Dental diagnosis for inlay restoration using an intraoral optical coherence tomography system: A case report

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Abstract

Patients: The patient was a 32-year-old man who underwent amalgam restoration of the mandibular right second molar. An amalgam restoration fracture was diagnosed by intraoral optical coherence tomography (OCT), and pulp exposure was examined during cavity preparation. Subsequently, a definitive ceramic restoration was fabricated, and the marginal fit in the oral cavity was evaluated using the OCT system.

Discussion: The existing OCT system cannot acquire images inside the oral cavity because of the large probe size. However, the proposed intraoral OCT system can access the prostheses in the mandibular right second molar. Therefore, dental diagnosis for restoration treatment with dental prosthesis fracture, marginal gap, and pulp exposure after tooth preparation is possible using the proposed intraoral OCT system.

Conclusions: The use of the intraoral OCT system improved dental diagnosis by allowing the dentist to confirm quantitative values through cross-sectional images, rather than that by determining a treatment plan after visual dental diagnosis.

Keywords: Optical coherence tomography; Dental diagnosis; Cross-sectional image; fixed dental restoration

1. Introduction

Visual and X-ray imaging examinations are performed by dentists for dental diagnosis[1–3]. Radiographic images obtained using X-ray and cone-beam computed tomography are suitable to make an overall diagnosis of the oral cavity[4]; however, providing a detailed diagnosis inside the oral cavity for each tooth is difficult because of the low resolution (voxel size, 200–400 µm) and limitations in the imaging direction[5,6]. Thus, a dental medical device capable of directly diagnosing the oral cavity is being developed and investigated[7,8]. Quantitative light-induced fluorescence in the oral cavity can be used to directly diagnose dental caries and cracked teeth[9,10]. Studies have also evaluated the degree of inflammation at implant sites and dental caries using ultrasonography[11,12]. However, the reliability of the diagnosis requires a consensus.

Optical coherence tomography (OCT) has been proposed as a nonradiative and noninvasive method for dental diagnosis[13,14]. OCT is a measurement method which acquires high-resolution two- or three-dimensional images from optical scattering media using coherent light[15]. OCT systems have mainly been used to diagnose pathological changes in the retinal layer, optic nerve, and skin diseases[16,17]. An OCT system can also be used to diagnose dental caries[18], cracked teeth[19], exposure of the pulp chamber according to the residual dentin thickness[20], and marginal and internal fit of ceramic prostheses[21,22]. However, in vivo diagnosis of the oral cavity is difficult because of the large size of the OCT probe; thus, only an in vitro study (outside the oral cavity) is possible. Although a prior study showed that the gingival sulcus could be measured in the oral cavity using an OCT system, because of the large size of the OCT probe, it was evaluated only at a specific location in the anterior region that was easily accessible[23]. Therefore, to use the OCT system directly in the oral cavity, application methods for an intraoral OCT system are required. This clinical report presents an application case for the...
diagnosis of inlay restorations using an intraoral OCT system that can access the oral cavity from any position.

2. Outline of the case

A 32-year-old man (K.S.) presented to the clinic following diagnosis of a mandibular right second molar. In 2009, he was directly treated with amalgam material for caries on the occlusal surface of the mandibular right second molar. Recently, he reported soreness when brushing his treated teeth. During the clinical examination, fractures were observed on the lingual side of the amalgam-restored prosthesis (Fig. 1). Other than lingual fractures, no other abnormalities were observed on the periapical radiograph (Fig. 2). Treatment planning involved the removal of the amalgam restoration, and restoration with a ceramic inlay.

We used an SD-OCT system designed using a 50:50 fiber coupler and a super-light-emitting diode (EXS210068-01, Exalos), with a central wavelength of 840 nm and a bandwidth of 50 nm. An intraoral OCT scanner was designed to diagnose the amalgam-restored prosthesis, as shown in Figure 3. The overall dimensions of the scanner were 41 mm × 320 mm × 64 mm (width × length × height), while the intraoral diagnostic tip measured 19 mm × 89 mm × 18 mm, similar to the size of a commercial oral scanner. The internal structure consists of a collimator, a microelectromechanical system (MEMS) scanner (A8L2.2, Mirrorcle) with a 5 mm diameter mirror, a focus lens, and mirrors. The essential design involves the placement of a small mirror between the collimator and MEMS scanning mirror to reduce the angle of incidence from 45 ° to 20 °, forming a Z-shaped optical path. This design improved the usable diameter of the incident beam by 32.89% (from 3.5355 mm to 4.6985 mm). From this, we secured a scanner that could use all 3.99 mm beam diameters of the collimator (F280FC-850, Thorlabs). The optical depth resolution of the system was 6.227 µm, based on the characteristics of the light source, and the optical lateral resolution was 40.208 µm from the focusing lens, light source, and collimator used in this system.

We measured the actual length of one pixel in the OCT tomographic image to determine the size of the subject from the OCT cross-sectional image. First, to measure the depth direction length of the pixel, we placed a 1 mm-thick slide-glass on an anodized aluminum plate and measured the step. We obtained the pixel numbers from the air to the aluminum plate, from the air to the slide glass surface, at the bottom of the slide glass, and through the slice glass to the aluminum plate by A-Line analysis. Thus, we obtained a refractive index of 1.5213 for the slide glass. We confirmed that the depth direction length of one pixel was 5.3192 µm from the measured refractive index of the slide glass and thickness of the slide glass. The horizontal length of a pixel is determined by the number of A-lines in the image and scanning range. Therefore, whenever the scanning range was changed, we imaged an interval of a Vernier caliper from 200 µm to 500 µm in increments of 100 µm, and the average value of each of the 100 images was used as the horizontal length of one pixel.

An intraoral OCT system with a small tip size, similar to a commercial intraoral scanner, was employed in this study, which can be easily used in the oral cavity. An investigator (K.S.) directly acquired the cross-sectional images of the oral cavity (Fig. 4). The depth (1.04 mm) and width (0.65 mm) of the fractures in the amalgam-restored prostheses were measured (Fig. 5A). The marginal fit (0.92 mm) of the amalgam-restored prosthesis was also evaluated (Fig. 5B). The mean marginal gap was calculated at 22 randomly selected positions in the amalgam-restored prosthesis, and an inaccurate marginal gap (0.76 ± 0.26 mm) was confirmed. Additionally, an internal fracture of 0.63 mm was observed 0.84 mm below the prosthesis (Fig. 5C). The A-Line analysis method for the D1 and D2 areas used the resampled signal near the crack based on the average slope of the tooth surface. The width of the fracture was calculated from the size of one previously confirmed pixel and the average slope. The depth of the fracture was measured from the deep trough of the fracture to the imaginary surface line, and calculated from the average slope of the
Cavity preparation for ceramic inlay in the mandibular right second molar was performed (Fig. 6). During this process, the bottom of the pulpal floor was observed using an intraoral OCT system to prevent exposure of the pulp (Fig. 7). A maximum of 0.7141 mm below the pulpal floor was observed, and no pulp was exposed (Fig. 7), indicating that there was no pulp chamber with a thickness of 0.7141 mm. The pulp chamber was not identified at an observable penetration depth (0.7141 mm), and this information helped the clinician prepare the cavity.

After cavity preparation, impressions were made using the double-impression technique with a stock tray and vinyl polysiloxane material (Aquasil; Dentsply Sirona, York, PA, USA). A definitive ceramic inlay restoration was fabricated from lithium disilicate glass ceramic (IPS e.max CAD; Ivoclar Vivadent AG, Schaan, Liechtenstein, USA). The intaglio of the ceramic inlay was acid-etched for 20 s with hydrofluoric acid (ceramic etching gel; Ivoclar Vivadent AG, Schaan, Liechtenstein), and a primer (Monobond N; Ivoclar Vivadent AG,
Schaan, Liechtenstein) was applied for 60 s. A luting resin cement (Multilink N; Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to the intaglio of the ceramic inlay, which was seated in the prepared cavity, carefully removing all excess after polymerization. The interface surface was carefully polished using silicone rubber points. A definitive inlay restoration was cemented into the cavity according to the manufacturer’s instructions (Fig. 8).

The definitive ceramic inlay was evaluated for marginal fit using an intraoral OCT system (Fig. 9). Because the resolution of the intraoral OCT system is 0.04 mm, the marginal fit was below 0.04 mm; thus, in the acquired image, it was difficult to distinguish between the ceramic inlay and the enamel (Fig. 9). The A-Line analysis method of the D1 and D2 areas was carried out in the same way as the previous analysis method shown in Figure 5.

3. Discussion

To the best of our knowledge, this is the first clinical report of the use of an intraoral OCT system for the diagnosis of inlay restorations. Herein, we report the diagnosis of a dental prosthesis fracture, marginal gap, and pulp exposure through images acquired using an intraoral OCT system. The existing OCT system cannot acquire images in the oral cavity because of the large size of the probe[21–23]; However, the proposed intraoral OCT system can access the prosthesis in the mandibular right second molar (Fig. 4). An amalgam restoration fracture was also observed (Fig. 5).

Sumi et al. reported OCT as a non-destructive method to exam-
ine the internal cracks of complete dentures[24]. Previous studies have reported that areas which cannot be visually assessed can be examined using OCT[13–24]. Others have also reported that nondestructive, noninvasive, and objective evaluations are possible using an OCT system[13–24]. In this study, internal cracks not seen on visual inspection were found; these cracks extended to the interior due to external impact (Fig. 5A and C). Amalgam materials cannot transmit light; however, internal cracks are detected as coherent light with diffraction through an external fracture. From the observed images, the fracture internally extended from the external fracture (Fig. 5C).

Residual dentin thickness can influence the intensity of pulp response during tooth preparation for various purposes[20]. Therefore, it is necessary to estimate the remaining distance from the pulp chamber to avoid pulp[20]. Krause et al. measured the maximum residual dentin thickness of 1.94 mm using the OCT system, and confirmed its potential as a useful diagnostic tool in the preparation of deep dentin cavities[20]. In this study, a maximum of 0.7141 mm below the pulpal floor was observed after the preparation of the dentin cavity, and there was no pulp exposure (Fig. 7). The results of the present study clearly indicated the applicability of the intraoral OCT system in clinical practice (Fig. 7). However, in this case, it was difficult to observe a thickness of 1 mm or more, or to accurately measure the thickness of the residual dentin. Further studies using an improved intraoral OCT system to measure the residual dentin thickness are needed.

Previous studies have evaluated the marginal and internal fit of ceramic crowns using an OCT system[21,22], and have confirmed the possibility of using an OCT system to evaluate marginal and internal fit[21]. However, an in vitro study cannot directly evaluate the marginal and internal fit of the oral cavity[21,22]. In this report, the marginal gap (0.76 ± 0.26 mm) of the amalgam restoration confirmed the clinically inappropriate marginal fit according to previous studies (Fig. 5). Additionally, the marginal fit of the definitive ceramic inlay was evaluated and a marginal gap < 0.04 mm was observed based on the resolution of the intraoral OCT system (Fig. 9).

Nevertheless, this study had several limitations. Although it is possible to quantitatively evaluate the diagnostic result through images acquired in the oral cavity, a reliability evaluation of the accuracy of the diagnostic result is still required. In addition, the diagnostic ability of the proposed intraoral OCT system should be validated in patients with various dental problems.

The OCT system can be applied for various indications when diagnosing diseases in the oral cavity. Because the OCT system uses coherent light for observation, depth observation is possible if it is optically transparent[9]. Therefore, it is possible to diagnose cracks in the enamel and observe the marginal fit of ceramic and resin restorations in dental clinics[10,22]. It is also penetrable under the gingiva[23], suggesting that there are future indications for periodontal disease. However, the drawbacks of the OCT system are that there is a limit to the penetration depth depending on the material, and coherent light cannot be transmitted through the metallic material. In the present case, the location of the pulp chamber was not identified at an observable penetration depth (0.7141 mm), which helped the clinician prepare the cavity (Fig. 7). However, with the intraoral OCT system used in the present case, it was difficult to observe a thickness of 1 mm or more and to measure the exact residual dentin thickness. Considering these drawbacks, application of the present OCT system would widen the range of its applications in dentistry.

4. Conclusion

A dental diagnosis for inlay treatment with dental prosthesis fracture, marginal gap, and pulp exposure after tooth preparation was possible using the intraoral OCT system. The use of the intraoral OCT system improved dental diagnosis by allowing the dentist to confirm quantitative values through cross-sectional images, rather than to determine a treatment plan through visual dental diagnosis.

Acknowledgments

The authors would like thank the researchers at the Advanced Dental Device Development Institute, Kyungpook National University for their time and contribution to the study. This work was supported by a Korea Medical Device Development Fund grant funded by the Korean government (Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Health & Welfare, and Ministry of Food and Drug Safety) (Project Number: KMDF_PR_20200901_0055, 202011C13). This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT, No.2022R1C1C2007040).

Declaration of Competing Interests

There are no conflicts of interest to declare.

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