Root Canal Preparation Using Er:YAG Laser

Mitsuhiro Ito, Kenji Koba, Jun-Ichiro Kinoshita, Koukichi Matsumoto

Purpose: The objective of the present study was to investigate the usefulness of high-output Erbium:Yttrium, Aluminum,Garnet (Er:YAG) laser in pulp cavity perforation, chamber roof removal, and root canal orifice enlargement.

Materials and Methods: Seventy extracted human incisors without curvature were used. Using an Er:YAG laser system (2940 nm, Smart 2940D, DEKA; Florence, Italy), chamber roof removal and root canal orifice enlargement were performed. A total of 14 subgroups, including two control groups, were formed. The following three laser application tips were used: mirror, sapphire, and spear-shaped sapphire (spear). Laser output was set at either 5 or 7 W. Time required for dental tissue removal was measured and statistically analyzed using Kruskal-Wallis and Fisher’s PLSD tests. After laser application, x-ray imaging, stereomicroscopy, and scanning electron microscopy were performed.

Results: In teeth without crowns, the time required for root canal orifice enlargement was clearly shorter with the mirror tip. In teeth with crowns, the root canal was enlarged almost up to the apical third of the root, and when using the mirror tip, a V-shaped hole was created. In teeth without crowns, a U-shaped hole was made almost up to the center of the root. SEM showed hardly any smear layer on the cut surface of the root canal wall.

Conclusion: Root canal preparation should be carried out by applying high-output Er:YAG laser using a spear tip.

Keywords: Er:YAG laser, root canal preparation, perforation into pulp chamber, treatment time, SEM, superimposition.

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field of dentistry. Hibst et al.\(^5\) reported that Er:YAG laser was highly efficient in cutting enamel and dentin. Other studies have found that heat generation during cutting\(^6,7\) and the degree of heat damage to periodontal tissue\(^8\) are minimal with Er:YAG laser. Because dental caries can be treated without infiltration anesthesia, Er:YAG laser application is more comfortable than air turbine-driven instruments.\(^9\) However, with the old Er:YAG laser, insufficient output resulted in low cutting efficacy, and the laser was only applicable in limited cases, such as caries removal and mucosal incision. Since the development of high-output Er:YAG with high peak power per pulse, dentin cutting can be performed in a short period of time without causing pain.\(^10\) In Japan, dental caries treatment by laser application without infiltration anesthesia has become very common in clinical settings. In April 2008, dental caries treatment by laser application was officially approved by the Ministry of Health, Labour and Welfare, and the treatment is now covered by the national healthcare insurance system in Japan.

Several types of lasers have been used for root canal therapy.\(^11,12\) Previously, we attempted to perform root canal enlargement using the old Er:YAG laser; at that time, we came to the conclusion that root canal preparation could not be sufficiently performed without appropriate parameters.\(^13\) Later, Lee et al.\(^14\) modified a cylindrical sapphire tip with a flat end—an attachment in the Er:YAG laser system—to create a cone-shaped tip with an angle of about 84 degrees, and used this modified tip to cut dentin inside root canals. They showed that the temperature increase while cutting root canal dentin for the cone-shaped tip was 7°C, while that for the unmodified cylindrical tip was 11°C. Furthermore, SEM showed that root canal preparation using the cone-shaped tip resulted in a cleaner canal than using a chemical agent.

The present study examined the time required for root canal preparation with the new Er:YAG laser and the morphological changes before and after laser cutting. Root canal preparation was also carried out by combining the conventional rotary and manual cutting devices, and root canal morphologies were compared. In order to ascertain the potential of Er:YAG laser as a new instrument for root canal enlargement, the present study was conducted to acquire basic data, and interesting findings were obtained.

**MATERIALS AND METHODS**

After receiving approval from the ethics review board of Showa University School of Dentistry (2008-28), 70 extracted human maxillary central and lateral incisors that had been extracted either due to periodontitis or apical periodontitis were collected. Teeth used in the study were nonvital and had no curvature or past history of root canal therapy.

Because the teeth were collected over a period of 2 months, they were soaked in a 10% formalin solution immediately after extraction and were then placed in distilled water for 7 days before the study in order to make the soft tissue properties of the root canals as uniform as possible.

First, an incision about 0.5 to 1.5 mm deep was made using a diamond disk from the crown to apical side on the buccal and lingual tooth root surfaces matching the root canal. Next, the tooth was split labiolingually along the incision using pliers, and the cross-sectional morphology of the root canal was ex-
amined under a stereomicroscope. After taking pictures, the tooth was put back together and fixed using wire, and then subjected to x-ray imaging.

An Er:YAG laser system (Smart 2940D, DEKA; Florence, Italy) was then used for chamber roof removal, root canal orifice enlargement, and root canal preparation. The laser had a wavelength of 2940 nm, maximum frequency of 20 Hz, pulse width of 80 to 700 μs and maximum output of 7.7 W (up to 700 mJ energy to the tissue). One of the following three tips was attached to the system’s application port for laser application: a mirror tip with a collection mirror (included with the system); a 10-mm sapphire tip (an attachment in the system); or a spear tip modified using a carborundum point to adjust the tip angle to about 45 degrees (Fig 1).

In order to make the cutting conditions uniform, laser was applied with running water (10 ml/min) so that the tooth surface was always wet. When using the mirror tip, the handpiece was immobilized so that the distance between the lens (laser light outlet) and the tooth was fixed at 10 mm. When using either the sapphire or spear tip, the laser light outlet (the end of the approximately 10-mm tip) was placed on the tooth. By placing a power meter (Laser Power/Energy Monitor Model DGX, OPHIR; Jerusalem, Israel) at the end of the mirror tip, the energy output at the tip was adjusted beforehand. In the present study, teeth with crowns (simulation of chamber roof removal) and teeth without crowns (dental crown was cut at about 15 mm from the root apex using a diamond disk; simulation of root canal orifice identification and root canal preparation) were used. As shown in Table 1, the study was conducted in a total of 14 groups divided based on tip type, energy output, and the existence of a crown. For control (groups 13 and 14), a No. 2 round bur was attached to a rotary engine (4500 rpm) for chamber roof removal, and a Peeso reamer (# 1) was used for root canal orifice enlargement.

The time required for dental pulp perforation and chamber roof removal was measured using teeth with crowns (groups 1, 3, 5, 7, 9, 11, and 13), and the Kruskal-Wallis test (p < 0.05) was used to statistically assess differences between the mirror tip, sapphire tip, spear tip and control (rotary engine) groups. The time required for root canal orifice enlargement was measured using teeth without crowns (groups 2, 4, 6, 8, 10, 12, and 14), and Fisher’s PLSD (p < 0.05) was used to statistically compare 21 combinations of the seven groups to ascertain the relationship between energy output and tip shape.

Laser was applied to enlarge the root canal until the morphology of chamber roof removal and the root canal orifice or the area of the root canal orifice were visually comparable to the control group. After enlargement, x-ray imaging was performed. The wire was cut to split the tooth again, and the cross-sectional surfaces were examined under a stereomicroscope (Ni-
kon; Tokyo, Japan) and then photographed. In order to compare morphology before and after root canal preparation, the root canal was traced on stereomicroscopic images before and after enlargement and the trace images were superimposed.

In order to perform stereomicroscopy analysis, split teeth were put back together using tray resin so that root canal morphologies before and after laser application could be compared by stereomicroscopy from the same direction.

Then, serial alcohol dehydration, critical point drying, and platinum coating were performed according to the conventional methods, and specimens were examined with scanning electron microscopy (FE-SEM4700, Hitachi; Tokyo, Japan) to ascertain the morphological changes in the dentin surface inside the root canal after laser cutting.

RESULTS

In the present study, 70 extracted human maxillary central and lateral incisors were used to obtain basic data regarding the cutting performance of high-output Er:YAG laser. The morphological changes after root canal preparation and the laser’s potential clinical usage were investigated. The results were as follows:

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean value (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.46* (5 W mirror)</td>
</tr>
<tr>
<td>3</td>
<td>31.62* (7 W mirror)</td>
</tr>
<tr>
<td>5</td>
<td>335.72 (5 W sapphire)</td>
</tr>
<tr>
<td>7</td>
<td>154.92 (7 W sapphire)</td>
</tr>
<tr>
<td>9</td>
<td>310.68 (5 W spear)</td>
</tr>
<tr>
<td>11</td>
<td>152.16 (7 W spear)</td>
</tr>
<tr>
<td>13</td>
<td>140.56 (rotary engine, 4500 rpm)</td>
</tr>
</tbody>
</table>

*significant difference by Kruskal-Wallis test (p < 0.05)

Table 2  Time required for removing chamber roof

**Radiographic findings**

Morphological changes in root canals after laser application were ascertained by comparing x-ray images before and after application.

The root canal orifice of teeth with crowns was slightly V-shaped, and the root canal was enlarged with labial deviation in some cases. This tendency was particularly strong in groups 1 and 3 using the mirror tip (Fig 2). On the other hand, groups 9 and 11 showed rather good preparation, and no deviation was seen. Less apical destruction was recognized in groups 1 and 3, but fewer marked steps and less root canal wall thinning were recognized in groups 9 and 11 (Figs 3 and 4). Teeth without crowns showed an enlarged, U-shaped root canal orifice with no areas of insufficient enlargement in the labial and lingual walls and no ledges. The root canal showed nearly even enlargement along the root canal wall (Figs 5 and 6).

**Stereomicroscopic findings and tracing**

Analysis of labiolingual cross sections showed an absence of root canal wall carbonization, marked vaporization, and root canal wall/apex perforation under all application conditions (Figs 7 to 10). Analysis of superimposed images of the split root canal before and after root canal preparation revealed that the root canal orifice of teeth with crowns was enlarged in a slight V shape from the lingual to the labial side in the groups using the mirror tips (Fig 11), confirming the tendency for vaporization with labial deviation in these groups. In some teeth, steps were seen on the labial wall, and some areas on the lingual wall appeared untreated. The laser penetrated near the center of the root but did not penetrate the root tip was 49 and 31 s, respectively, using the sapphire tip 310 and 152 s, respectively, and using the spear tip 310 and 152 s, respectively. When compared to the control (rotary engine: 140 s), the time required for removal and enlargement was significantly shorter for the mirror tip at 5 and 7 W (groups 1 and 3, respectively) (Kruskal-Wallis test, p < 0.05, Table 2).

Using the mirror tip, the time required for root canal orifice identification, chamber roof removal, and dental pulp perforation for teeth without crowns was significantly shorter than for the other groups. Results for the spear tip were slightly poorer than those for the control, with no significant difference at 7 W (Fisher’s PLSD, intergroup p = 0.130, Table 3).
Table 3  Time required for opening root canal orifice

<table>
<thead>
<tr>
<th>Group</th>
<th>p-value (shorter group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 2-4 (5 W mirror-7 W mirror)</td>
<td>0.8365 (7 W mirror)</td>
</tr>
<tr>
<td>Group 2-6 (5 W mirror-5 W sapphire)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 2-8 (5 W mirror-7 W sapphire)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 2-10 (5 W mirror-5 W spear)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 2-12 (5 W mirror-7 W spear)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 2-14 (5 W mirror-control)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 4-6 (7 W mirror-5 W sapphire)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 4-8 (7 W mirror-7 W sapphire)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 4-10 (7 W mirror-5 W spear)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 4-12 (7 W mirror-7 W spear)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 4-14 (7 W mirror-control)</td>
<td>&lt; 0.0001 (5 W mirror)*1</td>
</tr>
<tr>
<td>Group 6-8 (5 W sapphire-7 W sapphire)</td>
<td>&lt; 0.0001 (7 W sapphire)</td>
</tr>
<tr>
<td>Group 6-10 (5 W sapphire-5 W spear)</td>
<td>1.9400 (5 W spear)</td>
</tr>
<tr>
<td>Group 6-12 (5 W sapphire-7 W spear)</td>
<td>&lt; 0.0001 (7 W spear)*2</td>
</tr>
<tr>
<td>Group 6-14 (5 W sapphire-control)</td>
<td>&lt; 0.0001 (control)*3</td>
</tr>
<tr>
<td>Group 8-10 (7 W sapphire-5 W spear)</td>
<td>&lt; 0.0001 (7 W sapphire)</td>
</tr>
<tr>
<td>Group 8-12 (7 W sapphire-7 W spear)</td>
<td>0.2570 (7 W spear)</td>
</tr>
<tr>
<td>Group 8-14 (7 W sapphire-control)</td>
<td>&lt; 0.0001 (control)</td>
</tr>
<tr>
<td>Group 10-12 (5 W spear-7 W spear)</td>
<td>&lt; 0.0001 (7 W spear)*2</td>
</tr>
<tr>
<td>Group 10-14 (5 W spear-control)</td>
<td>&lt; 0.0001 (control)*3</td>
</tr>
<tr>
<td>Group 12-14 (7 W spear-control)</td>
<td>0.1300 (control)*3</td>
</tr>
</tbody>
</table>

Fisher's PLSD (p < 0.0001) between each two groups.
* 1 mirror groups are shorter than sapphire and spear groups.
* 2 7-W spear groups are shorter than 5-W spear and 5-W sapphire groups.
* 3 5-W sapphire, 5-W spear and 7-W spear groups are longer than control.

Fig 2  X-ray image of group 1 (5 W, mirror), representative of poor results. A V-shaped cavity and wide preparation at root canal orifice were observed. The tip of the V-shaped cavity was shifted slightly to the labial side.

Fig 3  X-ray image of group 9 (5 W, spear). No deviation, irradiation angle, or thinning of labial dentin were observed.

Fig 4  X-ray image of group 11 (7 W, spear). Other than a slight deviation to the labial side observed at coronal third of the root canal, no difference from group 9 (Fig 3) was seen.
not reach the apex of any of the teeth with crowns in the mirror tip groups. The root canal was enlarged closer to the root apex when using the sapphire tip than when using the mirror tip, and the laser penetrated slightly deeper when using the spear tip than the sapphire or mirror tips (Figs 7, 8, 11, and 12).

The root canal orifice of teeth without crowns was U-shaped without labial or lingual deviation, and there was no area with insufficient enlargement or root canal wall thinning. Vaporization was mostly even along the canal wall. Regarding the reach of the laser, the root canal was enlarged from the central to apex areas (Figs 13 and 14), and while there was no marked difference between 5 and 7 W with the mirror tip, deeper enlargement towards the apex was seen with the sapphire or spear tip at 7 W when compared to 5
W. Furthermore, when compared to the sapphire tip, enlargement was slightly deeper towards the apex with the spear tip.

**SEM findings**

In the control group, SEM showed irregularities in the root canal dentin, but no marked steps or cracks were seen. The cut dentin surface from the root canal orifice to the apex was covered by a smear layer, and dentinal tubules were not open (Fig 15).

On the surface of laser-treated root canal dentin, carbonization, cracking, and marked vaporization were not seen under any condition, and findings indicative of fused dentin were not observed. Neither was smear layer seen on the cut dentin surface, and dentinal tubules were open (Figs 16a and 16b).

In groups 2 and 4 using the mirror tip, the cut surface was slightly irregular, and a characteristic rough,
scale-like surface was seen, but dentinal tubules were open. In addition, when compared to 5 W, the irregularity of the cut surface due to vaporization was more pronounced at 7 W, but cracking, carbonization, and lava-like findings were not seen.

When compared to the mirror tip, the irregularity of the cut surface was milder with the sapphire or spear tip. In particular, the laser reached near the apex for group 12 (teeth without crowns, Fig 16a), and the cut surface exhibited a gentle dune-like pattern (Fig 16b), but marked vaporization was not seen, thus clarifying that excessive energy did not reach the apical seat. On the other hand, for group 7 (teeth with crowns), the laser did not reach the apex (Fig 17a), and residual dental pulp and debris were observed (Fig 17b).

### DISCUSSION

The use of laser in root canal therapy has rapidly advanced with the development of narrow fibrescopes and tips that can be placed in root canals. There have been numerous reports on the use of laser in endodontic therapy. As the origin of the word suggests, laser is an integrated light, and heat generation cannot be avoided. It is therefore necessary to pay close attention to heat generation during laser application. Koba et al applied the Nd:YAG laser to canine root canals after enlargement, and heat generation due to excessive application caused inflammatory reactions in the apical periodontal tissue, bone resorption and alveolar resorption. They cautioned that when applying laser into root canals, the prognosis of root canal therapy was negatively affected if laser-generated heat reached the apical periodontal tissue.
In recent years, the usefulness of Er:YAG laser with a wavelength of 2.94 μm, which can cut hard dental tissue, has been reported in the fields of medicine and dentistry. The oscillation wavelength of this laser resembles the maximum absorption band of water, and when compared to the Nd:YAG and CO₂ lasers, the heat generated by laser application and the effects of heat stimulation are minimal. Therefore, Er:YAG laser appears very promising in the field of dentistry.¹⁹

However, one of the reasons for the small number of reports on the use of laser in root canal preparation is that, although the old Er:YAG laser could cut hard dental tissue, its low output made it difficult to reach deep into the cavity, resulting in low cutting efficiency. In the present study, a pulsed Er:YAG laser was used with a maximum output of 7.7 W and improved dentin vaporization due to a higher peak power per pulse over the old Er:YAG laser,¹⁰ and the potential of applying the laser to root canal preparation was investigated. The results are discussed below.

Teeth

Extracted human maxillary central and lateral incisors without curvature or a past history of root canal therapy were used. The reason for this was that, because the objective of the present study was to collect basic data for the use of Er:YAG laser in root canal preparation, it was necessary to select teeth with a single root canal, wide dental pulp, and thick root dentin. Central and lateral incisors were suitable because the pulp cavity is wide and the pulp horn widens along the crown, making it relatively easy to remove the chamber roof and enlarge the root canal orifice. These features made it easy to gather basic data.

Anterior teeth without curvature were selected. However, in clinical settings, by focusing on esthetics during and after therapy, dental pulp perforation, chamber roof removal, and root canal orifice enlargement are performed from the palatal surface of the crown, not the incisal edge. In other words, even when the curvature of the root canal is small, root canal preparation must be done in a curved manner, and this complicates root canal therapy for maxillary incisors.²⁰ Therefore, in the present study, by assuming clinical application, three tips were used to compare reach and morphological characteristics using maxillary incisors with crowns and less curvature. Additionally, using teeth without crowns, reach and morphological characteristics were compared between the three tips, independent of crown morphology. This made it possible to gather more universal data.

**Time required for dental pulp perforation and chamber roof removal or for root canal orifice enlargement**

Statistical analysis showed that the time required for removal and enlargement with the mirror tip (groups 1 and 3) was significantly shorter than that for the control group (group 13), but the time required for removal and enlargement with the sapphire tip (groups 5 and 7) and spear tip (groups 9 and 11) was longer than that for the control group (Tables 2 and 3). When using a conventional mirror tip, the focal length from the lens to a target is set around 10 mm,²¹ but the diameter of a laser spot is less than 1 mm. Moreover, light emitted by a collection mirror travels through air and reaches the target; during this period, only hydrogen and nitrogen molecules in air attenuate the light energy. However, when using a columnar sapphire tip with a length of about 10 mm or a spear tip (a sapphire tip shaped like a spearhead) (Fig 1), even when the focal distance is the same, a large amount of energy is lost as the laser passes through the sapphire stone. Furthermore, the diameter of laser light immediately after leaving a columnar sapphire tip with a diameter of about 1.5 mm was larger than 1.5 mm², and with the modified tip with a 45-degree slope, light was emitted 360 degrees, orthogonal to the tip slope. Since the cross-sectional area is larger than an 84-degree cone-shaped tip, as reported previously,¹⁴ the focal point area for the spear tip is even larger. For example, when the diameter of a laser spot doubles, the amount of energy received by the target per unit area decreases to about one fourth. In the present study, when compared to the mirror tip, the cutting efficiency for the sapphire and spear tips was markedly lower, thus supporting the above findings. With 7-W output, there was no marked difference in cutting efficiency between the sapphire and spear tips, but with 5-W output, the cutting efficiency of the spear tip was slightly lower when compared to the sapphire tip. This suggests that when compared to the columnar sapphire tip, penetration is slightly inferior for the spear tip (Tables 2 and 3).¹⁴

**Radiographic findings**

In groups 1 and 3 with the mirror tip, the root canal orifice was V shaped, and this tendency was particularly marked due to the differences in the light guidance systems (Figs 2 to 4). With the sapphire and spear tips, the laser light leaving the tip is emitted in a
radial manner, but with the mirror tip, the lens gathers the laser light and applies it to a single spot. Because of the crown, laser could not be directed linearly towards the apical foramen, and it was necessary to apply it from the palatal side. A high amount of energy accumulated on the labial side of the root canal wall at the center of the root, forming a V-shaped hole with labial deviation.

The root canal orifice of the teeth without crowns was U shaped; the reason for this was the lack of the crown. Since it was easy to guide the laser to the direction of the apical foramen, the laser cut the root canal wall towards the apical side – the narrowest area of the root canal – in an energy-dependent manner, resulting in a smooth U shape. Since the diameter of the root canal near the apex is the smallest, even if the laser is aimed linearly in the direction of the root canal, the degree of absorption by the surrounding dentin is high enough to create a slightly concave surface circumferentially around the narrow root canal, creating a U shape. This small discovery suggests that laser energy reaching the apical area does not easily affect the periodontal tissue outside the apex via a narrow apical root canal.

**Stereomicroscopic findings and tracing**

The root canal was traced on stereomicroscopic images, making it easier to compare morphology before and after laser application. When superimposing traced images before and after application, the morphological characteristics before and after application supported the results of the above-mentioned x-ray findings. Moreover, the differences between 5 and 7 W and between sapphire and spear tips were clarified (Figs 7 to 14). In other words, when compared to the mirror tip, the sapphire and spear tips cut the root canal wall closer to the apex, and this related to the principle of hard tissue cutting using Er:YAG laser. Laser is absorbed by water molecules on the surface of the target area (including water molecules sprayed from the handpiece), and as a small amount of water molecules in a small area rapidly absorbs energy, water vaporizes to increase the inner pressure and causes a micro-explosion, physically damaging the surrounding hard tissue. Since the amount of water on the root canal surface was the same, it was clear that the morphologies of the sapphire tip were responsible for the different results. The cylindrical sapphire tip caused laser light absorption in the root canal wall near the tip, but with the spear tip, more laser energy was collected near the apex, resulting in the above-mentioned differences.

**SEM findings**

In the present study, SEM was performed on all laser-treated teeth. When the mirror tip was used at an output of 7 W, the amount of energy per unit area and the degree of damage were large, but carbonization, cracking, and marked vaporization were not observed (Fig 16). These findings suggest that the heat stimulation due to laser application was low. Therefore, the level of heat damage to apical periodontal tissue was also low. Er:YAG laser application does not generate excessive heat to surrounding tissue, and heat is markedly reduced by water spraying.

In general, a layer of cut dentin called a smear layer exists on the cut dentin surface (Fig 15). The presence of a smear layer not only lowers the adhesion of the filling material to dentin, but also indicates the presence of bacteria and harmful substances. Some authors have reported the need for removal of the smear layer.

In the present study, SEM did not show much smear layer on the cut dentin surface as prepared by Er:YAG laser, and dentinal tubules were open in all cases. When cutting hard tissue using laser, the smear layer is also washed away because application is performed with running water (Figs 16 and 17).

In one study where the Nd:YAG laser was applied to dentin, fusion of the dentin surface layer and the closure of dentinal tubules were observed. In the present study, SEM following Er:YAG laser application with running water did not show fusion, even for the mirror tip at 7 W. This suggests that heat does not accumulate substantially during application. Furthermore, Er:YAG laser application has been reported to sterilize, inactivate endotoxins and improve acid resistance, and unlike the other lasers and rotary cutting devices, dentinal tubules were open with minimal contaminants on the surface dentin cut by Er:YAG laser (Fig 16, right).

However, it has been reported that the smear layer could not be removed by applying Er:YAG or Nd:YAG laser after conventional root canal enlargement using a manual file. In the future, it will be necessary to ascertain the characteristics of water currents in root canals, which are long, narrow, complex structures, in addition to the reach and extent of laser energy.
Clinical application

In the present study, a spear-shaped tip was made by modifying the sapphire tip, and the results confirmed that compared to the sapphire tip, the spear tip delivered laser energy deeper towards the apex. In terms of clinical application, the usefulness of laser should be ascertained based on teeth with crowns, rather than teeth without crowns, and reach is one of the factors contributing to the usefulness of any tip. Although not conducted in the present study, when inserting a tip into a root canal and advancing the tip towards the apex to cut dental substances, it is possible to cut closer to the apical foramen using a spear tip. In the future, it will be necessary to develop a light-guide fibroscope that bends with root canal curvature. When compared to the mirror tip, the reach for the sapphire and spear tips was higher, but cutting efficiency was markedly lower; however, with an output of 7 W, the results were comparable to a rotary engine cutting with any tip. The maximum output of Er:YAG laser was 5 W in the past, but the introduction of high-output Er:YAG laser that can emit laser as high as 7 W immediately before entering the light guidance system made it possible to achieve the above-mentioned results. Hence, it is warranted to develop a system with even higher output.

When performing root canal preparation using laser, it is not easy to determine the laser output to avoid damaging the apical seat or harming the periapical periodontal tissue in each case. Since laser travels linearly and the amount of cutting is dependent on the physical properties of a target tissue, there is no guarantee that cutting stops at the depth desired by the surgeon. Therefore, when using laser to enlarge and prepare the root canal, it may be practical to employ the crown-down method to identify the root canal orifice, enlarge the center of the root, and enlarge up to two-thirds of the apical side, and then use a conventional manual cutting device in the apical area.

We believe that root canal therapy should be performed first to eliminate a source of infection by sterilizing the root canal system as much as possible and then allowing the tooth to heal based on the natural healing power of the periodontal tissue outside the apex. When laser is used for root canal preparation, the root canal is simultaneously washed and sterilized, and with the future advances in engineering, it may be possible to use laser to sufficiently enlarge root canals, thus leading to a unique root canal filling technique.

CONCLUSIONS

In order to use high-output Er:YAG laser in clinical settings, we gathered the basic data regarding the cutting performance of Er:YAG laser in root canal preparation and investigated the morphological differences in root canals prepared with various laser tips. We reached the following conclusions:

1. With Er:YAG laser, it was possible to enlarge the root canal orifice of teeth without crowns in a significantly shorter time using the mirror tip at an output of 5 or 7 W when compared to the control (rotary engine, 4500 rpm).
2. With Er:YAG laser, it was possible to perforate the dental pulp and remove the chamber roof of teeth with crowns in a significantly shorter time using the mirror tip at an output of 5 or 7 W when compared to the control (rotary engine, 4500 rpm).
3. Er:YAG laser was used to perforate the dental pulp and remove the chamber roof in teeth with crowns, and the root canal was traced on cross-sectional stereomicroscopic images. The results showed that the root canal was enlarged in a V shape with labial deviation from the root canal orifice to near the center, and this tendency was particularly strong for the mirror tip.
4. Er:YAG laser was used to enlarge the root canal orifice and prepare the root canal in teeth without crown, and the root canal was traced on cross-sectional stereomicroscopic images. The results showed that the root canal was enlarged in a U shape from the root canal orifice to near the center, and enlargement up to near the apex was seen when using the spear tip.
5. Er:YAG laser was used for root canal preparation, and SEM was performed for analyzing root canal wall dentin. On the cut surface, there was minimal smear layer, and carbonization, cracking, and marked vaporization were absent. The higher the energy, the greater the cut surface irregularity; this tendency was more pronounced with the mirror tip than with the sapphire or spear tips.
6. When compared to the sapphire tip, the amount of zip formation on root canal wall dentin was lower with the spear tip, and there were fewer abnormalities on the dentin surface.

Based on the above basic data, when perforating the dental pulp of incisors, removing the chamber roof, and identifying the root canal orifice with high-output Er:YAG laser using a modified sapphire tip at an output
of 7 W, it may be possible to relatively safely achieve a clean root canal wall in an amount of time comparable to the conventional method.

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