Removal of root canal filling materials using Er:YAG laser irradiation

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The purpose of this study was to examine the ability of Er:YAG laser to remove root canal filling materials. The root canals of 21 extracted human anterior teeth were enlarged, and then obturated with gutta-percha points and sealer by lateral condensation. Filling materials were removed from root canals using Er:YAG laser irradiation at three energy output levels (30, 40, and 50 mJ/pulse), and the corresponding time required for material removal at each energy output level was recorded. The amount of remaining filling material and the degree of dentin ablation in the canal wall were assessed using microfocus X-ray CT before and after removal. At 30 mJ, the time required for root canal filling material removal was significantly longer than at energy outputs of 40 and 50 mJ (p<0.01). On filling material remnants and the degree of dentin ablation, these parameters were not significantly different among the three energy outputs. In conclusion, these results suggested that Er:YAG laser irradiation is capable of removing root canal filling materials.

Keywords: Er:YAG laser, Root canal retreatment, Root canal filling material

INTRODUCTION

Before endodontic retreatment can be performed on an obturated tooth with a failed root canal treatment, the root canal filling material needs to be effectively and completely removed from the canal. In general, filling materials composed mainly of gutta-percha are used for hermetic sealing of the root canals during endodontic obturation. As for the root canal space, it is usually small and narrow such that it is difficult to gain direct vision to the root canal. Consequently, root filling material removal becomes a difficult task that requires considerable effort, time, and technique. Although several techniques, such as dissolution using solvents and softening by heat, have been advocated, none of these methods has proven to be an effective and reliable method for removing gutta-percha.

In 1964, Goldman et al. investigated the effectiveness of ruby laser in caries removal. This investigative work by Goldman et al., and hence the potential application of laser technology to caries removal as well as various fields of dentistry, has led to the development of dental laser systems with different wavelengths, which is accompanied with the development of peripheral equipment such as light guide fibers and tips for laser irradiation. Currently, lasers are widely used in different areas of dentistry.

In the field of endodontics, Weichman and Johnson reported in 1971 on the ability of the CO2 laser to seal the apical foramen. Since then, different laser systems have been applied to root canal treatment. Amongst which, the Er:YAG laser is considered to have lower thermal effect — and hence lower thermal damage — on the surrounding dental tissues than CO2 laser and the Nd:YAG laser. By means of a flexible fiber delivery system and a small-diameter laser tip for insertion into a root canal, numerous trials and evaluations have been conducted to determine if Er:YAG laser is safe and reliable for clinical dental applications. These included removal of smear layer and debris by irradiation in a root canal, root canal disinfection, root canal enlargement, and root resection, in addition to basic scientific research which focused on temperature changes at the root surface due to use of Er:YAG laser irradiation and the latter’s thermal effects on periradicular periodontal tissues.

The purpose of this study was to evaluate the ability of Er:YAG laser in removing root canal filling materials during retreatment. To this end, the root canals of extracted teeth obturated with gutta-percha points and root canal sealer were irradiated with Er:YAG laser to evaluate the effect of laser energy output on removal of root canal filling materials. Captured microfocus X-ray CT images were used to compare changes in the root canal and root canal dentin before and after the removal of root filling materials. Further, a digital microscope was used to observe the inner root canal wall so as to examine the effects of laser irradiation thereupon.

MATERIALS AND METHODS

Specimen preparation

In this study, a total of 21 extracted human teeth with relatively straight, single root canals and no prominent abnormality on the roots were used. After the teeth were radiographed to confirm completely formed apices and the absence of complicated root canal anatomy, they were stored in 1% thymol solution until use.

After opening the pulp chamber using a #301 diamond point (Shofu, Kyoto, Japan) under water spray, penetration at the root apex was confirmed using a #15 K-file. Working length was set to be 1 mm short...
of the anatomical apical foramen. Engine-driven rotary files (Mani, Utsunomiya, Japan) were used to prepare the root canal, which was irrigated with purified water. First, the upper part of the root canal was enlarged using a file of D,=0.40 mm (projected tip diameter) with a 0.14 taper. Then, the entire root canal was enlarged using files of D,=0.40 mm with tapers of 0.02, 0.04, and 0.06 in a stepwise manner. After the root canal was prepared, it was irrigated with 10% sodium hypochlorite and 3% hydrogen peroxide. Before the root canal was dried with paper points, absence of dentin chips at the tip of the root canal was confirmed using a #15 K-file. To obturate the root canal, a lateral condensation technique was performed using gutta-percha points (GC, Tokyo, Japan) and a root canal sealer (Canals, Showa Yakuhin Kako, Tokyo, Japan). After root canal filling, the gutta-percha points were cut at the level of the cervical line using a heated plugger. Access cavity was then sealed using Caviton (GC, Tokyo, Japan).

All tooth specimens were stored at 37°C and 100% humidity for 1 week. After which, the specimens were bisected at 11 mm from the anatomical apex using a diamond disk. The roots that remained were scanned using a microfocus X-ray CT apparatus (ELESCAN mini, Nittetsu Elex, Tokyo, Japan) with the following settings: tube voltage of 60 kV, tube current of 100 µA, x2.5 magnification, slice thickness of 33.8 µm, and pixel size of 41.6 µm.

Retreatment procedure
The specimens were divided into three groups (n=7). From the orifice of the root canal, the root canal filling material (10 mm working length) was irradiated with Er:YAG laser (Dentlite, Hoya Photonics, Tokyo, Japan) at three different energy output levels (30, 40, and 50 mJ/pulse) in repeated pulse mode (10 Hz) to remove the filling material. A straight quartz fiber irradiation tip (core diameter 0.3 mm; Hoya Photonics), as shown in Fig. 1, was used in this study. Energy output was measured using a power energy analyzer (Field Master GS™, Coherent Japan, Tokyo, Japan) and adjusted for each specimen. With due consideration to heat generation and the accumulation of transpiration residues in the root canal, the root canal was irrigated with water after every 1 minute of laser irradiation and likewise the cleaning of the irradiation tip.

Near-contact laser irradiation was performed under water spray (approximately 20 ml/min) in a circular motion to avoid laser concentration at one area. To avoid root canal dentin ablation, irradiation direction approximately corresponded with the root canal axis. This procedure was repeated until tip insertion was able to reach the full 10 mm working length of the root canal without resistance, indicating that root canal filling material removal was complete.

During the cleaning of the irradiation tip after every 1 minute of laser irradiation, it was also checked to make sure that it was not broken. To restore the penetration power of the laser, the tip was polished with polishing films and finished with 1,000-grit film. However, when the output energy became unstable, the tip would be replaced.

After the root canal filling materials were removed, the specimens were scanned using the microfocus X-ray CT apparatus at the same settings to examine changes in the root canals following laser irradiation.

Evaluation of the effects of Er:YAG laser irradiation on root canal filling material removal
1. Time required to remove root canal filling material
The time required to remove the root canal filling material was recorded for each specimen. In each group according to the laser energy output level, the mean time and standard deviation (SD) for material removal were calculated from the irradiation times of the seven specimens.

2. Amount of remaining root canal filling material and degree of dentin ablation
Before and after the removal of root canal filling materials, the images obtained by microfocus X-ray CT scanning were reconstructed three-dimensionally using an image processing software (TRI/3D-BON, Ratoc System Engineering, Tokyo, Japan). For each reconstructed 3D image, the volumes of remaining root canal filling material and root canal tooth structure were measured using the same image processing software. The percentage of remaining root canal filling material after laser irradiation was calculated by measuring and comparing the volumes of the filling material before and after removal. As for the degree of root canal dentin ablation after irradiation, it was obtained by measuring, back-calculating, and comparing the root canal dentin volumes before and after filling material removal.

Through the reconstructed 3D images, the condition of the remaining root canal filling material after laser irradiation and the changes to the root canal surface due to irradiation damage were also examined.

3. Statistical analysis
One-way ANOVA was performed to statistically analyze the effects of energy output on these aspects: time required for filling material removal, amount of remaining filling material, and the degree of root canal dentin ablation. The Tukey–Kramer procedure was used for multiple comparisons among the groups after ANOVA analysis. Level of statistical significance was set at 1%.
After microfocus X-ray CT scanning was completed, the specimens were bisected mesiodistally along the tooth axis with a diamond disk. The inner surfaces of the root canal walls were then observed at ×30 magnification using a digital microscope (VHX-100, Keyence, Osaka, Japan).

**RESULTS**

**Presence of turbidity during Er:YAG laser irradiation**

Brownish-black turbid matter flowed from the root canal under water spray during Er:YAG laser irradiation. Turbidity varied from small, black discolored particles to aggregations approximately 1 mm in diameter.

**Time required to remove root canal filling material**

At energy output levels of 30, 40, and 50 mJ, the times required to remove the root canal filling material were 1,160±208, 626±66, and 585±55 seconds respectively. In other words, the higher the energy output, the shorter was the removal time (Fig. 2). One-way ANOVA confirmed that the effect of energy output on the time required for filling material removal was significant (**p**<0.01) (Table 1). In particular, statistically significant differences (**p**<0.01) existed in the removal times between the 30 and 40 mJ energy output groups, and between the 30 and 50 mJ groups.

**Amount of remaining root canal filling material**

In the 30, 40, and 50 mJ groups, the amounts of remaining root canal filling material after removal were 5.0±3.5, 4.1±3.3, and 5.5±3.4% respectively. In other words, most of the filling material was removed from the root canal in each energy output group. According to one-way ANOVA, there were no statistically significant differences in the amount of remaining root canal filling material among the three energy output groups.

Figures 3a and 3b show the typical, reconstructed, 3D images from microfocus X-ray CT scanning before and after filling material removal. Fig. 3a shows the obturated root canals, while Fig. 3b shows the images after filling material removal, and hence the dispersed bits of the filling material in the root canals. In most cases, the filling material remained at the apical root canal, but in some specimens there was a tendency for it to remain at the cervical canal.

**Digital microscope observation of inner root canal wall**

Figure 3 shows the typical images of the inner root canal walls after laser irradiation, whereby residual filling materials were dispersed and attached to the canal wall. These findings were consistent with the images obtained from microfocus X-ray CT scanning. Although concave or rough areas possibly caused by laser irradiation were observed at some parts of the canal wall surface, none of them were severe damages that resulted in the perforation of the root canal wall.

**Degree of root canal dentin ablation**

The degrees of root canal dentin ablation, indicating a decrease in the volume of root canal dentin wall after removal of the root canal filling material, were 2.4±1.3, 2.1±0.7, and 2.6±2.0% in the 30, 40, and 50 mJ groups respectively. These findings demonstrated that only a small amount of dentin was lost during filling material removal. According to one-way ANOVA, there were no statistically significant differences in the degree of root canal dentin ablation among the different energy output groups.

With 50 mJ irradiation, the image in Fig. 3b showed ablation of the root canal wall after filling material removal. Nonetheless, there was no prominent abnormality.

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**Table 1** Effect of laser energy output on time required to remove root canal filling materials

<table>
<thead>
<tr>
<th>Output energy</th>
<th>Degree of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F-value</th>
<th>p-value</th>
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<td>Error</td>
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<td>1438692</td>
<td>719346</td>
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</tr>
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<td>T</td>
<td>18</td>
<td>303784</td>
<td>16876</td>
<td></td>
<td></td>
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<tr>
<td>T</td>
<td>20</td>
<td>1742477</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(One-way ANOVA)
Fig. 3 Three-dimensional reconstruction from CT images before (a) and after (b) root filling material removal, and digital microscope images (c) of the inner root canal walls.
DISCUSSION

According to established root canal procedure, a successful root canal treatment entails two steps: thorough removal of organic contents which could be a potential source of infection and nutrition for bacterial overgrowth, followed by tight sealing of the root canal to prevent bacterial invasion. To ensure tight sealing of the root canal, the condensation technique is widely performed using gutta-percha type filling material in conjunction with a root canal sealer. However, complete sealing of the root canal does not take into consideration the probability of poor prognosis due to anatomical complications of the root canal system or which could be caused by diverse unforeseen factors.

Consequently, endodontic retreatment may be required to remove a source of infection in the root canal. In such an event, the root canal filling material should be removed completely from the root canal. For gutta-percha type filling materials, they are typically dissolved using solvents such as chloroform or eucalyptus oil, followed by using hand files to remove the bulk of dissolved gutta-percha. This is a time-consuming and inefficient procedure, and some studies have raised the concern about the cytotoxic effects of gutta-percha solvents on periapical periodontal tissues.

To remove root canal filling materials efficiently, ultrasonic instrumentation and instruments such as Gates-Glidden drills or gutta-percha removers and engine-driven nickel-titanium files have been employed. All these removal methods have both advantages and disadvantages. Ultrasonic instrumentation may result in fracture of instruments in the root canal. With Gates-Glidden drills and engine-driven nickel-titanium files, they may cause overpreparation of the root canal and may also break when they are deep within the root canal. It should be cautioned and emphasized that it is particularly difficult to remove fractured or broken instruments from the apical root canal.

Recently, it was reported that root canal filling materials could be effectively removed using Nd:YAG laser, but there were evident signs of temperature increases in the surrounding tissues due to heat generation as well as dentinal tubules being blocked with melted dentin. On the other hand, the wavelength of Er:YAG laser is 2.94 μm with a high absorption rate in water, thus causing a smaller thermal effect on the surrounding apical tissues than other lasers. For these favorable reasons, Er:YAG laser has been clinically used for various types of endodontic treatments. In the field of operative dentistry, studies have shown that Er:YAG laser was able to melt and remove restorative filling materials. In light of these reports, this study was conducted to investigate the possible use of Er:YAG laser in removing root canal filling materials.

Er:YAG laser technology is widely thought to operate via two mechanisms: photothermal and photoablation. Keller and Hibst claimed that dental hard tissue removal resulted from microexplosions which occurred due to absorption of laser light by the moisture in the tooth structure. However, this suggestion runs contrary to the clinical requirements of root canal filling materials: they must not allow water to penetrate and neither must they dissolve in or absorb tissue fluid. Therefore, the gutta-percha cone used in this study was a dense material which contained no water and which did not absorb water. In other words, root canal filling material removal in this study could not be explained on the basis of microexplosion associated with water contained in the material. Instead, it is suggested that the photoablation mechanism was effected by the water from the water spray between the laser light and the irradiated surface, which then effected the ablation of the gutta-percha material.

Alternatively, it was suggested that the thermal effect of Er:YAG laser brought about the removal of dental restorative materials. Restorative alloys such as silver alloy do not contain water, and Senzui et al. reported that they were melted by laser irradiation with or without a fine water mist spray. In the present study, a turbid brownish-black fluid was observed to flow from the root canal following laser irradiation under water spray, suggesting that in addition to the photoablation effect, a photothermal effect resulted in the carbonization of root canal filling material at the irradiated surface. In light of this observation, it was thus suggested that the removal of root canal filling material by Er:YAG laser involved a combination of both photothermal and photoablation effects. However, for a detailed understanding of the underlying removal mechanism, more in-depth studies must be carried out.

On the method used to examine changes in the root canal caused by laser irradiation, a microfocus X-ray CT apparatus was used in this study to measure the amount of filling material before and after removal and the degree of root canal dentin ablation. Previously, radiography and tooth sectioning technique have been used for endodontic observation. However, the information obtained from radiographs is limited to two-dimensional images, and precise evaluation is difficult due to damage and deformation caused by the tooth sectioning procedure.

In sharp contrast, a prominent advantage of the microfocus X-ray CT apparatus was that the microstructure within the root canal could be easily observed without destructive effects. It revealed the amount and location of residual root canal filling material with no damage or deformation of the tooth specimen. Moreover, when used in conjunction with an image analysis software, it was possible to perform three-dimensional reconstruction of tomograms and measurement of sizes and forms. In other words, the amount of remaining root canal filling material and the degree of loss of dentin could be quantified by comparing the images before and after filling material removal. In light of these features and advantages, the
microfocus X-ray CT apparatus was an effective method and a logical choice for endodontic research that requires detailed observations in root canals\textsuperscript{27,28}.

In this study, the times required for root canal filling material removal were 1,160, 626, and 585 seconds for Er:YAG laser energy output levels of 30, 40, and 50 mJ respectively. Hence, it was apparent that the higher the energy output, the shorter was the removal time. The reduction in removal time between the 30 and 40 mJ energy output groups was 534 seconds, but the reduction was only 41 seconds between the 40 and 50 mJ energy output groups. It should be pointed out that the three energy outputs (30, 40, and 50 mJ) applied in this study were low, ranging between 1/3 and 1/10 of the energy output used for irradiation on dental hard tissue or restorative materials. Nonetheless, it was possible to remove root canal filling material effectively at an energy output of 40 mJ. At this juncture, it is apt to highlight that use of higher-energy laser could cause localized ablation of root canal wall dentin, forming a ledge or step rather than removing the root canal filling material, and even resulting in perforation of the root canal wall. In light of these detrimental effects, excessive increase in laser energy output should be avoided.

After laser irradiation, the amounts of remaining filling material were 5.0, 4.1, and 5.5% in the 30, 40, and 50 mJ groups respectively. In addition, residual filling material was frequently observed at the apical canal. In this study, the working length was set to be 1 mm short of the apical foramen. As a result, the filling material filled into the unprepared root end (near the apex) using the lateral condensation technique was not irradiated by Er:YAG laser. This could thus explain the frequent observations of residual root canal filling material near the apex.

If the filling material left in the unprepared apical side of root canal were excluded from measurement, the obtained amount of remaining filling material would be even lower. Nevertheless, additional laser irradiation for the purpose of removing filling materials condensed in unprepared, narrow root canals should be avoided, since it carries a high risk of destroying the apical constriction and damaging the periapical tissue. Therefore, laser tip insertion into the root canal must stop before reaching the apical constriction. Moreover, the position of tip insertion should be carefully determined from preoperative radiographs, especially for root canals with a wide-diameter apical foramen. However, since all traces of existing filling material must be removed from the root canal for endodontic retreatment, it is recommended that residual root canal filling material near the apex be removed with a hand file after laser irradiation.

In the present study, the degrees of root canal dentin ablation were 2.4, 2.1, and 2.6% in the 30, 40, and 50 mJ groups respectively. The results obtained indicated that the ablation extent of root canal wall was in the low range. However, some specimens in the 50 mJ irradiation group showed localized ablation of the root canal walls. It should be mentioned that the irradiation tip used in this study had a flat tip, which meant that the laser beam did not irradiate laterally to a great extent. However, excessive ablation of root canal dentin wall is not expected to occur frequently in a straight root canal, since the direction of laser tip insertion corresponds with the root canal axis.

Although on the overall, the extent of dentin ablation was seemingly small in this study, the local ablation of root canal dentin wall at 50 mJ energy output could be a concern. Since there were minimal differences in data between 40 and 50 mJ energy outputs with regard to removal time, amount of remaining filling material, and the degree of root canal dentin ablation, the energy output of 40 mJ could be considered to be the optimal Er:YAG laser output for the removal of gutta-percha type root canal filling materials. At this juncture, it must be cautioned that when curved root canals are encountered, the use of laser should be avoided. This is because there are still limitations in current laser technology with regard to precisely guiding the laser beam to irradiate root canal filling materials in curved root canals.

The effect of heat generation by Er:YAG laser irradiation was not evaluated in this study. However, at an energy output of 40 mJ, approximately 10 minutes of laser irradiation was required to remove a 10-mm-long bulk of root canal filling material. For such an irradiation duration, the thermal effect on periodontal tissues clearly would not be negligible. Kimura et al. reported that when the inner root canal walls of extracted human teeth were irradiated by Er:YAG laser at 230 mJ/pulse (2 Hz) for 1 minute under water spray (20 ml/min), the surface temperature increased by less than 6°C\textsuperscript{12}. However, when the inner root canal walls of extracted rat teeth were irradiated at 34 mJ/pulse (2 Hz) without water spray for 30 seconds, Kimura et al. found no undesirable thermal damage on the periapical tissues\textsuperscript{18}. Similarly, when Sekine et al. used Nd:YAG laser at 100 mJ/pulse (10 pps) for 30 seconds without water spray to irradiate the root canals of dogs, there were no evident signs of thermal injury to the surrounding tissues\textsuperscript{8}.

It is noteworthy that temperature increase can be suppressed by water spray during irradiation\textsuperscript{11,30}. Coupled with the cooling effect provided by blood circulation in the microvessels of periodontal tissue\textsuperscript{31}, it was thus suggested that both factors accounted for the low thermal effect of laser irradiation on periradicular tissues. For a more comprehensive understanding on this topic, it would require further investigations in future studies.

**CONCLUSIONS**

Twenty-one extracted human anterior teeth with relatively straight, single root canals were obturated using a lateral condensation technique. To simulate endodontic retreatment, they were irradiated with Er:
YAG laser at three different energy output levels (30, 40, and 50 mJ/pulse) to remove the root canal filling materials. After laser irradiation, the following were evaluated to examine the effects of Er:YAG laser irradiation on root canal filling material removal: time required to remove root canal filling material (length of filling material bulk was 10 mm), amount of remaining filling material (assessed by microfocus X-ray CT images before and after removal), and the degree of root canal dentin ablation (degree of root canal dentin wall loss). The findings were confirmed using a digital microscope, and the following conclusions were obtained:

1. The higher the laser energy output, the shorter was the removal time.
2. There were no statistically significant differences in the amount of remaining filling material and the degree of root canal dentin ablation among the three energy output groups.
3. After irradiation with 50 mJ laser, digital microscopy revealed concave or rough spots on some parts of the root canal surface, which were probably caused by laser irradiation.
4. Findings of this study demonstrated that Er:YAG laser irradiation at an energy output of 40 mJ could effectively remove gutta-percha type root canal filling materials without causing perforation of the root canal wall or excessive root canal dentin ablation.

REFERENCES