Root Canal Irrigation Using Nd:YAG Laser in Combination with Various Solutions – A Morphological Study

Teruo Ikarugi[a], Kenji Koba[b], Jun-Ichiro Kinoshita[b], Koukichi Matsumoto[c]

[a] *Researcher, Department of Clinical Cariology and Endodontology, Showa University Dental School, Tokyo, Japan.*
[b] *Lecturer, Department of Clinical Cariology and Endodontology, Showa University Dental School, Tokyo, Japan.*
[c] *Professor and Chair, Department of Clinical Cariology and Endodontology, Showa University Dental School, Tokyo, Japan.*

Purpose: In order to minimize thermal damage when Nd:YAG laser is applied in root canals and to improve the cleaning effects of laser irradiation, the Nd:YAG laser was combined with NaOCl or EDTA, and the morphological effects were investigated by scanning electron microscopy.

Materials and Methods: Seventy-eight extracted human mandibular central and lateral incisors were used. After root canal enlargement, each root canal was filled with either 5% or 12% sodium hypochlorite or 7% or 14% EDTA. In the laser irradiation group, the pulsed Nd:YAG laser was applied at an output of 1 or 3 W and a frequency of 15 PPS for 5 s, and a 320-µm fiber was inserted into the root canal filled with the irrigant solution and moved up and down within a range of about 5 mm from the apical end. Ultrasonic cleaning was used as control. Each tooth was sectioned mesiodistally, and SEM observation was performed to statistically compare the cleaning effects of the laser irradiation and ultrasonic cleaning groups.

Results: No statistically significant differences existed in the cleaning effects with respect to irrigant solution type and concentration. However, NaOCl tended to be superior to EDTA. In the laser irradiation group, cleaning effects were greatest in the apical area. When compared to the control, statistically significant cleaning effects were obtained by combining 3-W Nd:YAG laser and an irrigant solution.

Conclusions: The results confirmed that 3-W Nd:YAG laser eliminated the smear layer without damaging the hard tissue inside the root canal.

Keywords: root canal irrigation, NaOCl, EDTA, concentration, Nd:YAG laser, SEM.

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In root canal therapy, it is important to completely eliminate the dental pulp, contaminants, and bacteria from the canal by root canal preparation and irrigation. As a general rule, root canals are cleaned mechanically using a reamer or file, or chemically using various agents. Since the root canal system is complicated and delicate, it is difficult to completely eliminate organic and inorganic substances that remain in the root canals, even with the most thorough mechanical cleaning. Therefore, in clinical settings, the residual dental pulp tissue and contaminants are dissolved and eliminated using chemicals that can also sterilize root canals.[1] Root canals are usually filled with an irrigant and then mechanically enlarged and cleaned with the aid of the irrigant.

During mechanical root canal preparation, dentin particles and dental pulp fragments may accumulate on the reamers and files and reduce the cutting efficiency.

Instrumentation may also result in accumulation of debris in the apical or lateral root canal, thus hindering root canal preparation. Furthermore, if contaminants are pushed out of the apical foramen, the risk for acute apical lesions increases, and the smear layer remaining on the root canal wall can lead to incomplete root canal filling. In order to solve these problems associated with mechanical cleaning, it is necessary to perform mechanical preparation under chemical irrigation to prevent metal galling and fatigue, and repeatedly irrigate the root canal to dissolve and eliminate dentin particles and residual contaminants.[2]

Sodium hypochlorite solution is widely used as a root canal irrigant in endodontics, and basic studies are being conducted to ascertain the dissolution of organic substances, such as dental pulp and bacteria, remaining in root canals.[2] In addition, EDTA solution has been shown to eliminate the dentinal fragments on the root canal wall following root canal enlargement and preparation.[3] Furthermore, it has been reported that cleaning effects can be improved by combining an ultrasonic generator and a chemical irrigant.[4]

Since the development of laser fibers that can be placed in root canals, the use of lasers in endodontic therapy has rapidly advanced. However, excessive heat generation due to laser irradiation can cause severe tissue damage, such as carbonization and burns on the root canal wall and apical periodontal tissue. This can markedly worsen the prognosis of root canal therapy.[5] Because a laser beam is concentrated light, heat generation cannot be avoided, and it is necessary to pay close attention to controlling heat.[6]

Therefore, in the present study, in order to minimize thermal damage during laser irradiation and improve the effects of the irrigant, laser irradiation was performed while irrigating root canals with either sodium hypochlorite, which readily dissolves organic substances, or EDTA, which effectively dissolves inorganic substances.

It has also been reported that the cleaning effects of sodium hypochlorite and EDTA vary depending on the concentration;[7] however, only a few studies have investigated cleaning effects. Therefore, in the present study, laser irradiation was performed in conjunction with different concentrations of the irrigants, and scanning electron microscopy was performed to morphologically analyze the irradiation effects.

MATERIALS AND METHODS

Teeth and Experimental Groups

After obtaining approval from the ethics review board of Showa University School of Dentistry, 78 human mandibular central and lateral incisors were used. The teeth were extracted due to periodontitis or periapical infection and were nonvital, with no curvature or past root canal therapy.

Because it took 2 months to collect the teeth, the properties of soft tissue inside the root canals had to be made as similar as possible. For this purpose, the teeth were soaked in 10% formalin immediately after extraction and then stored in distilled water 7 days before the start of the study.

At a distance of 17 mm from the apex, the crown was cut off using a diamond bur, and a #2 largo bur was used to expose the root canal orifice. According to the conventional method, 5 ml of 5% sodium hypochlorite and 3% hydrogen peroxide solutions were alternately used 4 times each. Using an ISO 2/100 tapered manual K file, the working length was set at 1 mm short of the physiological root canal foramen, and resistance form was established using a finishing #40 file. While filing with a length of 14 mm, flare was created in the middle area of the root canal to complete root canal preparation.

As shown in Table 1, the 78 teeth were randomly divided into 13 groups of 6 teeth each. NaOCl was used in groups 1 to 6, EDTA in groups 7 to 12, with group 13 serving as the negative control.

Laser Irradiation and Ultrasonic Cleaning

In each root canal, either 5% or 12% NaOCl or 7% or 14% EDTA was filled into the root canal orifice. Either an Nd:YAG laser fiber was inserted for laser irradiation or a file-type tip of the ultrasonic cleaner was inserted to generate oscillation. Group 13 served as the negative control: after root canal preparation, 5% NaOCl and 3% H_2O_2 solutions were used alternatively once, but no external energy was applied.

In the laser irradiation group (groups 1 to 4 and 7 to 10), an Impulse Dental Laser (Denics International; Tokyo, Japan) was used. The device generates the Nd:YAG laser with a wavelength of 1.064 µm, a maximum output of 6 W and a frequency of 5 to 100 pps. In the present study, the output was set at either 1 or 3 W, the frequency at 15 pps, and the irradiation time 5 s. The fiber tip was positioned about 1 mm above the apical seat, and as irradiation began, the fiber tip was moved up and down within a range of about 5 mm from the apex.

In the ultrasonic cleaning groups (groups 5, 6, 11, 12), an ultrasonic root canal cleaner (ENAC AC-6, Osada Denki; Tokyo, Japan) was used, and as the tip, a #30 U-file (ultrasonic oscillator) was used with the power level set at 2.0. The file tip was positioned about 1 mm above the apical seat, and once oscillation began, the tip was moved up and down within a range of about 5 mm from the apex for 5 s to clean the root canal.

Observation and Assessment Methods

Each tooth was covered to prevent contamination of the root canal with dust, and the irrigant remaining in the root canal was allowed to evaporate naturally at room temperature. A diamond disk was used to make a mesiodistal cut along the tooth axis including the apical foramen, and the root was divided vertically using a pair of pliers. At this stage, caution was exercised so that the diamond disk or plier blade did not come in contact with the inner surface of the root canal wall. After observing the root canal wall surface using a stereomicroscope (Nikon; Tokyo, Japan), serial alcohol dehydration, critical point desiccation, and platinum coating of the samples were conducted. Then, using a scanning electron microscope (FE-SEM 4700, Hitachi; Tokyo, Japan), the dentin surface 5 to 10 mm from the apical seat was morphologically observed. Three operators who were unaware of the study details assessed the condition of the residual smear layer using modified Hülsmann's standards[8] in 5 grades from scores of 0 to 4.

Score 0: No smear layer is seen, dentinal tubule orifices can be clearly seen, no residues in the tubules.

Score 1: No smear layer exists on the root canal wall, but residues are visible in dentinal tubules.

Score 2: A slight smear layer is seen, and many dentinal tubule orifices are visible.

Score 3: A smear layer is attached to the root canal wall, and dentinal tubule orifices are slightly visible.

Score 4: A smear layer remains covering the root canal wall, and no dentinal tubule orifices are visible.

Statistical Analysis

The Mann-Whitney U-test was used to statistically analyze the differences between groups 1 to 6 (NaOCl) and 7 to 12 (EDTA). The Kruskal-Wallis test was additionally used to statistically compare the 1-W Nd:YAG laser groups (1, 2, 7, 8), the 3-W Nd:YAG laser groups (3, 4, 9, 10), and the ultrasonic cleaning groups (5, 6, 11, 12).

Table 1 Experimental groups

Group	Chemicals	Accelerator	No. of samples
1	5% NaOCl	1-W Nd:YAG	(n=6)
2	12% NaOCl	1-W Nd:YAG	(n=6)
3	5% NaOCl	3-W Nd:YAG	(n=6)
4	12% NaOCl	3-W Nd:YAG	(n=6)
5	5% NaOCl	Ultrasonic	(n=6)
6	12% NaOCl	Ultrasonic	(n=6)
7	7% EDTA	1-W Nd:YAG	(n=6)
8	14% EDTA	1-W Nd:YAG	(n=6)
9	7% EDTA	3-W Nd:YAG	(n=6)
10	14% EDTA	3-W Nd:YAG	(n=6)
11	7% EDTA	Ultrasonic	(n=6)
12	14% EDTA	Ultrasonic	(n=6)
13 (control)	—	—	(n=6)
Total:			78

RESULTS

Stereomicroscopic Findings

No carbonization or severe dissolution of the root canal wall or apical seat damage were seen under any of the irradiation conditions (Figs 1 and 2). After ultrasonic cleaning, root canals showed no marked ledges or fissures in the wall or apical area, irrespective of the irrigant type (Fig 3). In the control group, no marked differences were seen near the apical seat when compared to the other groups (Fig 4), but in group 1 (5% NaOCl and 1W-Nd:YAG laser) and group 13 (control), white powder-like dentin particles remained near the middle area of the root canal wall (Figs 1 and 4).

Scanning Electron Microscopic (SEM) Findings

1) Dentin loss in the apical area

SEM showed that irrespective of the irrigant type and irradiation condition, the surface of laser-treated dentin inside the root canal did not show carbonization, fissures, or unevenness caused by marked loss, nor were there findings indicative of dentin fusion and fixation

Fig 1 A representative light-microscopic image of a group 1 specimen (5% NaOCl, 1-W Nd:YAG laser). No damage to the shape of the canals was observed. A whitish substance, which suggested the existence of remaining debris, was seen at the middle area of the canal wall (magnification 8X).

Fig 2 A light-microscopic image of a group 3 specimen (5% NaOCl, 3-W Nd:YAG laser). No damage to the shape of the canals was observed. The canal wall appeared very clean at the middle as well as apical area (magnification 8X).

Fig 3 A light-microscopic image (magnification 8X) of a group 5 specimen (5% NaOCl, ultrasonic treatment). No damage to the shape of the canals was observed. The canal wall at the apical area was not clean. The white color at the middle area appeared to be excavated dentine upon SEM observation.

Fig 4 A light-microscopic image of a group 13 specimen (control). Debris and tissue remnants were detected in all areas of the canal system (magnification 6X).

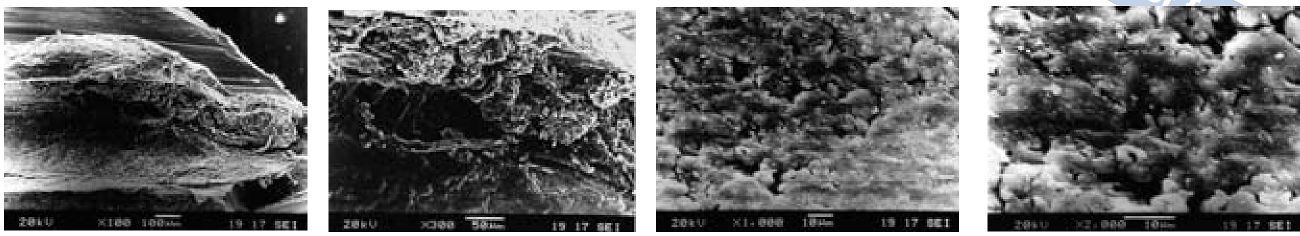

Fig 5 Representative SEM images of group 3 (5% NaOCl, 3-W Nd:YAG laser), showing apical area. From left to right: no destruction of apical seat (100X); a small remnant of pulp tissue (300X); a thin smear layer (1000X); debris on the smear layer (200X). The score was 2.

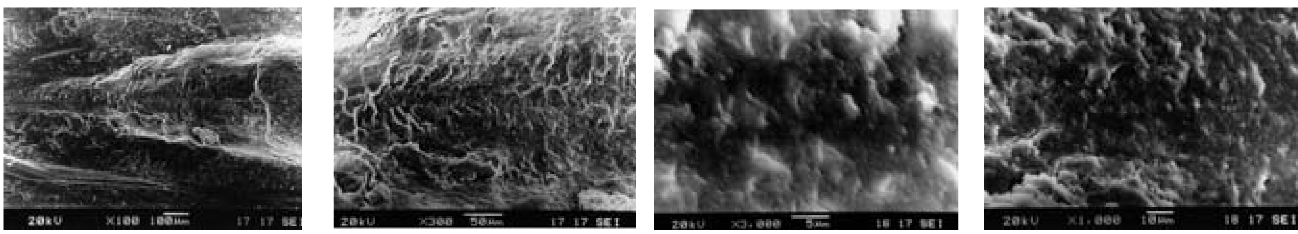

Fig 6 Representative SEM images of group 4 (12%-NaOCl, 3 W-Nd:YAG laser), showing apical area. From left to right: ideal shaping of apical seat (100X); no remnant of pulp tissue (300X); no smear layer (3000X); no debris on the wall (1000X). The score was 1.

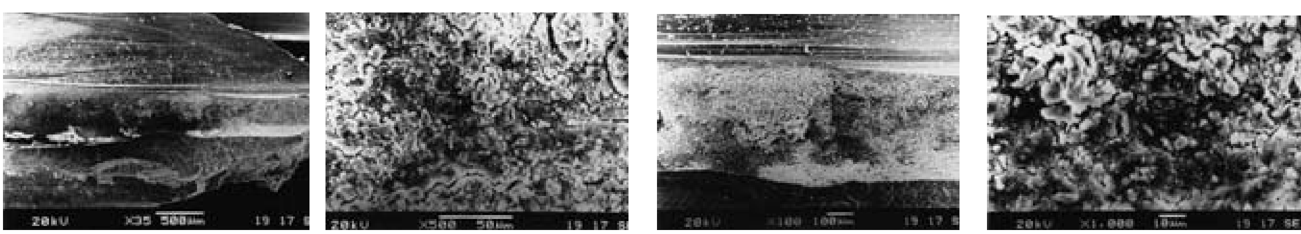

Fig 7 Representative SEM images of group 10 (14% EDTA, 3-W Nd:YAG laser), showing apical area. From left to right: thick smear layer in the middle third (35X); clean, flat appearance of apical third (50X); no debris (100X); smear layer conceals dentinal tubules (1000X). The score was 2.

(Fig 5). Of the 24 samples in groups 3, 4, 9, and 10, where 3-W laser was used, small ledges were seen near the apical seat in 11 samples (Fig 6). In the ultrasonic cleaning group, the dentin surface inside the root canal was smooth, and no marked ledges or fissures were seen (Fig 9). In group 13 (control), no scars from excessive cutting were observed.

2) Surface of the middle area

With regard to the cleaning effects of the root canal wall in the middle area, when compared to the control group, there was less smear layer covering the root canal wall in the laser group for both 1 and 3 W, and dentinal tubule orifices were clearly seen in some regions (Fig 5). Moreover, the cleaning effect of sodium hypochlorite tended to be greater than that of EDTA (Figs 6 and 7). When compared to the 3-W group, the thickness of the smear layer in the middle area was greater for the 1-W and control groups, and there was more debris (Fig 8). When compared to the laser irradiation group, the smear layer covering the root canal wall was slightly less for the ultrasonic cleaning group, and many dentinal tubule orifices were seen, albeit not clearly (Fig 9). When comparing the 2 irrigant solutions in the ultrasonic cleaning group, sodium hypochlorite tended to yield better results.

3) Surface of the apical area

In the apical area, the cleaning effects were seen more clearly in the 3-W than the 1-W laser irradiation

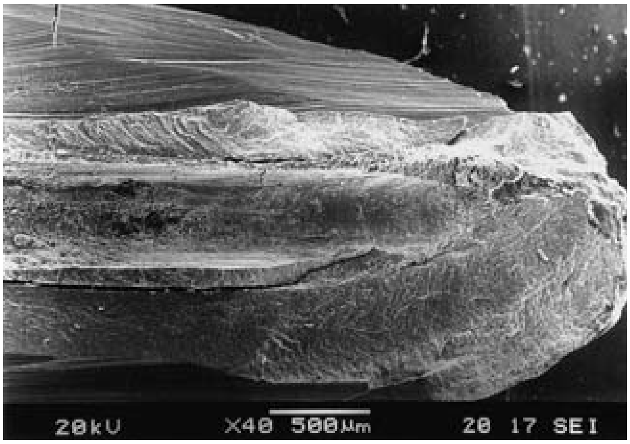

Fig 8 A low-magnification SEM image (40X) of group 1 (5% NaOCl, 1-W Nd:YAG laser), showing the apical area up to middle area. A thick smear layer was seen only at the middle area of the canal. The score was 3.

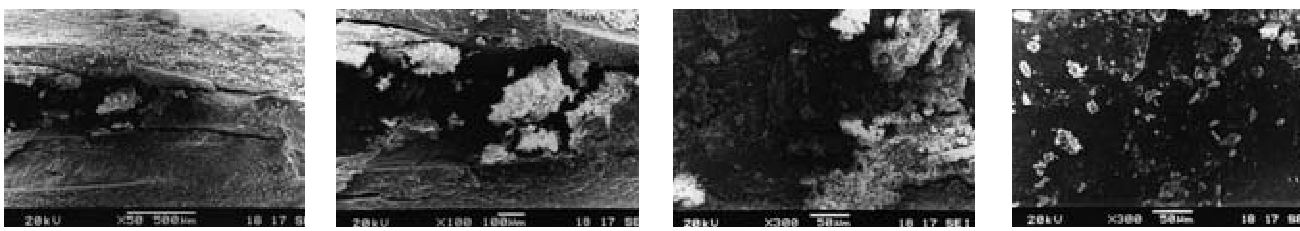

Fig 9 Representative SEM images of group 12 (14% EDTA, ultrasonic treatment), showing the apical area. From left to rigth: plug at apical foramen with compacted debris (50X); a large amount of debris (100X); much remaining pulp tissue (300X); debris on the thick smear layer (300X). The score was 2.

group. Although the smear layer partially remained, the smear layer covering the apical area was markedly less when compared to the control group. The surface of the apical area was smooth, and dentinal tubule orifices were clearly seen (Fig 5). When comparing the 2 irrigant solutions, the above-mentioned tendencies were more pronounced with NaOCl than EDTA (Figs 5 to 8). Compared to the control group, less smear layer covered the apical area than in the ultrasonic cleaning group, but when compared to the root canal wall, the cleaning effects tended to be lower (Fig 9). In addition, dentinal tubule orifices were partially seen, and residues were observed in tubules. With regard to irrigant solution type, the number of dentinal tubule orifices was the highest with 12% NaOCl (Fig 6).

Results of Statistical Analyses

The Kruskal-Wallis test was used to assess elimination of the smear layer in the apical area at a significance level of 5%. Irrespective of the solution types, significant cleaning effects were seen in the apical area with 3-W laser irradiation (groups 3, 4, 9 and 10), and the results were most favorable in group 4 (12% NaOCl and 3-W Nd:YAG laser) in terms of mean and standard deviation. A Mann-Whitney U-test did not show any significant difference between the NaOCl and EDTA group (Table 2).

DISCUSSION

Since the development of thin, flexible Nd:YAG laser fibers that can guide a laser beam inside root canals, laser irradiation inside root canals has shown promise for various applications, including wound surface hemostasis and analgesia following pulp extraction, cauterization of residual dental pulp tissue, promotion of wound healing on the vital pulp surface, root canal enlargement, and root canal sterilization.[9-11]

Studies have reported that when Nd:YAG laser irradiation was applied into a root canal, the root canal was sterilized[12] and the number of bacteria in deep dentin was reduced.[13] Levy[14] used the Nd:YAG laser to enlarge the root canal of extracted human teeth and

Table 2 Relative root canal cleanliness (scores 0 to 4)

Group	Mean score	Irrigant	Accelerator
1	2.163	NaOCl	1-W laser
2	2.167	NaOCl	1-W laser
3	1.333	NaOCl	3-W laser*
4	1.167	NaOCl	3-W laser*
5	2.333	NaOCl	Ultrasonic
6	2.167	NaOCl	Ultrasonic
7	2.333	EDTA	1-W laser
8	2.333	EDTA	1-W laser
9	1.333	EDTA	3-W laser*
10	1.333	EDTA	3-W laser*
11	2.333	EDTA	Ultrasonic
12	2.333	EDTA	Ultrasonic
13	4.000		

Scores: 0 = No smear layer is seen, dentinal tubule orifices can be clearly seen, no residues in the tubule. 1 = No smear layer exists on the root canal wall, but residues are visible in dentinal tubules. 2 = A slight smear layer is seen, and many dentinal tubule orifices are visible. 3= A smear layer is attached to the root canal wall, and dentinal tubule orifices are slightly visible. 4 = A smear layer remains covering the root canal wall, and no dentinal tubule orifices are visible.

* indicates a statistically significant difference. Irrigants: There was no statistically significant difference between groups 1, 2, 3, 4, 5, 6 (NaOCl) and groups 7, 8, 9, 10, 11, 12 (EDTA) (Mann-Whitney U Test, $p > 0.05$). Accelerators: There was a statistically significant difference between groups 1, 2, 7, 8 (1-W laser) and groups 3, 4, 9, 10 (3-W laser) and groups 5, 6, 11, 12 (ultrasonic) (Kruskal-Wallis test, $p < 0.05$).

reported that, compared to manual root canal instrumentation, laser irradiation enhanced the cleaning effects inside the root canal by debris and smear layer removal and sealing of dentinal tubules. It has also been reported that Nd:YAG laser irradiation closed dentinal tubules and smoothed the root canal wall.[15]

However, if the root canal wall or apical periodontal tissue is excessively heated, severe tissue injury such as carbonization and burning can occur, thus negatively affecting the prognosis of root canal therapy. Bahcall and colleagues[16] performed root canal enlargement using the Nd:YAG laser on canine teeth and reported heat-induced inflammation of apical periodontal tissue, and bone and tooth root resorption.

In the present study, in order to buffer heat generated during laser irradiation and improve the irradiation effects, root canals were filled with either sodium hypochlorite, which readily dissolves organic substances,[2,17] or EDTA, which efficiently dissolves inorganic substances.[2,3] Laser irradiation was applied by constantly moving the fiber tip up and down instead of fixing the tip at the apical seat.[18] Irradiation effects were closely examined by morphologically analyzing the samples using scanning electron microscopy, as discussed below.

In all samples of the control group in this study (after root canal enlargement, 5% NaOCl and 3% H_2O_2 were used alternatively), large amounts of the smear layer remained around the apical seat, and conventional alternative cleaning alone was not enough to completely eliminate the smear layer. When compared to the control group, the both laser irradiation and ultrasonic cleaning combined with a chemical agent were more effective in cleaning root canals. The reason for this was that because either sodium hypochlorite or EDTA was placed in the root canal during laser irradiation or ultrasonic cleaning; areas that are difficult to clean were effectively cleaned, thus resulting in greater cleaning effects than the control group.

Combined Effects with NaOCl

When compared to the control, the cleaning effects were greater in the groups in which the laser irradiation was applied in conjunction with sodium hypochlorite (groups 1 to 4) and in the groups in which ultrasonic cleaning was performed with sodium hypochlorite (groups 5 and 6). In the present study, no significant differences were seen in cleaning effects between group 1 (5% NaOCl and 1-W laser), group 2 (12% NaOCl and 1-W laser), group 3 (5% NaOCl and 3-W laser), and group 4 (12% NaOCl and 3-W laser), although cleaning effects were slightly better for group 4 (12% NaOCl and 3-W laser). Therefore, unlike EDTA, sodium hypochlorite tended to be more effective at higher concentration with the output of 3 W.

Comparing group 5 (5% NaOCl and ultrasonic cleaning) and group 6 (12% NaOCl and ultrasonic cleaning), the cleaning effects in group 6 were slightly higher, thus suggesting that unlike EDTA, the effects of sodium hypochlorite are concentration dependent. This could be explained based on the generally accepted notions that most chemical actions are accelerated at higher temperatures, and when energized, molecules in a solution become radical ions which facilitate chemical reactions. In other words, because laser irradiation generated heat and was carried out in a solution, linear laser light hit and scattered ions in the solution, thus evenly diffusing laser photon energy throughout the root canal with minimal damage. Subsequently, the temperature of sodium hypochlorite increased, accelerating chemical reactions, which promoted the cleaning effect.

Combined Effects with EDTA

In the present study, when compared to the control group, higher cleaning effects were seen for all groups where EDTA was used without any sign of marked dentin loss, ie, groups 7 to 10, in which laser irradiation was combined with EDTA, and groups 11 and 12, in which ultrasonic cleaning was combined with EDTA. No significant differences were seen in cleaning effects between group 7 (7% EDTA and 1-W laser), group 8 (14% EDTA and 1-W laser), group 9 (7% EDTA and 3-W laser), and group 10 (14% EDTA and 3-W laser). Neither were significant differences observed in cleaning effects between group 11 (7% EDTA and ultrasonic cleaning) and group 12 (14% EDTA and ultrasonic cleaning).

The above findings may be explained as follows. As the final size of root canal enlargement was #40 in the present study, the root canal debris contained many organic substances, such as pulp, predentin, or dental fibers, but not many dentin particles, which constitute the inorganic components of the smear layer. Therefore, the cleaning effects of sodium hypochlorite were greater than those of EDTA. Furthermore, laser irradiation improved cleaning effects by accelerating the organic-substance dissolving action of sodium hypochlorite more than the chelating action of EDTA.

Irrigant Solution Action Time

In the present study, no statistically significant differences existed in cleaning effects between sodium hypochlorite and EDTA with respect to irrigant type or concentration. This could be due to the fact that when compared to the other studies, the reaction time of the chemical agents was shorter, and as a result, the effects of the irrigants could not be sufficiently expressed. According to Gurbuz and colleagues,[18] significant differences were seen between the two irrigant solutions, but these solutions were allowed to react with root canals for 15 min, which is too long and not clinically applicable.

Comparison of Cleaning Effects in Different Areas

Cleaning effects in the middle area of the root canal wall were observed but not statistically processed based on a score, but the cleaning effects of the ultrasonic cleaning group appeared to be greater. On the other hand, the cleaning effects of the laser irradiation group were greater in the apical area. This was not influenced by irrigant type or concentration. The reason for this was that while laser light travels linearly, an ultrasonic tip must be in contact with the dentin wall to be effective,[19] and although 5 s of ultrasonic oscillation and cavitation is enough to sufficiently clean the root canal wall, it is not enough for the apical area. Furthermore, the above-mentioned findings reflected the positional relationship between the root canal tip following preparation and the direction of energy dissemination based on the shape of the file tip of the ultrasonic cleaner, or the volume of irrigant solution around the file tip.

Laser Irradiation

During cleaning of root canals with pulsed Nd:YAG laser, some dentin loss may occur. In one study, after applying black ink, 2 W of laser irradiation at 30 pps for 60 s eliminated about 40 µm of dentin.[20] In the present study, when 24 samples were irradiated at 3 W, some loss of root canal dentin was seen in 11 samples. In all cases, loss was limited to the dentin surface layer, and underlying loss or carbonization was seen. With regards to dentin loss and smear layer elimination, even when the irradiation conditions were the same, the results varied, and the reason for this was that the amount of laser energy absorption varied over a short period of time. Furthermore, laser absorption could have been affected by the differences in dentin color, the moisture content, the severity of calcification, and the difference in surface properties. When laser irradiation causes marked dentin loss and carbonization in root canals, tight adhesion between the root canal wall and filling material can be impaired. Therefore, it is necessary to adjust laser energy to avoid marked tissue loss and carbonization. In order to prevent dentin loss and carbonization inside the root canal while still promoting cleaning effects, it will be necessary to develop a method to selectively stain only the smear layer, lower the pulse count by reducing peak power, and increase the irradiation effect by either lowering laser tip output or shortening single irradiation time.

In terms of the effects of apical cleaning on the prognosis of root canal therapy, laser irradiation that achieves better cleaning effects in the apical area as opposed to the root canal wall would be therapeutically more effective than ultrasonic cleaning. Moreover, laser irradiation possesses hemostatic, analgesic, wound-healing, and sterilization effects, and when combined with a chemical agent, laser irradiation is useful for both infected root canals and root canals without a dental pulp.[21-23]

Lastly, in the present study, the results showed that cleaning effects could be improved by combining a chemical cleaning agent and external energy application, but it is necessary to consider the unique techniques and risks associated with laser irradiation and ultrasound usage. During surgery, a laser fiber or ultrasound tip is placed in areas that are considered difficult to enlarge or clean, eg, apical seat and stenosis, and it is necessary to pay attention to the location of the root canal being cleaned with the tip. Furthermore, in both laser irradiation and ultrasonic cleaning, there is a risk of dispersing the irrigant solution over a wide area, and as a result, it is necessary to take into account oral soft tissue damage and the importance of moisture prevention using rubber-dam. In order to further improve cleaning effects, it is necessary to develop techniques to safely increase energy output, selectively eliminate contaminants, treat curved root canals, activate cells by laser irradiation, and investigate the effects and safety of direct irradiation inside apical lesions.

CONCLUSIONS

In the present study using 78 human mandibular central and lateral incisors, Nd:YAG laser irradiation or ultrasonic cleaning was performed by filling root canals with sodium hypochlorite, which readily dissolves organic substances, or EDTA, which efficiently dissolves inorganic substances. The best cleaning effects in the apical area were found with 3-W laser irradiation combined with 12% sodium hypochlorite; the smear layer was eliminated without damaging the hard tissue inside the root canal.

In general, this study confirmed that Nd:YAG laser irradiation accelerated chemical reactions in root canal irrigating solutions, indicating the potential for extending the application of Nd:YAG laser devices in private practices.

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REFERENCES

1. Haapasalo M, Endal U, Zandi H, Coil JM. Eradication of endodontic infection by instrumentation and irrigation solutions. Endod Topics 2005;10:77-102.
2. Zebnder M. Root canal irrigants. J Endod 2006; 32:389-398.
3. Hülsmann M, Heckendorff M, Lennon Á. Chelating agents in root canal treatment: mode of action and indications for their use. Int Endod J 2003;36:810-830.
4. Cameron JA. The use of ultrasonics in the removal of the smear layer: A scanning electron microscope study. J Endod 1983; 9:289-292.
5. Murakami Y, Unno A, Kimura Y, Okano T, Hossain M, Nakamura Y, et al. A histochemical study of the regeneration process after injury by pulsed Nd:YAG laser irradiation of root canals. Acta Histochem 2002;104:131-137.
6. Lin CP, Lee BS, Lin FH, Kok SH, Lan WH. Phase, compositional, and morphological changes of human dentin after Nd:YAG laser treatment. J Endod 2001;27:389-393.
7. Perez F, Pourcel NR. Effect of a low-concentration EDTA solution on root canal walls: A scanning electron microscopic study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99:383-387.
8. Hülsmann M, Rümmelin C, Scafers F. Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: a comparative SEM investigation. J Endod 1997; 23:301-306.

9. Brugnera A Jr, Zanin F, Barbin EL, Spano JC, Santana R, Pécora JD. Effects of Er:YAG and Nd:YAG laser irradiation on radicular dentine permeability using different irrigating solutions. Laser Surg Med 2003;33:256-259.
10. Takeda FH, Harashima T, Kimura Y, Matsumoto K. Efficacy of Er:YAG laser irradiation in removing debris and smear layer on root canal walls. J Endod 1998;24:548-551.
11. Zhang C, Kimura Y, Matsumoto K, Harashima T, Zhou H. Effects of pulsed Nd:YAG laser irradiation on root canal wall dentin with different laser initiators. J Endod 1998;24:352-355.
12. Kawahito T, Gotoh K, Kataoka M, Kasahara S, Nagata T, Ishida H, et al. Sterilized and destructive effects of Nd:YAG laser on root canal dentin. Jpn J Conserve Dent 1992;35:1187-1191.
13. Ebihara A, Ueno K, Nishioka M, Sekine Y, Takeda A, Nakajima M, et al. Effect of Nd:YAG laser on infected dentin. Jpn J Conserve Dent 1994;37:1029-1036.
14. Levy G. Cleaning and shaping the root canal with a Nd:YAG laser beam: a comparative study. J Endod 1992;18:123-127.
15. Dederich DN, Zakariasen KL, Tulip J. Scanning electron microscopic analysis of canal wall dentin following neodymium-yttrium-aluminium-garnet laser irradiation. J Endod 1984;10:428-431.
16. Bahcall J, Howard P, Miserendino L, Walia H. Preliminary investigation of the histological effects of laser endodontic treatment on the periradicular tissues in dogs. J Endod 1992;18:47-51.
17. Kashima-Tanaka M, Tsujimoto Y, Kawamoto K, Senda N, Ito K, Yamazaki M. Generation of free radicals and/or active oxygen by light or laser irradiation of hydrogen peroxide or sodium hypochlorite. J Endod 2003;29:141-143.
18. Gurbuz T, Ozdemir Y, Kara N, Zebir C, Kurudirek M. Evaluation of root canal dentin after Nd:YAG laser irradiation and treatment with five different irrigation solutions: A preliminary study. J Endod 2008;34:318-321.
19. Imamura M. The cleansing effect by the different irrigation methods of the root canal on endodontic therapy: Part 2. The analysis by computer-aided three-dimensional reconstruction of root canal system. Jpn J Conserve Dent 1994;37:633-642.
20. Nakayama T. A morphological study on the enamel and dentine irradiated by pulsed Nd:YAG laser (D-Lase 300). J Jpn Soc Laser Dent 1992;3:57-64.
21. Piccolomini R, D'Arcangelo C, D'Ercole S, Gatamo G, Schiaffino G, De Fazio P. Bacteriologic evaluation of the effect of Nd:YAG laser irradiation in experimental infected root canals. J Endod 2002;28:276-278.
22. Takeda FH, Harashima T, Eto JN, Kimura Y, Matsumoto K. Effect of Er:YAG laser treatment on the root canal walls of human teeth: an SEM study. Endod Dent Traumatol 1998;14:270-273.
23. Altundasar E, Özçelik B, Cebreli ZC, Matsumoto K. Ultramorphological and histochemical changes after Er,Cr:YAGG laser irradiation and two different irrigation regimes. J Endod 2006; 32:465-468.

Contact address: Koukichi Matsumoto, Showa University School of Dentistry, Department of Clinical Cariology and Endodontology, 2-1-1 Kitasenzoku, Ohta-ku, Tokyo 145-0062, Japan. Tel: +81-3-3787-1151 (ext. 247), Fax: +81-3-3787-1229. e-mail: koukichi@senzoku.showa-u.ac.jp