Journal of Clinical Laser Medicine & Surgery
Volume 21, Number 5, 2003

Pp. 307–315

Comparative Study of Carious Dentin Removal by Er,Cr:YSGG Laser and Carisolv

JUN-ICHIRO KINOSHITA, D.D.S., YUICHI KIMURA, D.D.S, Ph.D., and KOUKICHI MATSUMOTO, D.D.S., Ph.D.

ABSTRACT

***Objective:* The present study aimed to compare carious dentin removal by air turbine, Carisolv and erbium,chromium:yttrium,scandium,gallium,garnet (Er,Cr:YSGG) laser, and examine morphological changes before and after these caries removal techniques under light microscopy and scanning electron microscopy (SEM). *Background Data:* Although there have been numerous studies on removing caries by Er,Cr:YSGG laser, none has compared Er,Cr:YSGG laser and Carisolv, or reported on the usage of DIAGNOdent as a diagnostic tool particularly for advanced caries in *in vitro* experiments. *Materials and Methods:* Sixty extracted human teeth diagnosed as advanced caries were divided into three groups based on the treatment received, namely air turbine, Carisolv, and Er,Cr:YSGG laser groups. Each group was sub-divided into two in order to examine the results with or without finishing using nylon brush, 15% ethylene diamine tetraacetic acid (EDTA) or low-power laser, respectively. After evaluation by DIAGNOdent, specimens were observed under light microscopy or SEM. *Results:* Light microscopic observations varied considerably in the three treatment groups. SEM revealed that the surfaces treated by air turbine were very smooth, but with substantial debris. The Carisolv group exhibited a very rough surface with a thick smear layer, while the Er,Cr:YSGG group demonstrated smooth undulations with little smear layer and debris. Among the finishing techniques, the laser group demonstrated the best efficiency. DIAGNOdent scores supported the results of light microscopy. *Conclusion:* These results suggest that caries removal by Er,Cr:YSGG laser is very effective even without finishing and DIAGNOdent is useful for diagnosing advanced caries in *in vitro* experiments.**

INTRODUCTION

EXTENSIVE INFORMATION is available regarding the removal of caries dentin.[1–17] To attain good treatment outcomes, many methods to remove caries have been reported and are still being tested.

In recent years, caries removal by laser has been recognized as a useful method. An erbium,chromium:YSGG (Er,Cr:YSGG) laser device that emits a laser beam at a 2780-nm wavelength with a unique hydrokinetic system was introduced recently.[18] It was reported that clean cuts with minimum damage to enamel and dentin could be achieved by laser irradiation under water spray.[19,20] Studies have covered the effects of laser irradiation on enamel, dentin, root surface,[21] mandibular bone,[22] and soft tissue.[23] Use in endodontic treatment[24,25] and caries prevention has also been studied.[26,27] Regarding possible damage to vital pulp tissue, a few researchers have reported that Carisolv causes no harm to pulp.[28,29] The caries removal efficiency and pulpal thermal response while using Er,Cr:YSGG laser and air turbine have been compared, with results favoring the laser.[30–32] However, no report comparing the caries removal efficacy of Er,Cr:YSGG and Carisolv has been published. It was reported that patients accept Calisolv treatment more than air turbine treatment since anesthesia is not required,[33] but some pediatric patients seemed to dislike the taste.[34] The vast majority of patients accepted caries removal treatment by Er,Cr:YSGG lasers.[35–37]

Various criteria have been used to assess surfaces after removing caries in *in vitro* experimental studies. In addition to light microscopy and scanning electron microscopy (SEM) for morphological investigation, energy dispersive x-ray spectroscopy (SEM-EDX) is used for atomic analyses.[20,21] Al-

Department of Endodontics, Showa University School of Dentistry, Tokyo, Japan.

though radiographs, bacterial culture tests and caries detecting dyes also help to detect caries,[38–42] these tests have several disadvantages in *in vitro* experiments, including troublesome procedures, waste of time and damage to samples.

Experiments have been conducted to examine the caries detection potential of laser-induced fluorescence. Lasers of various wavelengths were examined and their mechanisms and reproducibility were discussed.[43–49] DIAGNOdent, a caries-detecting device using laser, was introduced in 1999. The accuracy of this device was compared to that of an electric caries detector[50] and radiography,[51,52] and showed better results *in vivo*. This laser device is currently used for diagnosis of initial caries. [53,54] However, no studies report of the use DIAGNOdent as an evaluation tool for advanced caries in *in vitro* experiments.

The present study was performed to compare caries dentin removal efficiency and examine the morphological differences among the above three techniques under light microscopy and SEM. In addition, the coincidence of the findings of DIAGNOdent with light microscopic and SEM photographs was evaluated to identify whether it could be used as an evaluation tool *in vitro*.

MATERIALS AND METHODS

Sample selection

More than 100 extracted human permanent teeth with deep proximal caries were collected in our dental hospital and stored in 10% formalin solution. DIAGNOdent (KaVo Dental GmbH, Jena, Germany) was used to evaluate the degree of dental caries in these teeth. This device ($12 \times 15 \times 9$ cm) uses a semiconductor laser of less than 1 mW, emitting a beam of 655-nm wavelength from the tip of the handpiece, which is reflected from the surface of teeth, and is collected at the same tip. The score ranges from 00 to 99, and diagnosis is immediate, with no damage to the tooth. DIAGNOdent scores (D-scores) depend on the amount of metabolic byproducts of caries-causing bacteria, dark color, and irregular surfaces. Although the criteria for diagnosis are not definite, it was considered that the scores between 10 and 15 (D-15, and so forth) would represent initial stage caries capable of recalcification. Scores above D-25 were judged as advanced or chronic caries requiring removal. Sixty teeth that scored between D-45 and D-99 were selected for this experiment as samples with advanced caries. These 60 teeth were arranged based on D-scores and then divided into three groups, each group consisting of almost the same value elements (Table 1).

Air turbine drilling (groups 1-a and 1-b)

Caries removal of the 20 teeth of group 1 was performed using an air turbine at 300000 rpm by an operator who was not informed of the true nature and purpose of the experiment. Drilling was performed under sufficient water spray until caries was completely removed, judging from visual inspection and needle probing. Based on the D-score after drilling, samples were subdivided into two, groups 1-a and 1-b, arranging the samples again so that each sub-group consisted of elements of almost the same value. The 10 teeth of group 1-a were left untreated, while those in group 1-b were finished with an engine-driven nylon brush. D-scores of group 1-b were then recorded and treated surfaces were visually inspected.

Carisolv application (groups 2-a and 2-b)

Caries on group 2 specimens were removed by Carisolv (Medi Team, Sävedalen, Sweden). According to the manufacturer's instructions, the caries surface was dried, the two liquids were mixed, and then applied to the carious area. After 30 sec, caries was removed with excavators and the muddy gel was washed away with water spray. This procedure was repeated until the red gel was not discolored, indicating absence of residual caries. After sub-grouping, the 10 teeth of 2-a were left untreated, and those of group 2-b were finished by rinsing with 15% ethylene diamine tetraacetic acid (EDTA) for 30 sec, though this was not suggested by the manufacturer. All chemical treatment procedures were performed by another operator who was not informed of the true nature and purpose of this experiment. D-scores were recorded, and treated surfaces were visually inspected.

Er,Cr:YSGG laser irradiation (groups 3-a and 3-b)

Caries removal in the 20 teeth of group 3 was performed using Er,Cr:YSGG laser irradiation (Millenium, Biolase, San Clemente, CA) by another operator who was not informed of the true nature and purpose of this experiment. The delivery system of this device consisted of a fiberoptic tube with a sapphire crystal tip (diameter 750 µm) bathed in an adjustable water-air spray. The device emitted a laser beam at 2.78-µm wavelength, pulse duration from 140 to 200 µsec, frequency of 20 Hz, and an output range up to 6 W. Parameters were set at

TABLE 1. EXPERIMENTAL DESIGN: DISTRIBUTION OF TREATED TEETH

Group	*Sub-group*	*Number of teeth*	*Treatment method*	*Finishing*
1	1-a	10	Air turbine	None
	1-b	10	Air turbine	Brush
2	2-a	10	Carisolv	None
	2-b	10	Carisolv	15% EDTA
3	3-a	10	Er ,Cr:YSGG laser	None
	3-b	10	Er,Cr:YSGG laser	Low-power laser

4.0 W and 20 Hz. With the fiber tip lightly touching the surface, teeth were irradiated under water spray until caries was removed, as judged by visual inspection. Irradiation time never exceeded 4 sec at a time. After sub-grouping, the 10 teeth of 3-a were left untreated, whereas a lower output laser irradiation (3.0 W and 20 Hz for 2 sec) was performed on group 3-b from a 5-mm distance for finishing. At each stage, D-scores were recorded and treated surfaces were visually inspected.

Supplementary records

During caries removal, supplementary data concerning the clinical convenience of the three methods, in terms of time, noise, and difficulty in operation were recorded and compared.

DIAGNOdent score analysis

D-scores at each stage were recorded, and results were expressed as mean and standard deviation (SD) rounded off to one decimal place. Statistical analysis was performed using Mann-Whitney's U test, and a value of $p < 0.01$ was considered statistically significant. D-scores after the first treatment were compared to light microscopic or SEM photographs. All D-scores were measured by another operator.

Observation by light microscopy

Nine samples consisting of three from each of the 1-a, 2-a, and 3-a sub-groups, in addition to one advanced chronic caries sample without any treatment, were fixed in 10% neutral-buffered formalin, decalcified in 15% EDTA solution, and then dehydrated in alcohol (70%, 80%, 90%, 100%). After immersion in pure xylene and then a mixture of xylene and paraffin, samples were finally embedded in paraffin. Paraffin blocks were serially sectioned to a thickness of 10 μm. The cut sections were stained with hematoxylin and eosin (H-E) under conventional methods and examined by light microscopy at magnifications of ×200 and ×400 (model BX40F-3, Olympus Optical Co., LTD., Tokyo, Japan).

Observation by SEM

Twenty-four samples consisting of four from each of the six sub-groups were randomly selected and dehydrated through a series of aqueous ethanol (70%, 80%, 90%, 95%, and 100%). After drying with liquid CO_2 using a critical point dryer device (JCPD-3, JEOL, Tokyo, Japan), specimens were sputter-coated with platinum using a platinum ion sputter device (E-1030, HITACHI, Tokyo, Japan) and observed under field emission-SEM (FE-SEM) (S-4700, HITACHI) using a high accelerating voltage of 15.0 kV.

RESULTS

Findings during treatments

The shade or color on treated surfaces noted on visual inspection indicated that some carious substance was left after Carisolv treatment. The samples in the Carisolv group were darker than those in the other two groups. Irregularity of the surface was also observed in Carisolv-treated cases. Laser treatment resulted in a smooth but undulated surface. The air turbine group exhibited a pit with smooth surface. Turbine- and Carisolv- finished groups (1-b, 2-b) seemed to display less debris than their respective unfinished groups (1-a, 2-a). However, the laser finished group (3-b) did not differ greatly from the unfinished group (3-a). Both air turbine and laser groups demonstrated definite cavity margins, which the Carisolv group lacked. There were no sharp edges in the cavity floors in laser and Carisolv groups. Right-angled cavity walls were seen in the air turbine group, while bowl-like cavities were produced by the other two methods. Undercuts in cavity walls were observed in the Carisolv group.

Laser treatment took only 10 sec, while Carisolv with EDTA treatment took 600 sec. Treatment with Carisolv was a rather easy technique, which could be mastered in a few days. Treatment with laser required meticulousness and experience to operate the device as it could produce severe effects on hard tissue in a short time. The failure in choosing parameters or inexperienced handling of the handpiece led to unnecessary damage. Vibration and noise during treatment were noticed only in air turbine treatment, whereas Carisolv treatment had only a minor pressure by hand-instrument with almost no sound (Table 2).

Measurement scores by DIAGNOdent

The D-scores of all groups were significantly reduced after treatment ($p < 0.01$). The D-score of group 1-b recorded the best mean score of D-8.4, while the worst mean score was D-25.6 of group 2-a (Table 3). Carisolv treatment demonstrated significantly worse scores than the other two methods ($p < 0.01$). After finishing, the score decreased by 7.1 points to D-18.5 (group 2-b), although the difference was not statistically significant ($p > 0.01$). Groups 1-a and 3-a also did not show any significant changes in D-score after finishing. Generally, the results by visual inspection were very different from those

TABLE 2. COMPARISON OF SUPPLEMENTARY RECORDS

Group	*Time (sec)*	*Noise*	*Skill*	*Surface appearance*
1-a. Air turbine	40	Terrible	Easy	Clean
1-b. Air turbine + brush	60	Terrible	Easy	Clean
2-a. Carisolv	500	Nothing	Very easy	Not clean
2-b. Carisolv + EDTA	600	Nothing	Very easy	Not clean
3-a. Er,Cr:YSGG	10	Moderate	Difficult	Very clean
3-b. Er,Cr:YSGG + laser	15	Moderate	Difficult	Very clean

TABLE 3. RESULTS OF DIAGNODENT SCORES OF EACH GROUP

Group	*Before treatment*	*After final treatment*
1-a	D-64.5 ± 19.4	D-8.6 ± 5.4
1-b	D-64.6 ± 18.8	D-8.4 ± 6.9
2-a	D-64.4 ± 19.8	D-25.6 ± 15.8]a
2-b	D-64.5 ± 19.9	D-18.5 ± 9.3]a
3-a	D-64.8 ± 19.2	D-10.7 ± 7.7]a
3-b	D-64.5 ± 19.7	D-10.7 ± 6.4]a

[a]Significant statistical difference noted ($p < 0.01$).
Values show mean and SD of 10 teeth scores.

of D-scores, and in most cases, D-scores were lower than those recorded by visual inspection. Conversely, there were a few cases where D-scores were very high, although the surface did not show any apparent caries. D-scores coincided with the light microscopic images individually but there were a few exceptions where light microscopic and SEM images differed.

Light microscopic observations

Photographs of untreated caries surface were taken as controls (Fig. 1). The irregular edge was darkly stained, and the fact that staining ran into the dentinal tubules was recognized. A layered appearance characteristic of chronic caries could be observed. Observation of vertical sections under low magnification (×200) showed that the turbine group left a smooth surface (Fig. 2), the Carisolv group left gentle undulations with a step (Fig. 3), and the Er,Cr:YSGG laser group left a rounded cavity with a small deep pit (Fig. 4). Higher magnification (×400) showed that the turbine-treated specimen had the most irregular edges. Under higher magnification, Carisolv- and laser-treated specimens exhibited very smooth edges with gentle curve. A dark and narrow line on the edge was partially observed in the Carisolv group, while laser-treated specimens had a thin dark-stained band on the whole edge.

FIG. 2. Representative light microscopic photograph from group 1-a. Linear edge without undulation was observed. No caries affected substance or thermal effects were observed (original magnification, ×200; bar represents 30 µm). D-score was 9.

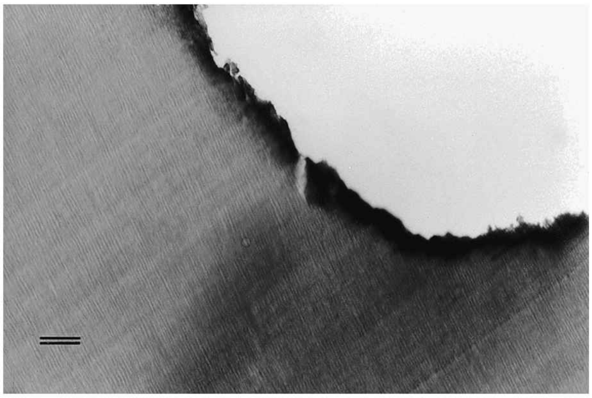

FIG. 1. Representative light microscopic photograph before treatment. Very irregular edge stained dark with hematoxylin was observed. Advanced caries infection was identified on the margin (original magnification, ×200; bar represents 30 µm). D-score was 64.

FIG. 3. Representative light microscopic photograph from group 2-a. Edge was shaped in mild undulation with a step. Very smooth cutting margin was observed (original magnification ×200; bar represents 30 µm). D-score was 26.

FIG. 4. Representative light microscopic photograph from group 3-a. Round cavity with a few small pits was observed. Darkly stained thin band was visible on the margin (original magnification, ×200; bar represents 30 μm). D-score was 10.

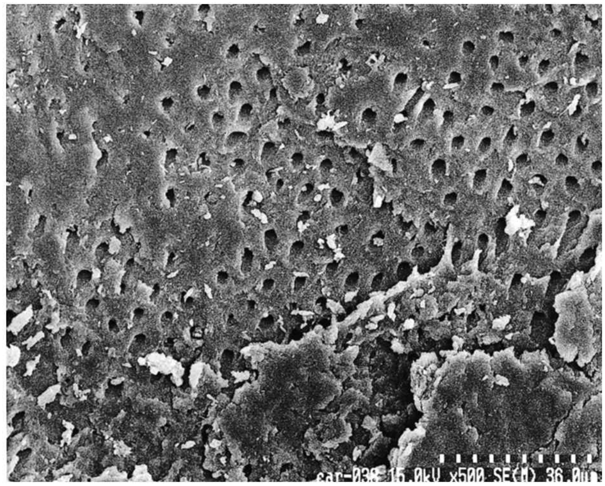

FIG. 6. Representative SEM photograph from group 2-a. Debris plugged in dentinal tubules and partially removed smear layer were observed. Some dentinal tubules were visible (original magnification, ×500; bar represents 36 μm). D-score was 25.

FE-SEM observations

SEM photographs revealed different morphological features in the six sub-groups. In group 1-a (air turbine), the treated dentin surface appeared rather flat in spite of parallel scratch marks. Dentinal tubules were obliterated with debris, and their location could barely be identified. Smear layer and debris were observed on the surface (Fig. 5). This group appeared to be the worst of the six groups in SEM photographs in terms of remaining debris. Group 2-a (Carisolv) showed irregular dentin with a thick smear layer partly sticking onto the surface. Dentinal tubules were partially open, but some were obliterated with excavated debris (Fig. 6). In the image of group 3-a (Er,Cr:YSGG laser), the surface was relatively clean, and almost all dentinal tubules could be identified, with very little debris. No thermal damage such as carbonization or melting was observed (Fig. 7). Among the finished groups, air turbine followed by brushing (group 1-b) showed less debris, but the tubules were still not open (Fig. 8). Carisolv treatment followed by EDTA rinsing (group 2-b) resulted in the removal of the thick smear layer and debris (Fig. 9). Er,Cr:YSGG laser treatment followed by low-power laser irradiation for finishing (group 3-b) showed less remaining debris than that of the unfinished group (Fig. 10). In all groups, finishing techniques were effective in removing smear layer and debris, judging from SEM observations.

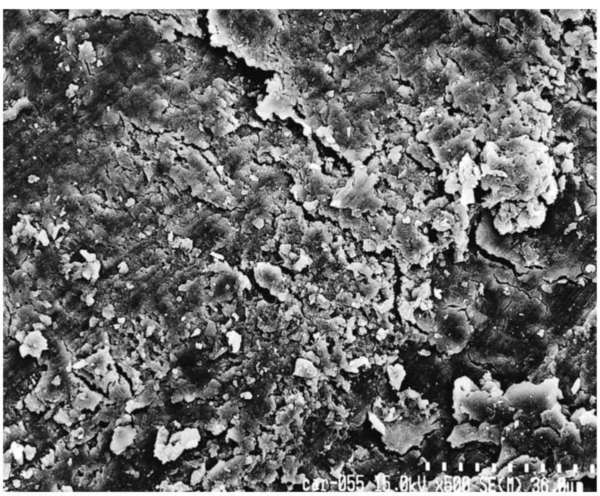

FIG. 5. Representative SEM photograph from group 1-a. Even surface with parallel scratches and much smear layer and debris were observed. No dentinal tubules were visible (original magnification, ×500; bar represents 36 μm). D-score was 8.

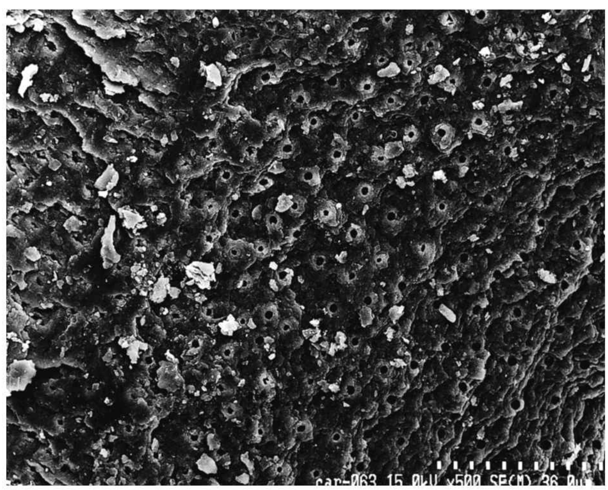

FIG. 7. Representative SEM photograph from group 3-a. Gentle undulation with relatively clean orifices of dentinal tubules and some debris were observed (original magnification, ×500; bar represents 36 μm). D-score was 10.

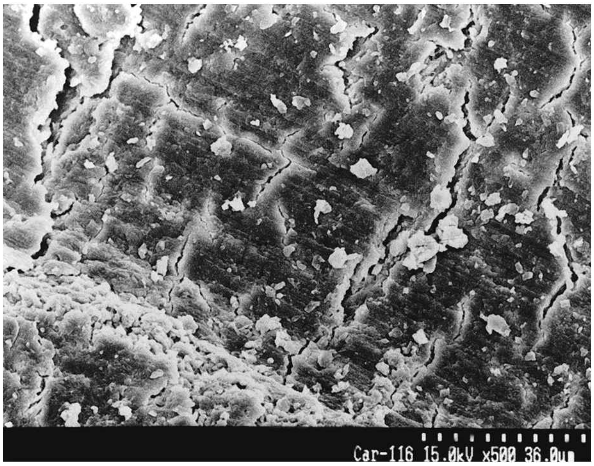

FIG. 8. Representative SEM photograph from group 1-b. Finishing treatment removed much debris, but smear layer and some debris were still observed (original magnification, ×500; bar represents 36 μm). D-score was 8.

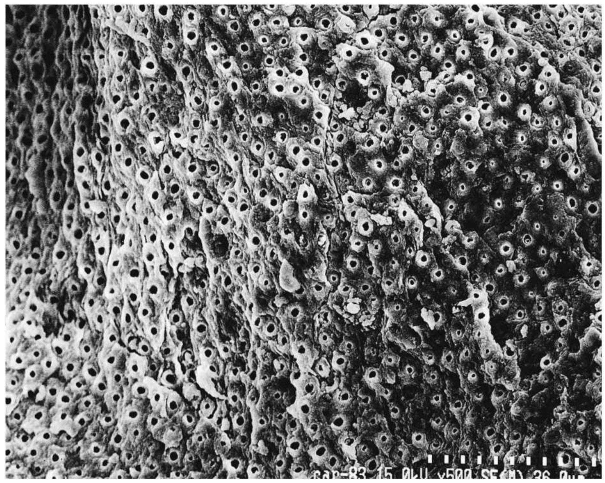

FIG. 10. Representative SEM photograph from group 3-b. Finishing laser treatment made surfaces cleaner. Peritubular dentin remained and intertubular dentin was evaporated (original magnification, ×500; bar represents 36 μm). D-score was 10.

DISCUSSION

Specimens

In the present study, DIAGNOdent was utilized to determine the degree of caries in each tooth. Because this diagnostic method was very easy and quick, sample selection could be performed in a very short time without any harm to the specimens or any subjective judgment by an operator. This device could provide us with prompt answers at any stage of the experiment and any number of times on the same specimen, which enabled us to determine an objective judgment without any bias.[55] Moreover, since DIAGNOdent scores have been reported to be reproducible and valid,[56] the grouping in the present study was successfully performed with each group containing samples with similar scores (Table 1). Although DIAGNOdent used a 655-nm wavelength semiconductor laser and was reported to be the most useful in detecting initial stage caries at occlusal grooves,[50,51] another researcher has pointed out that krypton ion laser devices (407 nm) induce a fluorescent reflection on carious regions of any stage and that the reflection comes from fluorescent porphyrins, particularly protoporphyrin IX.[57] The samples that scored over 45 by DIAGNOdent were judged to be advanced chronic caries because protoporphyrinIX exists in all stages of caries.

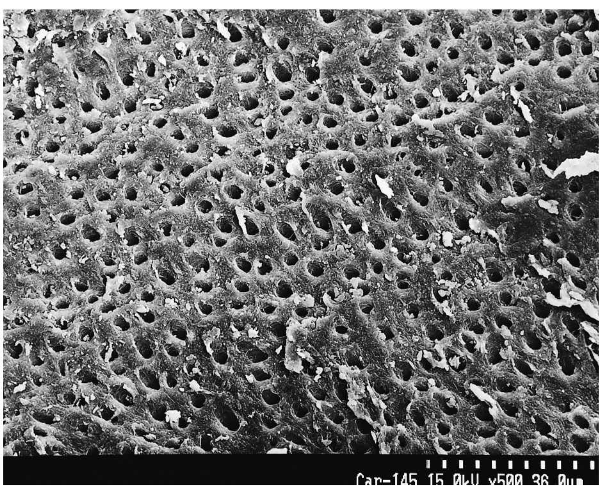

FIG. 9. Representative SEM photograph from group 2-b. Chemical finishing treatment made the surface cleaner and most dentinal tubules were visible (original magnification, ×500; bar represents 36 μm). D-score was 18.

Analysis of light microscopic findings

Light microscopic photographs of vertically sectioned samples showed considerable morphological difference at the edges. One of the most impressive results in this examination was that the air turbine treatment left the most irregular surface in higher magnification (×400) photographs. There was no trace of carbonization by friction heat, which suggested that water spray while drilling prevented thermal damage to the surface, although a slightly dark stained line was seen at a certain distance away from the surface. The dyed line may be interpreted as an artifact from sample preparation. The smear layer and debris must have been removed by decalcification with EDTA during sample preparation for light microscopy.

Photographs of the Carisolv-treated specimen under light microscopy suggested that the blade of a hand excavator produced curved edges with some steps in the softened region, which would be more affected by caries. However, under higher magnification, the edge could be described as smoother than that produced after turbine drilling and a very dark stained portion was observed along the edge. When compared to untreated caries samples, the phase and degree of darkness combined with the dark color on visual inspection suggested that this might be residual caries. Higher magnification photographs (×400) suggested that the stain was running along dentinal tubules. This might be a smear layer that remained even through the process of sample preparation by EDTA.

Light microscopic photographs of specimens irradiated by Er,Cr:YSGG laser showed that laser irradiation resulted in a smooth surface as in Carisolv even in the high magnification image. However, a small pit that was very deep was identified in a lower magnification photograph. This suggested that the laser beam could make a very smooth cavity surface when the time and power of the irradiation were controlled. Unskilled irradiation would result in a pinhole cavity, which might lead to an irregular surface. The dark stained band beneath the surface with smooth border was considered not to be caries but the result of evaporation of water from hydroxyapatite, based on previous studies.[58]

Analysis of SEM findings

SEM observations showed very different morphological features after three treatments. This may be explained by the differences in the mechanisms of caries removal.

First of all, concerning the smoothness of dentin surface, the mechanical friction force of air turbine resulted in a flat surface with parallel cuts or scars. The rotating cylindrical bur made the surface flat. This method cuts off all dentin that was contacted by the bur regardless of the degree of caries. The parallel scars made by diamond particles on the bur suggested vibration and friction heat which might result in pain or damage to pulp during treatment. However, thermal damage such as burnt tissue was not observed in SEM photographs due to cooling by water spray.

Carisolv treatment left a rather rough dentin surface even before EDTA decalcification. SEM images showed a deeply excavated area and a shallowly cut area. It could be interpreted that the chemicals in Carisolv removed only caries affected dentin, which seemed to be a superior feature over air turbine in terms of minimum removal of tooth structure. Researchers supporting chemical caries treatment have insisted that the remaining dentin which appeared as residual caries on visual inspection would be recalcified later.[6–8,15] However, irregular scratches by the hand excavator cannot be ignored. This suggests that there would be areas beyond the reach of the hand-excavator blade. One drawback of Carisolv treatment is the fact that it is not purely a chemical method, but is supplemented by mechanical removal.

SEM showed that a smooth dentin surface with undulation was produced by Er,Cr:YSGG laser irradiation. Melting, which was often observed after the treatment with the other lasers such as Nd:YAG and CO_2 lasers, was not noted. Some researchers inferred that this cutting without thermal damage resulted from the hydrokinetic force of this device.[52,53] Fine droplets sprayed from the laser handpiece absorb laser energy at 2780 nm and modify the strong mechanical force into a powerful but controlled microexplosion on the target tissue surfaces, resulting in a clean cut without thermal damage. Moreover, the undulations made by laser suggested that only the carious substance, which was likely to be removed easily, was vaporized, while sound dentin remained intact.

Er,Cr:YSGG laser treatment showed a cleaner image than the other two. It may be interpreted that the water mist from the laser handpiece flushed off the debris and floating vaporized substances without any direct contact. Contrary to this, air turbine and Carisolv methods require contact for the removal procedure. During air turbine or Carisolv treatment, the bur or hand instrument pushed debris onto the treated surface and obliterated dentinal tubules.

Analysis of DIAGNOdent scores

Based on results of DIAGNOdent measurement, all three methods had significant statistical difference after first treatment. There was a significant statistical difference between Carisolv and the other two in the degree of remaining caries in each sample after the first treatment (Table 3). The highest D-score indicating residual caries was D-25.6 of the Carisolv group, while the lowest score of D-8.6 was that of the air turbine group. It may be suspected that Carisolv made a shallower cavity than the other two techniques because Carisolv treatment was designed to leave as much dentin as possible if it was not completely affected.

In examining the relationship between the presence of caries-like discoloration in light microscopic color images and D-scores, general concurrence could be observed in all cases. On the other hand, compared to SEM photographs, D-scores were not completely coincident. For example, SEM showed more open dentinal tubules in Carisolv cases than in turbine cases, while D-scores were worse in Carisolv cases. The DIAGNOdent might have been affected by the thick smear layers, which were characteristic of Carisolv-treated samples, whereas the debris in dentinal tubules of turbine samples would not have affected the D-score.

The large statistical deviation in Carisolv groups (2-a, 2-b) might be considered as the results of the pinpointed examination by DIAGNOdent and coexistence of sound and caries-affected dentin adjacent to each other in Carisolv-treated samples. Although there was no statistically significant difference, the dramatic decrease of mean D-scores after finishing should be noted.

Although some researchers have reported that DIAGNOdent is most useful in detecting initial stage caries, the present study demonstrated that DIAGNOdent was useful for detection of chronic or advanced caries. In addition to this, measurements could be performed repeatedly at several stages for one specimen without causing any damage. This device possessed some merits that SEM and light microscopy did not have. This laser device may be suitable for caries evaluation in *in vitro* experiments as well as in clinical situations.

CONCLUSION

1. Among the three different methods to remove carious dentin, Er,Cr:YSGG laser treatment required the shortest time with no irritating noise, but appropriate parameters for irradiation were rather difficult to choose.

2. Morphological examination by light microscopy and SEM demonstrated that the Er,Cr:YSGG treatment resulted in a clean surface with open dentinal tubules and was almost free

from carious dentin. Compared to other methods, this laser device did not require the finishing procedure.

3. Morphological examination by light microscopy or SEM combined with examination by DIAGNOdent revealed that air turbine and Er,Cr:YSGG laser treatment removed all of the carious dentin from treated surface. Carisolv treatment removed most of the caries-affected substance easily, but left a gray zone consisting of partially affected dentin that should be removed.

4. A caries-detecting device, DIAGNOdent showed D-scores coinciding with the results of light microscopy. This result suggested that DIAGNOdent was useful for evaluation of chronic advanced caries in *in vitro* experiments.

ACKNOWLEDGMENTS

This study was supported in part by a Grant-in-Aid for Scientific Research (12470407) from the Japan Society for the Promotion of Science (JSPS).

REFERENCES

1. Dyson, J.E., and Darvell, B.W. (1993). The development of the dental high-speed air turbine handpiece. Part 1. Aust. Dent. J. 38, 49–58.
2. Yamanaka, K. (1975). Cellular responses to vibration during dental drilling with belt drive motor engine (*in vitro*). J. Jpn. Soc. Dent. Apparatus Mater. 16, 110–122.
3. Watson, T.F., Flanagan, D., and Stone, D.G. (2000). High and low torque handpieces: cutting dynamics, enamel cracking and tooth temperature. Br. Dent. J. 188, 680–686.
4. Ottl, P., and Lauer, H.-C. (1998). Temperature response in the pulpal chamber during ultrahigh-speed tooth preparation with diamond burs of different grit. J. Prosthet. Dent. 80, 12–19.
5. Dahl, B.L. (1977). Dentine/pulp reactions to full crown preparation procedures. J. Oral Rehabil. 4, 247–254.
6. Habib, C.M., Kronman, J., and Goldman, M. (1975). A chemical evaluation of collagen and hydroxyproline after treatment with GK-101 (*N*-chloroglycine). Pharmacol. Ther. Dent. 2, 209–215.
7. Kronman, J.H., Goldman, M., Habib, C.M., et al. (1977). Electron microscopic evaluation of altered collagen structure induced by *N*-monochloroglycine (GK-101). J. Dent. Res. 56, 1539–1545.
8. Schutzbank, S.G., Galaini, J., Kronman, J.H., et al. (1978). A comparative *in vitro* study of GK-101 and GK-101E in caries removal. J. Dent. Res. 57, 861–864.
9. McCune, R.J. (1986). Report on a symposium on chemomechanical caries removal: a multicenter study. Compend. Contin. Educ. Dent. 7, 151–159.
10. McInnes-Ledoux, P., Ledoux, W.R., and Weinberg, R. (1987). Bond strength of dentinal bonding agents to chemomechanically prepared dentin. Dent. Mater. 3, 331–336.
11. Emanuel, R., and Broome, J.C. (1988). Surface energy of chemomechanically prepared dentin. Quintessence Int. 19, 369–372.
12. Wolski, K., Goldman, M., Kronman, J.H., et al. (1989). Dentinal bonding after chemomechanical caries removal—effect of surface topography. Oper. Dent. 14, 87–92.
13. Wedenberg, C., and Bornstein, R. (1990). Pulpal reactions in rat incisors to Caridex™. Aust. Dent. J. 35, 505–508.
14. Barwart, O., Moschen, I., Graber, A., et al. (1991). *In-vitro* study to compare the efficacy of *N*-monochloro-D,L-2-aminobutyrate (NMAB, GK-101E) and water in caries removal. J. Oral Rehabil. 18, 523–529.
15. Ericson, D., Zimmerman, M., Raber, H., et al. (1999). Clinical evaluation of efficacy and safety of a new method for chemomechanical removal of caries. A multi-centre study. Caries Res. 33, 171–177.
16. Ohshima, T., Kinoshita, J.-I., Suzuki, N., et al. (1998). Basic study of Carisolv™: chemomechanical caries removal reagent. J. Showa Univ. Dent. Soc. 18, 360–365.
17. Cederlund, A., Lindskog, S., and Blomlöf, J. (1999). Efficacy of Carisolv-assisted caries excavation. Int. J. Periodont. Restorat. Dent. 19, 465–469.
18. Eversole, L.R., and Rizoiu, I.M. (1995). Preliminary investigations on the utility of an erbium,chromium YSGG laser. J. Calif. Dent. Assoc. 23, 41–47.
19. Hossain, M., Nakamura, Y., Yamada, Y., et al. (1999). Effects of Er,Cr:YSGG laser irradiation in human enamel and dentin: ablation and morphological studies. J. Clin. Laser Med. Surg. 17, 155–159.
20. Yu, D.-G., Kimura, Y., Kinoshita, J.-I., et al. (2000). Morphological and atomic analytical studies on enamel and dentin irradiated by an erbium,chromium:YSGG laser. J. Clin. Laser Med. Surg. 18, 139–143.
21. Kimura, Y., Yu, D.-G., Kinoshita, J.-I., et al. (2001). Effects of erbium,chromium:YSGG laser irradiation on root surface: morphological and atomic analytical studies. J. Clin. Laser Med. Surg. 19, 69–72.
22. Kimura, Y., Yu, D.-G., Fujita, A., et al. (2001). Effects of erbium,chromium:YSGG laser irradiation on canine mandibular bone. J. Periodontol. 72, 1178–1182.
23. Rizoiu, I.M., Eversole, L.R., and Kimmel, A.I. (1996). Effects of an erbium, chromium: yttrium, scandium, gallium, garnet laser on mucocutanous soft tissues. Oral Surg. Oral Med. Oral Pathol. 82, 386–395.
24. Kimura, Y., Wilder-Smith, P., and Matsumoto, K. (2000). Lasers in endodontics: a review. Int. Endod. J. 33, 173–185.
25. Yamazaki, R., Goya, C., Yu, D.-G., et al. (2001). Effects of erbium,chromium:YSGG laser irradiation on root canal walls: a scanning electron microscopic and thermographic study. J. Endodon. 27, 9–12.
26. Fried, D., Featherstone, J.D.B., Visuri, S. R., et al. (1996). The caries inhibition potential of Er:YAG and Er:YSGG laser radiation. SPIE Proc. 2672, 73–78.
27. Hossain, M., Kimura, Y., Nakamura, Y., et al. (2001). A study on acquired acid resistance of enamel and dentin irradiated by Er,Cr:YSGG laser. J. Clin. Laser Med. Surg. 19, 159–163.
28. Dammaschke, T., Stratmann, U., Mokrys, K., et al. (2001). Histocytological evaluation of the reaction of rat pulp tissue to Carisolv. J. Dent. 29, 283–290.
29. Young, C., and Bongenhielm, U. (2001). A randomised, controlled and blinded histological and immunohistochemical investigation of Calisolv™ on pulp tissue. J. Dent. 29, 275–281.
30. Rizoiu, I., Kohanghadosh, F., Kimmel, A. I., et al. (1998). Pulpal thermal responses to an erbium,chromium:YSGG pulsed laser hydrokinetic system. Oral Surg. Oral Med. Oral Pathol. 86, 220–223.
31. Rizoiu, I., Kimmel, A.I., and Eversole, L.R. (1996). The effects of an Er,Cr:YSGG laser on canine oral hard tissues. SPIE Proc. 2922, 74–83.
32. Eversole, L.R., Rizoiu, I., and Kimmel, A.I. (1997). Pulpal response to cavity preparation by an erbium,chromium:YSGG laser–powered hydrokinetic system. J. Am. Dent. Assoc. 128, 1099–1106.
33. Fure, S., Lingström, P., and Birkhed, D. (2000). Evaluation of Carisolv™ for the chemo-mechanical removal of primary root caries *in vivo*. Caries Res. 34, 275–280.
34. Maragakis, G.M., Hahn, P., and Hellwig, E. (2001). Clinical evaluation of chemomechanical caries removal in primary molars and its acceptance by patients. Caries Res. 35, 205–210.

35. Keller, U., Hibst, R., Geurtsen, W., et al. (1998). Erbium:YAG laser application in caries therapy. Evaluation of patient perception and acceptance. J. Dent. 26, 649–656.
36. Hadley, J., Young, D.A., Eversole, L.R., et al. (2000). A laser-powered hydrokinetic system for caries removal and cavity preparation. J. Am. Dent. Assoc. 131, 777–785.
37. Matsumoto, K., Hossain, M., Hossain, I., et al. (2002). Clinical assessment of Er,Cr:YSGG laser application for cavity preparation. J. Clin. Laser Med Surg. 20, 17–21.
38. Furrer, B. (1922). Die Verkalkungszonen bei der Dentinkaries. Schweiz. Mschr. Zhk. 32, 329–353.
39. Fusayama, T. (1988). Clinical guide for removing caries using a caries-detecting solution. Quintessence Int. 19, 397–401.
40. Foreman, P.C., and Soames, J.V. (1989). Comparative study of the composition of primary and secondary dentine. Caries Res. 23, 1–4.
41. Kidd, E.A.M., Joyston-Bechal, S., and Beighton, D. (1993). The use of a caries detector dye during cavity preparation: a microbiological assessment. Br. Dent. J. 174, 245–248.
42. Yip, H.K., Stevenson, A.G., and Beeley, J.A. (1994). The specificity of caries detector dyes in cavity preparation. Br. Dent. J. 176, 417–421.
43. Bjelkhagen, H., Sundström, F., Angmar-Månsson, B., et al. (1982). Early detection of enamel caries by the luminescence excited by visible laser light. Swed. Dent. J. 6, 1–7.
44. Angmar-Månsson, B., and ten Bosch, J.J. (1987). Optical methods for the detection and quantification of caries. Adv. Dent. Res. 1, 14–20.
45. Albin, S., Byvik, C.E., and Buoncristiani, A.M. (1988). Laser-induced fluorescence of dental caries. SPIE Proc. 907, 96–99.
46. Hafström-Björkman, U., Sundström, F., de Josselin de Jong, E., et al. (1992). Comparison of laser fluorescence and longitudinal microradiography for quantitative assessment of *in vitro* enamel caries. Caries Res. 26, 241–247.
47. Barron, J., Paton, B., and Zakariasen, K. (1992). Micro-analysis of dental caries using laser scanned fluorescence. SPIE Proc. 1643, 503–509.
48. Zakariasen, K.L., Barron, J.R., and Paton, B.E. (1993). Scanned laser-induced fluorescence reproducibility. SPIE Proc. 1880, 221–225.
49. Hill, W., and Petrou, V. (1997). Detection of caries and composite resin restorations by near-infrared raman spectroscopy. Appl. Spectrosc. 51, 1265–1268.
50. Lussi, A., Imwinkelried, S., Pitts, N.B., et al. (1999). Performance and reproducibility of a laser fluorescence system for detection of occlusal caries *in vitro*. Caries Res. 33, 261–266.
51. Shi, X.-Q., Welander, U., and Angmar-Månsson, B. (2000). Occlusal caries detection with KaVo DIAGNOdent and radiography: an *in vitro* comparison. Caries Res. 34, 151–158.
52. Lussi, A., Megert, B., Longbottom, C., et al. (2001). Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur. J. Oral Sci. 109, 14–19.
53. Karlsson, L., Tranæus, S., and Angmar-Månsson, B. (2001). DIAGNOdent—the influence of calibration frequency on longitudal *in vitro* measurements of caries lesions. Caries Res. 35, 268 (abst).
54. Liberatore, A. (2002). Quantitative laser fluorescence and primary occlusal caries diagnosis. J. Dent. Res. 81, A-90(abst).
55. Igarashi, I., Araki, K., Mataki, S., et al. (1999). Clinical evaluation of DIAGNOdent. Jpn. J. Conserv. Dent. 42, 783–785.
56. Shi, X.-Q., Tranæus, S., and Angmar-Månsson, B. (2001). Validation of DIAGNOdent for quantification of smooth-surface caries: an *in vitro* study. Acta Odontol. Scand. 59, 74–78.
57. König, K., Flemming, G., and Hibst, R. (1998). Laser-induced autofluorescence spectroscopy of dental caries. Cell. Mol. Biol. 44, 1293–1300.
58. Kumazaki, M., and Toyoda, K. (1995). Removal of hard dental tissue (cavity preparation) with the Er:YAG laser. J. Jpn. Soc. Laser Dent. 6, 16–24.

Address reprint requests to:
Jun-ichiro Kinoshita, D.D.S.
Department of Endodontics
Showa University School of Dentistry
2-1-1 Kitasenzoku
Ohta-ku, Tokyo 145–8515, Japan

E-mail: juun1b3@aol.com