we could clarify the presence of calculus by using two-tone processing, as well as auto-tracing of the area. Detection of subgingival cementum was limited, but supragingival cementum on the exposed root surface could be clearly visualized. Thus, with regard to cementum, OCT can be useful for detecting supragingival cementum, as well as...
subgingival cementum on root surfaces that have been surgically exposed.

Several new technologies are currently available for calculus detection; however, these technology-assisted treatments have not yet demonstrated clinical superiority in comparison with conventional systems (3,30). Fiber-optic endoscopy-based technology is utilized in one device (Perioscopy, Perioscopy Inc., Oakland, CA, USA) for real-time visual detection (3,30). The system consists of an endoscope fiber within a probe, which is directly inserted into the periodontal pocket (5). Compared to the OCT system, this system has the benefit of providing visual feedback from the actual image of subgingival calculus during root debridement. However, the system’s relatively thick probe occasionally limits its insertion into periodontal pockets, and cementum detection is not possible. Spectro-optical technology uses a light-emitting diode and fiber-optic technology. The system employs the production of a characteristic spectral signature caused by absorption, reflection, and diffraction of red light irradiated on the subgingival calculus (3,30). The autofluorescence approach detects fluorescent light from calculus following irradiation with light of a certain wavelength (Diagnodent Pen, KaVo, Biberach, Germany). In a preclinical situation, the system’s superior effect was demonstrated on molars (31). The ultrasonic calculus-detection device is based on a conventional piezo-driven ultrasonic scaler (Perioscan, Sirona, Bensheim, Germany). The system assesses oscillation signals from the reaction of the root surface to low-power square pulses via a conventional working tip (32). Unlike the OCT system, these systems require direct insertion of the probe into periodontal pockets. Although these systems differentiate calculus deposits from the root surface (cementum) by receiving characteristic signals from the calculus that differ from those of the root surface, they cannot specifically identify cementum itself, unlike the OCT imaging system.

In contrast to the aforementioned technologies, the OCT system employs a non-contact method and enables non-invasive, high-resolution, real-time analysis. These qualities make it ideal as a new tomographic diagnostic system for use in periodontal therapy. It can facilitate detailed visualizations of the inner periodontal area covered by gingiva, without the hazards associated with repeated radiation exposure. In the current study, the detection of root cementum and subgingival calculus in vivo was possible via the ss-OCT system, but the observable subgingival region was restricted to the buccal marginal gingiva, which has relatively thin tissue in the anterior and premolar teeth. This restriction was due to the limited imaging depth of the current system. The possibility of direct depiction of subgingival calculus within periodontal pockets via a miniature endoscopic OCT system was recently reported (23).

In the near future, the first dental OCT apparatus will be commercially available in Japan. The OCT system is expected to be expensive and the cost-benefit with regard to calculus detection may not be favorable because of the limited number of sites where OCT can detect calculus. Notably however, the system is fundamentally useful and effective in other fields, such as for the visualization of dental caries, tooth fractures, and oral soft tissue lesions. Thus, the total cost-benefit of the OCT apparatus will improve considerably with increases in its potential utilization in various dental applications. Because the ss-OCT system has the capacity to transmit imaging data in real-time (or very close to it), the possibility of real-time monitoring of subgingival calculus and/or root cementum during non-surgical and surgical root debridement should also be examined in future studies.

In conclusion, the ss-OCT system may constitute a periodontal diagnostic tool with the capacity to detect subgingival calculus and root cementum. Although subgingival imaging is still limited in practice due to low imaging depth capability, the detection of root cementum on the surfaces of exposed roots via ss-OCT may be feasible.

Some of the results of this study were presented at the 98th American Academy of Periodontology Annual Meeting held in Los Angeles from September 29 to October 2, 2012.

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Conflict of interest
The authors have no potential conflict of interest to declare.

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