Abstract: Transparent epoxy resin root canal models were used to evaluate vertical condensation techniques for obturating lateral canals. The root canal model was configured with a straight main root canal and four right-angled lateral canals at 1.0 and 3.0 mm from the apex. Root canal obturation was performed with Thermafil, Obtura II, or NT condenser. Obturation volume in lateral canals was measured by three-dimensional microcomputed tomography, and one-way analysis of variance was used to analyze differences between groups. Lateral canals at 1.0 and 3.0 mm were uniformly filled by all obturation methods. Among the three obturation methods, Thermafil resulted in the highest obturation volumes for all lateral canals.

Keywords: warm vertical condensation; lateral canals; obturation volume; micro-CT.

Introduction

Root canal obturation is the final stage of root canal treatment. Its purpose is to tightly seal the root canal space and prevent bacterial reinfection from coronal leakage or apical exudation (1-4). In dental practice, various root canal obturation techniques are performed by using chemically stable root canal filling materials (5-8). In recent years, several warm gutta-percha root canal obturation systems have been introduced, and numerous root canal obturation devices are now commercially available. Treatment with these methods provides dense, three-dimensional root canal sealing in anatomically complex root canal systems (5-8).

Several methods of evaluating the quality of root canal obturation have been introduced, such as bacterial leakage, dye penetration, fluid filtration, and cone-beam computed tomography (CT). However, several factors were reported to complicate the assessment of three-dimensional root canal obturation, including root canal morphology (cross-sectional morphology and root canal taper), type of heating instruments, and insertion depth of root canal pluggers (5-10).

We previously used transparent epoxy resin root canal models to determine the effects of canal taper and plunger size on warm gutta-percha obturation of lateral canals (9). Although transparent epoxy resin root canal models enable visualization of the quality of root canal obturation, accurate determination of three-dimensional obturation volume is difficult. Micro-CT device-based qualitative evaluations have received attention in histomorphological studies, and this study used micro-CT to compare three root canal obturation methods: Thermafil (Thermafil Prep Plus, Dentsply Maillefer, Ballaigues, Switzerland), Obtura II (Obtura Corp., Fenton, MO, USA), and NT Condensor (Ormco Corp., Orange, CA, USA).
Materials and Methods

Experimental root canal models
We used a transparent epoxy root canal model (Nissin Dental Products, Kyoto, Japan) with a straight tapered main root canal (taper: 0.08, diameter of apical foramen: 0.3 mm, working length: 17.0 mm, apical seat: size #80) and four right-angled lateral canals to the main root canal, located at 1.0 mm and 3.0 mm from the apex (Fig. 1). The patency of all lateral canals and the apical foramen was ensured before warm gutta-percha obturation with hand instruments (#80). In this study, we divided 10 root canal models into three groups.

Root canal plugger
A 0.08-tapered root canal plugger (tip diameter: 1.20 mm; YDM, Tokyo, Japan) was used to perform vertical compaction after warm gutta-percha obturation.

Root canal obturation methods
Zinc-oxide eugenol-based root canal sealers (Canals: Showa Yakuhin Kako Co., Ltd., Tokyo, Japan) were used in all experimental groups. The root canal sealer was thinly applied to the root canal wall with a #80 paper point before root canal obturation. The three methods of root canal obturation were performed in accordance with the manufacturers’ instructions, as detailed below.

Thermafil (TH)
The silicone stopper of the TH was adjusted to working length. The #80 TH was heated with a special heating device (ThermaPrep Plus Oven, Dentsply Maillefer, Ballaigues, Switzerland) and carefully inserted to the working length of root canal models. The carrier was then cut at a position corresponding to the root canal orifice by using a Thermacut bur (Dentsply Maillefer). Root canal pluggers were not used for TH group models. The melting point of gutta-percha in TH is 51.5°C.

Obtura II (OB)
The OB was used as the obturation device. An Obtura II needle (diameter: 0.88 mm) was inserted to working length, and adequately heated (200°C) gutta-percha was carefully injected to a point 6.0 mm from working length, without vertical pressure. The position of the root canal plugger was maintained at 5.0 mm from the working length, after injection of the warmed gutta-percha. Thereafter, vertical one-time compaction (for 60 s) was performed immediately. The melting point of gutta-percha in OB is 60.0°C.

NT Condenser (NT)
A #60 NT fitted to a low-speed handpiece coated with softened Obturation NT (Ormco Corp.) was inserted to a depth of 1 mm from working length. At that position, NT condenser was rotated at 3,000 to 5,000 rpm for 3 s, without pull-down motion. Thereafter, the NT condenser was slowly removed from the root canal, and vertical compaction was performed with a plugger. The melting point of gutta-percha in NT is 46.0°C.

Micro-CT analysis
In each group the condition of gutta-percha obturation in lateral canals at 1.0 and 3.0 mm was evaluated with micro-CT analysis. The imaging conditions for the micro-CT device (R mCT, Rigaku, Tokyo, Japan) were a magnification of 6.7× (voxel size: 30 × 30 × 30 μm), a tube voltage of 90 kV, a tube current of 120 μA, and an imaging duration of 2 min. Imaging data for all samples were evaluated after visualization with i-View-R software (Rigaku). In addition, volume-measurement...
Software (i-View Image Center, Kitasenju Radist Dental Clinic, Tokyo, Japan) was used to determine obturation volumes in lateral canals by quantitatively evaluating cross-sectional screenshots of the four lateral canals at 1.0 and 3.0 mm from working length. In this study, two operators performed the root canal obturation, and two evaluators, blinded to the obturation method, conducted the analysis by using volume-measurement software.

**Statistical analysis**

The gutta-percha obturation volumes in lateral canals for the three obturation methods were analyzed by one-way analysis of variance and the Fisher least significant difference test. The volumes of lateral gutta-percha obturation at 1.0 and 3.0 mm from working length in each group were evaluated with the Mann-Whitney test at a significance level of $P < 0.05$.

**Results**

A representative micro-CT image of an obturation is shown in Fig. 2. The image shows uniform gutta-percha filling in the four lateral canals, at both 1.0 and 3.0 mm from working length. Representative micro-CT images of gutta-percha obturation with the three methods are shown in Fig. 3a-f. Root canal obturation in lateral canals was mostly uniform for all methods. Micro-CT images of gutta-percha obturation in lateral canals showed little obturation around the surface area of root canal models.

Fig. 4 shows obturation volumes in lateral canals. The obturation volumes at 1.0 mm were 0.633 mm$^3$ for TH, 0.419 mm$^3$ for OB, and 0.452 mm$^3$ for NT. Obturation volumes at 3.0 mm were 0.774 mm$^3$ for TH, 0.487 mm$^3$ for OB, and 0.599 mm$^3$ for NT. TH resulted in the highest root canal obturation volumes in lateral canals at 1.0 and 3.0 mm from working length. As compared with OB and NT, obturation volumes in lateral canals were significantly higher for TH at 1.0 and 3.0 mm from the apex. The obturation volumes for OB and NT did not significantly differ.

**Discussion**

Obturation of the root canal system after optimal root canal preparation, cleaning, and disinfection is essential.
in achieving stable long-term outcomes after endodontic therapy (1-4). However, Weine et al. reported that obturation of lateral canals with various root canal obturation methods did not yield satisfactory results (11). The warm gutta-percha root canal obturation technique was introduced by Schilder (5), who proposed that root canal obturation should include three-dimensional obturation of the root canal system, including the main and accessory canals. Brothman reported that the number of lateral canals filled with warmed gutta-percha by vertical obturation techniques was approximately twice that achieved by lateral condensation technique (12). Obturation methods using warmed gutta-percha are now widely utilized and achieve good long-term outcomes (5-8). The root canal system has a complex morphology that includes fins, deltas, accessory canals, and lateral depressions (1-5). Lateral depressions are present in the apical third of 27% to 45% of teeth (13). Warm gutta-percha obturation techniques provide satisfactory sealing of lateral depressions in the anatomical root canal complex (5-8). The present study used transparent epoxy resin root canal models with a #80 main root canal and four lateral canals. Some previous studies of obturation techniques used non-transparent root canal models or extracted teeth to examine the effects of obturation (14-17). However, an obvious disadvantage of such studies is that the models must be split for examination after root canal obturation. In addition, assessment is limited to investigation of two-dimensional surfaces. To overcome these limitations, we used transparent root canal models to assess obturation quality in lateral canals. In addition, micro-CT was used for three-dimensional quantitative analysis in this study.

Micro-CT has diverse applications (18,19). A number of experimental methods have been used to assess the quality of root canal obturation, including radiography, fluid filtration, and dye penetration. However, conventional methods have disadvantages. Radiographs yield two-dimensional images, and the time required for fluid filtration and dye penetration are not clinically relevant. Micro-CT is rapid and noninvasive, and the results are reproducible and comparable to those of histological studies. In addition, obturation volumes can be calculated, and qualitative analysis of images can be performed.

No three-dimensional studies of obturation volume in lateral depressions have been performed. Therefore, we used a micro-CT device for three-dimensional measurement and analysis of obturation volume in transparent epoxy resin root canal models that had lateral canals treated with three warm-gutta-percha compaction methods. TH comprises gutta-percha surrounding a plastic core carrier for root canal obturation. The time required for obturation was shorter for TH than for the other two methods, and it easily achieved three-dimensional root canal obturation. Among the three methods studied, the obturation volume in lateral canals was highest for TH at both 1.0 and 3.0 mm. This result was consistent with those of several previous studies, which reported that gutta-percha content was higher for TH than for the other obturation methods (20-22).

Use of TH ensures a favorable gutta-percha content in root canal obturation, and the pressure applied to the canal wall during obturation is low. Obturation time was shorter for TH than for OB and NT, which indicates that it would be more convenient for clinical use. OB was developed for warm gutta-percha root canal obturation and is capable of rapidly and densely filling complex root canal systems. It is widely used for root canal obturation because of its ability to fill gutter-shaped roots, teeth with internal resorption, and curved root canals (14). A dedicated gutta-percha pellet is placed in the chamber of a handheld gun and heated to a minimum temperature of 160°C. The plasticized and warmed gutta-percha is injected into the prepared root canal through a silver needle. With this method, proper positioning of the inserted needle tip is essential for successful root canal obturation. Because the insufficient fluidity of the root canal filling material, a needle tip positioned at 5.0 mm or more from working length is unlikely to completely fill the root canal. Therefore, to ensure sufficient obturation in this study, needle tips were positioned at 2.0 mm above working length. The lowest obturation volumes were observed for OB, perhaps because the fluidity of the plasticized gutta-percha was less than that for the other two devices, and the contraction rate of cooling gutta-percha was higher.

Root canal obturation with the NT system utilizes a condenser made from a nickel-titanium alloy and proprietary gutta-percha (23). Because its shape can apply both vertical and lateral condensation, it can obturate lateral depressions, narrow root canals, and curved root canals. However, the condensation is difficult to control, and the condition of softened gutta-percha affects the success of root canal obturation (23). In this study, NT had the second highest obturation volume; however, the standard deviation was greater than that of the other two devices, which suggests difficulty in ensuring procedure uniformity. Yared and Bou Dagher reported that, to perform an efficient obturation, the plugger must be positioned at 5.0 to 7.0 mm from working length (24). Zhang et al. showed that appropriate condensation was affected by plugger size and the degree of root canal taper and
suggested that selection of an appropriately sized plugger for the prepared root canal is very important in achieving optimal root canal obturation (9). These findings indicate that a 0.08-tapered plugger matching the root canal taper of the transparent root canal model should be selected, to reach a point 5 mm from working length. In this study, extrusion of gutta-percha from apical foramina of the experimental root canal models was observed for the three devices (TH: 60%, OB: 80%, NT: 40%). These findings are consistent with those of a previous study (25). The authors of that study concluded that extrusion of gutta-percha from working length could not be controlled. Extruded gutta-percha may result in periapical inflammation attributable to the adverse effects of this overflow. Thus, it is important to control the obturation procedure (1-4).

Acknowledgments
This work was supported by a Grant from the Dental Research Center, Nihon University School of Dentistry for 2013.

Conflict of interest
The authors declare no conflict of interest in relation to this study.

References