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# Effects of Diode Laser Irradiation on Smear Layer Removal from Root Canal Walls and Apical Leakage after Obturation

XIAOGU WANG, D.D.S., YICHAO SUN, D.D.S., YUICHI KIMURA, D.D.S., Ph.D., JUN-ICHIRO KINOSHITA, D.D.S., Ph.D., NELSON TATSUNARI ISHIZAKI, D.D.S., and KOUKICHI MATSUMOTO, D.D.S., Ph.D.

## ABSTRACT

***Objective:*** **The objective of this study was to investigate the rise in temperature in root surfaces during and immediately after diode laser irradiation, to observe morphological changes of root canal wall after irradiation, and to evaluate the apical leakage after irradiation and obturation *in vitro*.** ***Background Data:*** **There have been very few reports on root canal treatment by 980-nm wavelength diode laser.** ***Methods:*** **Sixty-six extracted human single-rooted teeth were instrumented up to size 60 K-file, and then randomly divided into three groups of 22 teeth each. Groups 1 and 2 were irradiated with a diode laser at 5 W for 7 sec using fibers of diameters 550 and 365 μm, respectively. Group 3 was not irradiated, and served as a control. The rise in temperature on root surfaces of the teeth in groups 1 and 2 were measured by thermography. Six teeth in each group were bisected longitudinally and observed morphologically. Other teeth were obturated and immersed in rhodamine B solution, and the degree of apical leakage was evaluated longitudinally and transversally.** ***Results:*** **A maximum temperature rise of 8.1°C was recorded in group 1. The smear layer in the laser-treated groups was evaporated and removed, resulting in clean root canal walls, which was significantly superior to the control group ($p < 0.05$). After obturation, the laser-treated groups showed significantly less apical leakage than the control group ($p < 0.05$).** ***Conclusions:*** **These results indicate that the diode laser is useful for removing smear layer and debris from root canal walls, and reducing apical leakage after obturation *in vitro*, and suggest that it would be useful for root canal treatment in clinic.**

## INTRODUCTION

Apical leakage allows microorganisms to invade the root canal system and affects the prognosis of periapical healing. One of the fundamental aims of root canal treatment is to clean the root canals as thoroughly as possible to eliminate debris and microorganisms and achieve perfect obturation without leakage.[1] During root canal preparation, instrumentation generates organic and mineral debris, which can not be completely removed by routinely used sodium hypochlorite (NaOCl) irrigation. Whether the smear layer is beneficial or detrimental for root canal therapy is still controversial. Some researchers reported that the smear layer might be beneficial because it reduces the permeability of dentin and prevents or slows the penetration of bacteria into dentinal tubules.[2,3] However, many researchers believe that the smear layer should be considered deleterious.[1,4,5] The smear layer prevents irrigants, medicaments and filling materials from penetrating into the dentinal tubules and even from contacting the canal wall, and it is considered to be responsible for the leakage between root canal wall and filling material.[6] Consequently, many efforts have been made to remove smear layer and debris, and improve the adaptation of obturation materials to root canal wall.

With regard to laser application to endodontics, laser systems such as neodymium:yttrium-aluminum-garnet (Nd:YAG) and carbon dioxide ($CO_2$) lasers have proved effective in cleaning and disinfecting the root canal and lateral dentinal tubules.[7,8] Following development of the laser technique and device, the diode laser has gained increasing importance due to its compactness and low cost. The diode laser is recommended

Department of Cariology and Endodontology, Showa University School of Dentistry, Tokyo, Japan.

for endodontic treatment because its wavelength is within the infrared range, and thin and flexible fibers can be used. Previous reports demonstrated the bactericidal effects of 810-nm wavelength[9,10] and 980-nm wavelength diode lasers.[11] However, to date, the potential application of 980-nm wavelength diode laser in endodontics has seldom been addressed. The safety in clinical use, effects of diode laser on removal of smear layer and debris and degree of apical leakage in obturated teeth have not been reported.

The objectives of this study were to investigate the rise in temperature on root surfaces of the teeth during and immediately after diode laser irradiation, to observe morphological changes of root canal wall after irradiation, and to evaluate the degree of apical leakage from apical foramen after irradiation and obturation *in vitro*.

## MATERIALS AND METHODS

### *Tooth preparation*

Sixty-six extracted non-carious single-rooted maxillary human teeth with straight canals were used in this study. Before the experiment, root surfaces of all specimens were cleaned mechanically and ultrasonically. The crowns of the teeth were resected at the cemento-enamel junction with a high-speed diamond bur under water irrigation and then discarded. The canals were cleaned and instrumented by the step-back technique up to size 60 K-type endodontic files (Dentsply-Maillefer, Ballaigues, Switzerland). The working length was visually determined 1 mm shorter from the anatomical apical foramen. The root canals were irrigated with 3 mL of 5% NaOCl (Wako Pure Chemical Industries Ltd., Osaka, Japan) and 3% hydrogen peroxide ($H_2O_2$; Wako Pure Chemical Industries Ltd.) alternately between each file. After root canal preparation, the canals were irrigated with 3 mL of sterile water to terminate any solvent action of the irrigants and to remove any precipitates that may have formed from the irrigants. The root canals were dried with paper points. The teeth were then randomly divided into three groups of 22 teeth each.

### *Laser irradiation*

A 980-nm wavelength GaAlAs diode laser device (Prototype, MANI, Inc., Takanezawa, Japan) was used in this experiment. The maximum output was 5 W, and continuous as well as pulsed modes were available. The delivery system consisted of a series of flexible fibers that had diameters of 365 or 550 µm.

Forty-four teeth in groups 1 and 2 were irradiated in the continuous mode at 5 W. The diameters of the fibers used were 550 (group 1) and 365 µm (group 2). During laser irradiation, each fiber tip was introduced into the root canal, kept in contact with the root canal walls, and then moved out. The irradiation time was 2 sec at the apical stop, followed by 5 sec at the root canal walls with vertical movement from the apex to cemento-enamel junction. Total irradiation time for each root canal was 7 sec. The 22 teeth in group 3, which served as control, were not irradiated.

### *Temperature measurement*

Temperature changes on root surfaces of the teeth during and immediately after irradiation were measured using a thermovision device (AGEMA, infrared system AD, Danderyd, Sweden) linked to a personal computer with a maximum resolution of 0.1°C at the room temperature of 22°C. To standardize the experimental conditions during measurement, the samples were fixed using clamps and an ice block was placed at a distance of 10 cm from the samples. Since the thermovision system generates a television-like image, thermal images were recorded on a computer in real time for later analysis. Ten teeth from each group were measured for temperature changes to determine ongoing thermal events and provide information on possible thermal effects of the exposure to laser on periodontal tissues surrounding the root surfaces. The temperature was measured for 20 sec (7 sec during irradiation and 13 sec after irradiation) in each sample. The maximum rise in temperature on the root surface during this measurement period was recorded. The data were expressed as the mean and standard deviation (SD), and Mann Whitney $U$ test was performed to determine whether there was any significant difference ($p < 0.05$) between both laser-treated groups.

### *Stereoscopic and scanning electron microscopic observation*

Six teeth from each group were longitudinally bisected by pliers after a single longitudinal groove was made on the labial and lingual root surfaces with a diamond disk. Each sample was observed by stereoscopy (SMZ-10, Nikon, Tokyo, Japan), and then they were progressively dehydrated using graded concentrations of aqueous ethanol (70%, 80%, 90%, and 100%) for 24 h at each concentration. After dehydration, the samples were sputter-coated with platinum ion (Ion sputter, E-1030, Hitachi Ltd., Tokyo, Japan) and observed by scanning electron microscopy (SEM; T220A, JEOL Ltd., Tokyo, Japan and S-4700, Hitachi Ltd., Tokyo, Japan) at an accelerating voltage of 15–20 kV. Samples were viewed and evaluated at a magnification of ×500 for assessment of smear layer and patency of dentinal tubules. This level of magnification was selected for viewing, because it showed the best detail required to make an accurate evaluation. The smear layer remaining on root canal walls was scored in a blind manner on a four-grade scale (Table 1) independently by three examiners using a modified method.[12] Prior to scoring the samples, the examiners viewed samples to ensure calibration and to reach a mutual understanding as to what amounts of smear layer and patent or blocked dentinal tubules constituted each ranking from 1 to 4. Both halves of each sample were evaluated in the apical, middle and coronal portions of the root canal walls. When discordant scores were reported on a sample by the examiners, the examination was repeated, and any further controversy was resolved by discussion.

### *Apical leakage*

Sixteen teeth in each group were obturated by lateral condensation method with gutta-percha points and sealer (Canals N, Showa Yakuhin, Tokyo, Japan) and then root surfaces were covered with nail varnish except 1 mm around the apical foramen. The teeth were immersed in 0.6% rhodamine B solution (Muto Chemical Co., Tokyo, Japan) for 48 h at 37°C and the container with the samples was agitated. After 48 hours, the samples were rinsed with distilled water, and allowed to dry. The roots were bisected longitudinally (eight samples) or sec-

TABLE 1. CRITERIA FOR DEGREE OF REMAINING SMEAR LAYER

| *Score* | *Criteria* |
|---|---|
| 1 | Little or no smear layer; covering <25% of the specimen; most tubules were visible and patent, or almost complete laser melting |
| 2 | Little to moderate or patchy mounts of smear layer; covering 25–50% of the specimen; many tubules were visible and patent, or laser melting |
| 3 | Moderate amounts of scattered of aggregated smear layer; covering 50–75% of the specimen; minimal to no tubule visibility or patency, or scattered laser melting |
| 4 | Heavy smear layer covering >75% of the specimen; no tubule orifices were visible or patent; or no visible laser melting |

TABLE 2. CRITERIA FOR DEGREE OF TRANSVERSAL DYE PENETRATION

| *Score* | *Criteria of transversal leakage* |
|---|---|
| 0 | No dye penetration |
| 1 | 25% |
| 2 | 25% to 50% |
| 3 | 50% to 75% |
| 4 | 75% to 100% |

tioned transversally (eight samples) with an Isomet saw (Buchler, IL). In the longitudinal section, the roots were bisected through the apex and in a direction approximately parallel to the long axis of the root. The maximum depth of dye penetration was measured by stereoscopy at a magnification of ×16. The linear dye penetration was blindly measured on either side of the samples, from the apex to the point where the dye no longer penetrated the interface between the root canal walls and the root canal filling materials, and the greatest value was considered for statistical analysis. In the transverse section, the roots were sectioned transversally at 1, 2, 3, and 4 mm from apex. The cut surfaces were photographed by stereoscopy at the magnification of ×20. In every photograph, the length of dye penetration along the root canal wall and the whole circumference of root canal wall were measured in millimeter with a computer-aided digitizer. The percentage of the length of linear dye penetration in the whole circumference of root canal wall was calculated from each photograph. Thereafter, the linear dye penetration in each transverse section was scored blindly on a five-grade scale (Table 2).

### *Statistical analysis*

Statistical analysis was performed using the Kruskal-Wallis test, and a value of $p < 0.05$ was considered significant.

## RESULTS

### *Measurements of temperature changes by thermography*

Table 3 shows the results of temperature changes. The maximum rise in temperature recorded at the middle third of the root canal was 8.1°C in group 1 and 6.4°C in group 2. The mean rise in temperature observed in group 1 was 7.86°C and that in group 2 was 6.01°C. Statistical analysis showed that the rise in temperature in group 1 was significantly higher than the other two groups ($p < 0.05$).

### *Stereoscopic and SEM observation*

Stereoscopic observation showed that a generally clean and smooth root canal wall was achieved after laser irradiation. The apical stop was retentive and was not destroyed by laser irradiation. No obvious charred area or cracks were noted on the irradiated root canal, but slight carbonization was observed in three specimens in groups 1 and 2.

The SEM findings varied in different portions of the root canal. In the non-irradiated specimens (control), the root canal walls were generally clean in the coronal and middle thirds with smear layer remaining in only some specimens. In the apical third, most of the specimens revealed heavy smear layer and debris obscuring the dentinal tubules (Fig. 1a). In the laser-treated groups, most of the smear layer and debris had evaporated, and the orifices of dentinal tubules were open in all portions of the root canal walls (Fig. 1b). Localized melting, fusion and recrystallization of dentin walls were observed in some areas at the apical third in the laser-treated groups. Specimens in group 1 had the most clean root canal wall.

The scores of the remaining smear layer on the prepared root canal wall of each group are shown in Table 4. In group 1,

TABLE 3. RESULTS OF TEMPERATURE RISE MEASUREMENTS

| *Group* | *Temperature rise (°C)* | *Mean and SD* |
|---|---|---|
| 1 | 8.0, 7.9, 8.1, 8.0, 7.9, 8.1, 7.7, 6.8, 8.1, 8.0 | 7.86 ± 0.39[a] |
| 2 | 6.4, 6.0, 6.2, 5.9, 5.5, 6.0, 5.8, 6.2, 6.1, 6.0 | 6.01 ± 0.25 |
| 3 | 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 | 0.00 ± 0.00 |

[a]Significant difference ($p < 0.05$).

Table 4. Scores of Smear Layer

| | Score | | | |
|---|---|---|---|---|
| *Group* | *1* | *2* | *3* | *4* |
| 1 | 4 | 2 | 0 | 0[a] |
| 2 | 3 | 2 | 1 | 0[a] |
| 3 | 0 | 0 | 4 | 2 |

[a]Significant difference ($p < 0.05$).

Table 6. Scores of Transversal Apical Leakage

| | Level from the apex (mm) | | | |
|---|---|---|---|---|
| *Group* | *1* | *2* | *3* | *4* |
| 1 | 1 | 0 | 0 | 0[a] |
| 2 | 1 | 0 | 0 | 0[a] |
| 3 | 3 | 1 | 1 | 0 |

[a]Significant difference ($p < 0.05$).

there were four specimens with score 1, two with score 2; and none with scores 3 and 4. In group 2, there were three specimens with score 1, two with score 2; one with score 3; and none with score 4. In group 3, there were no specimens with scores 1 and 2; four with score 3; and two with score 4. The scores for smear layer of the two laser-treated groups were significantly less compared to the control group ($p < 0.05$). The mean score of group 1 was the least; however, there was no significant difference between two laser-treated groups.

### *Apical leakage scoring*

The mean and standard deviation (SD) of the longitudinal dye penetration for each group are shown in Table 5. The mean penetration depths were 0.88 in group 1, 1.01 in group 2, and 2.12 in group 3. The scoring of apical leakage for transverse sections at each level from the apex is shown in Table 6. Laser-irradiated groups revealed significantly less leakage than the control group ($p < 0.05$) in both longitudinal and transverse sections. Specimens in group 1 showed the least leakage scores, but no significant difference could be found between the two laser-treated groups. Figures 2 and 3 illustrate representative photographs from groups 1 and 3, respectively.

## DISCUSSION

Recently, laser therapy has shown great promise in endodontics, especially in removal of the smear layer that remains on the instrumented root canal wall. Studies have shown that conventional instrumentation together with irrigant solution can only remove the smear layer partially.[6,13] Thus, many researchers have opted for the laser. Argon, $CO_2$, Nd:YAG, Er:YAG, and Er,Cr:YSGG lasers have been reported to be effective in removing intracanal debris.[8,14–17] Previous studies demonstrated that the diode laser showed promising bactericidal effects in root canals.[11,18] Moreover, Moritz *et al*. reported that an 809-nm diode laser was able to clean the root canal wall as well as close the dentinal tubules.[10] In the present study, a diode laser of 980-nm wavelength was used, and results obtained were similar. Compared with a conventionally instrumented root canal wall, a canal wall prepared by mechanical instrumentation combined with a diode laser was significantly cleaner. The apical third of the root canal wall was cleaner than the middle third. This can be attributed to the narrower canal in the apical third (i.e., the narrower the root canal was, the closer the laser tip was to the canal), thus melting and evaporating the smear layer easily. However, unlike the findings reported by Moritz et al.,[10] notable dentin fusion or closure of dentinal tubules were not observed in the present study. The different wavelength, mode of laser irradiation, power, exposure time or fiber diameter used in the present study may explain this difference.

Removal of the smear layer may facilitate the antibacterial effect of intracanal medicament, as well as clean the root canal system adequately.[19] Moreover, removal of the smear layer may improve the adaptation of the filling material to the canal wall, resulting in a better obturation seal. Indeed, the results of the present study demonstrated that the more completely the smear layer was removed, less was the apical leakage observed after obturation. Since leakage is considered an important factor in the failure of root canal therapy and root canal retreatment,[20,21] conventional root canal preparation combined with application of a diode laser may be beneficial for the overall success of the treatment.

The thermal effect on periodontal and alveolar bone tissues is usually a major concern when using lasers in root canals. A study indicated that bone tissue is sensitive to heat at the level of 47°C, which represents an approximate 10°C increase in temperature for 1 min.[22] In another study, greater damage to bone was demonstrated after the temperature was raised to 53°C for 1 min. Temperatures above this value resulted in tissue necrosis.[23] Therefore, one must not exceed these thresholds during laser application in root canal. Other reports demonstrated that heat generation on the root surface induced

Table 5. Results of Longitudinal Apical Leakage

| *Group* | Linear dye penetration (mm) | | | | | | | | *Mean and SD* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.5 | 0.3 | 0.9 | 0.8 | 1.6 | 2.1 | 0.2 | 0.6 | 0.88 ± 0.62[a] |
| 2 | 1.1 | 0.5 | 0.2 | 2.6 | 0.5 | 0.6 | 0.9 | 1.7 | 1.01 ± 0.74[a] |
| 3 | 2.9 | 2.2 | 3.3 | 0.5 | 2.4 | 0.9 | 2.8 | 2.0 | 2.12 ± 0.91 |

[a]Significant difference ($p < 0.05$).

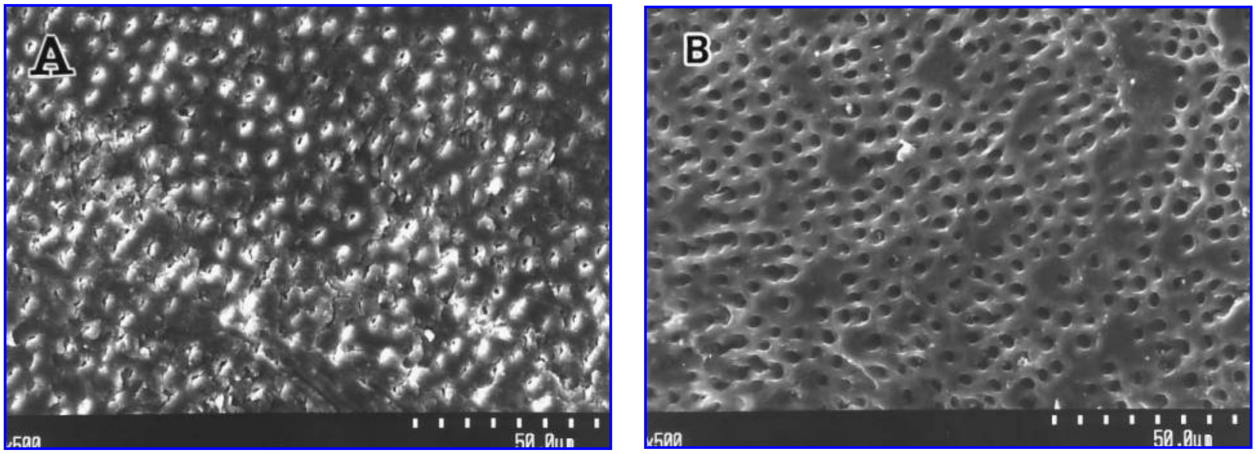


**FIG. 1.** (**A**) Representative scanning electron microscopy (SEM) photograph from group 3. In the apical third, heavy smear layer and debris obscured the dentinal tubules (original magnification, ×500). (**B**) Representative SEM photograph from group 1. In the apical third, smear layer and debris were evaporated, and the orifices of dentinal tubules were open. Localized melting and fusion of dentin wall was observed (original magnification, ×500).

by 809-nm diode laser irradiation in the root canal wall was proportional to the duration of laser irradiation. When the fiber was kept in one spot for 1, 2, and 3 sec, temperature rises of 6°C, 12°C, and 18°C were detected.[9,10] In the present study, a maximal temperature elevation of 8.1°C was registered in group 1 (fiber diameter 550 μm), which was less than the level that causes tissue damage. Therefore, periradicular tissue was considered to be capable of tolerating the temperature change during diode laser irradiation in root canals in the clinic. A significantly higher mean temperature rise was

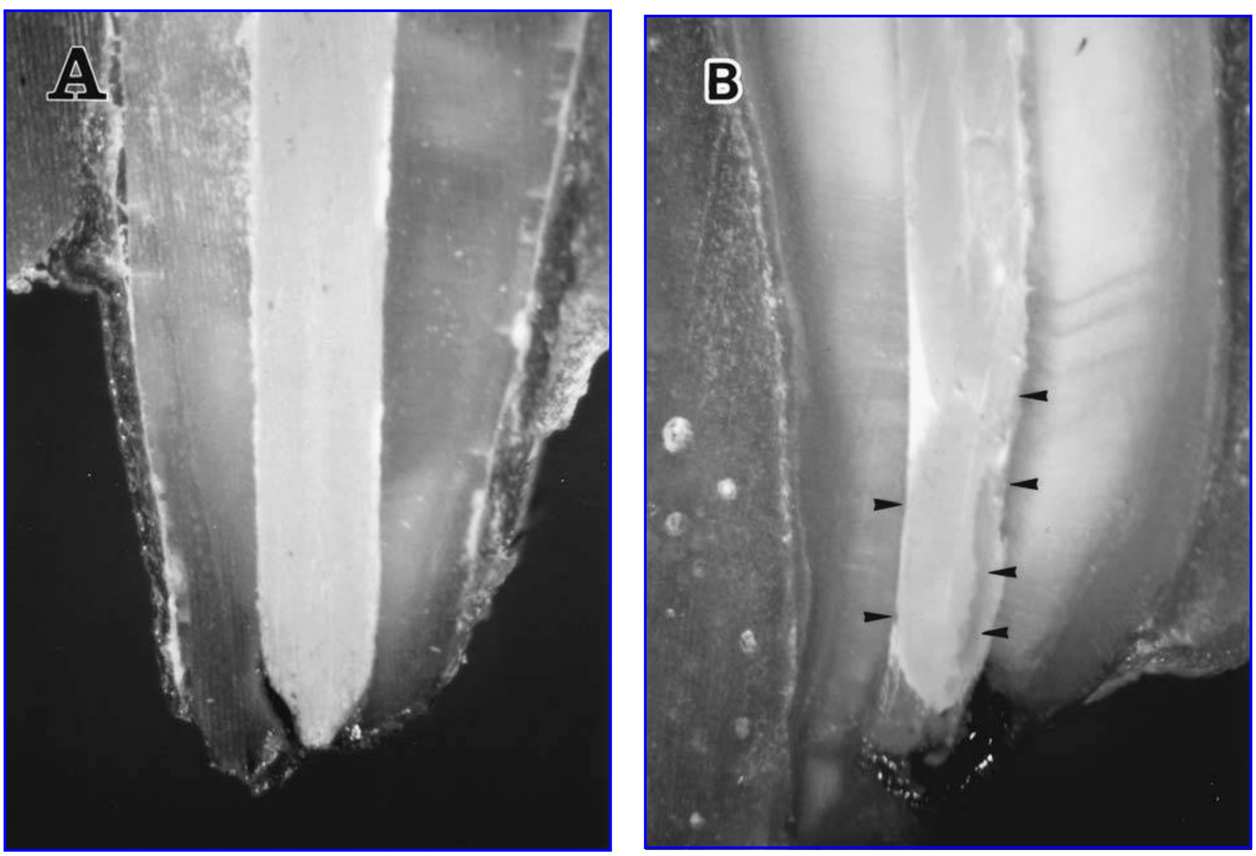


**FIG. 2.** (**A**) Representative stereoscopic photograph of longitudinal bisection from group 1. No notable apical leakage was observed (original magnification, ×16). (**B**) Representative stereoscopic photograph of longitudinal bisection from group 3. There was significant leakage in the apical area (arrows; original magnification, ×16).

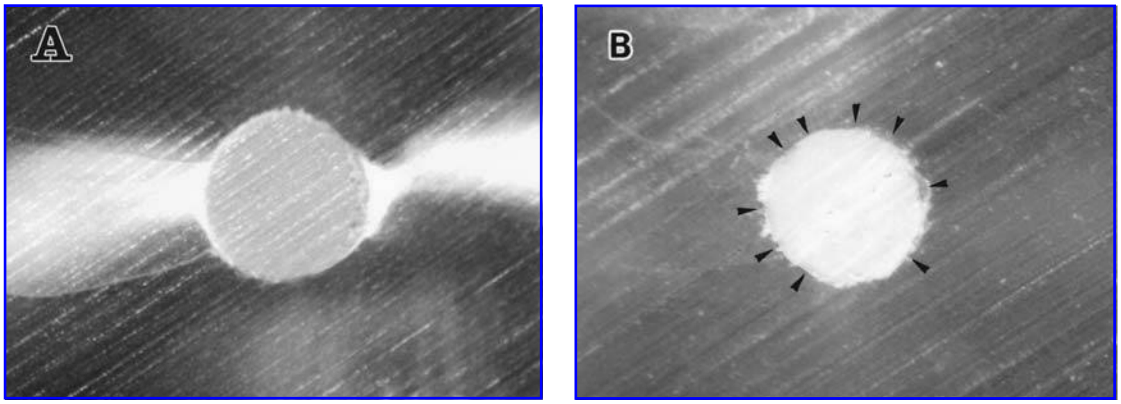


**FIG. 3.** (**A**) Representative stereoscopic photograph of transversal section from group 1. No notable apical leakage was observed (original magnification, ×20). (**B**) Representative stereoscopic photograph of transversal section from group 3. There was significant leakage in the apical area (arrows; original magnification, ×20).

noted in group 1. Nevertheless, the two laser-treated groups did not show any significant difference in the smear layer score and leakage observation. Regarding the results in the present study, we could speculate that employing thinner, more flexible fibers may help to achieve a safer outcome when the diode laser is used for root canal treatment. However, it must be stressed that the fiber should be kept in constant motion while in the root canal during irradiation to avoid rise in temperature on the root surface.

Dye is commonly used as an indicator to apical leakage in *in vitro* studies for evaluating different endodontic instrument techniques, by measuring the linear dye penetration between the canal walls and the obturating materials.[24] However, a very significant element in the experimental design of dye penetration studies is the method used to evaluate the degree of immersion.[25] The methods generally used are horizontal section[26,27] and longitudinal section.[28,29] Either technique has its advantages and disadvantages. Therefore, both methods were adopted in the present study. The results from both types of sections were consistent, and showed that irradiation of 980-nm wavelength diode laser was useful for reduction of apical leakage after obturation.

Many different laser wavelengths have been investigated for use in the field of endodontics. Among them, Nd:YAG laser is the most frequently used and accepted one.[8,30,31] The relatively new diode laser is portable, compact and efficient for practical applications, such as to stop bleeding during surgical operation,[32] to achieve disinfection and sterilization in root canal,[18] and to relieve pain after treatment.[33] Moreover, its thin and flexible fiber benefits access into narrow and curved root canals. This advantage is of great value in its potential for endodontic application. It was also verified in the present study that root canal preparation combined with 980-nm wavelength laser was able to clean canal walls and open dentinal tubules, as well as reduce apical leakage. Because the penetration depth by this laser is lower than that of Nd:YAG laser (wavelength 1064 nm), the risk of thermal side effects seems to be lower. Therefore, the encouraging results of the present study suggest that the diode laser is potentially a valid and safe tool for endodontic treatment. Further research on this laser for practical use is needed before it is clinically applied.

## CONCLUSION

The results of the present study suggest that a diode laser of 980-nm wavelength is useful for removing smear layer and debris from root canal walls, and for reducing apical leakage after obturation *in vitro*. As the rise in temperature on the root surfaces during and after laser irradiation was below the limit to cause damage of periodontal tissues, it is suggested that it would also be useful for root canal treatment in clinic.

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Address reprint requests to:
*Dr. Koukichi Matsumoto*
*Department of Cariology & Endodontology*
*Showa University School of Dentistry*
*2–1-1 Kitasenzoku, Ohta-ku*
*Tokyo 145–8515, Japan*

*E-mail:* yukimura@senzoku.showa-u.ac.jp

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