

HOLMIUM:YAG LASER: EFFECTS OF VARIOUS TREATMENTS ON ROOT SURFACE TOPOGRAPHY AND ACID RESISTANCE

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(Paper JBO-019 received July 10, 1995; revised manuscript received December 11, 1995; accepted for publication March 20, 1996)

ABSTRACT

The effects of Holmium:YAG laser energy with and without a topical fluoride mixture (resin to NaF) was compared with two types of topical fluorides on surface topography and resistance to acid destruction of root surfaces. Scanning electron microscopy (SEM) was used to evaluate the effects of the selected treatments on surface topography before acid exposure. Toluidine blue dye was used to test the permeability of root surfaces after acid exposures. SEM examinations of the dentinal root surfaces showed consistently smooth surfaces with tubule closures when using topical resin to fluoride and HO:YAG laser treatment; in contrast, HO:YAG laser energy treatment alone exhibited increased roughness of root surfaces. Topical fluoride applications alone presented surfaces similar to untreated control sites. Toluidine blue dye penetration into root surfaces of the fluoride/laser-treated root surfaces showed significantly less dye penetration after acid exposures than controls and other treatment protocols. The results of this study indicate that the resin-fluoride application and holmium:YAG irradiation effectively produced increased smoothness and increased resistance to destruction of root surfaces in human extracted teeth under these *in vitro* conditions.

Keywords Holmium:YAG laser; human teeth; dentin; fluoride; permeability.

1 LITERATURE REVIEW

Various surface treatments (e.g., topical fluorides) have been used in attempts to increase the resistance of enamel and dentin to solubility in acidic solutions.¹ Research in areas of etiology and treatment have clarified some of the problems associated with root surface caries,^{2–4} but prevention and restorative treatment of root surface caries still present poor prognosis for medically compromised older adults.^{3–4}

Other methods reported to increase the resistance to decalcification of enamel and dentin tooth surfaces are the use of laser energy and/or fluoride applications. Pogrel et al.,⁵ using a continuous CO₂ laser, reported various uneven surface alterations but with some resistance to acid dissolution of human extracted teeth. Stern et al.⁶ reported that lased versus unlased enamel surfaces showed increased resistance to subsurface demineralization. Yamamoto and Sato^{7,8}—using a coating of laser absorption material on the tooth surfaces before exposure with the Q-switched Nd:YAG laser—reported a large decrease in the formation of incipient caries-like lesions in enamel under *in vitro* conditions. Nelson et al.⁹ reported the effects of various wave-

lengths of the TEA CO₂ laser (9.32, 9.57, 9.73, and 10.59 μm) on enamel surfaces; the 9.32 wavelength with 10 J/cm² produced the least carious-like formations in enamel surfaces.

Pashley et al.¹⁰ reported energy levels of 11 and 113 J/cm² with the CO₂ laser-produced surface alterations. This produced increased permeability of dentin due to partial loss of the smear layer but showed some acid-resistant areas within crater formations. White et al.,¹¹ using the Nd:YAG laser, found increased roughness on dentinal surfaces, with partial closure of some dentinal tubules while other areas were unmodified. Nammour et al.¹² reported that energy levels of 280–715 J/cm² with CO₂ laser exposures on dentinal surfaces reduced the extent of carious-like lesions to a significant degree.

Morioka, Tagomori, and Nara¹³ reported that a combination of TEA CO₂ laser energy exposure followed by application of acidulated phosphate fluoride (APF) showed less calcium dissolved from enamel surfaces than with laser energy only. Fox et al.¹⁴ reported that the combination of continuous-wave CO₂ laser energy and the chemical agents (dodecylamine hydrochloride or ethane-1-hydroxyl-1, 1-diphosphonic acid) greatly increased

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the resistance to demineralization over laser energy only on enamel surfaces. Goodman and Kaufman,¹⁵ using argon laser energy with a mixture of NaF on enamel, showed less release of calcium and phosphorus ions than in nontreated enamel specimens. These studies suggest that laser energy and topical fluorides may increase the resistance of enamel and dentin surfaces to acid dissolution. They also indicate that laser irradiation of dentin and enamel surfaces may produce various types of adverse surface alterations (e.g., loss of surface integrity or crater formations).

The objectives of this study were to (1) examine the effects of holmium:YAG laser energy and/or topical fluorides on the resistance of root surfaces of extracted human teeth to acid destruction; and (2) compare the effects of these combinations of laser energy and/or fluorides on root surface alterations of human teeth *in vitro*.

2 MATERIALS AND METHODS

The root surfaces of a group of 60 freshly extracted human teeth were treated with laser energy exposures and/or topical fluoride mixtures. The teeth—which had been stored in 10% neutral buffered formalin—were prepared for surface treatments by scaling and root planing of their root surfaces with a Gracey 3-4 curette 5 mm apical from the dentinoenamel junction until smooth and hard. After root surface preparation, the teeth were stored in water for 24 hr at room temperature.

The laser instrument used in this study was chromium-sensitized thulium, holmium-doped yttrium aluminum garnet (HO:YAG) at 2.12 μ wavelength with a 0.3-ms pulse length and a repetition rate of 15 pulses per second. The beam delivery system was a 500- μ fiber-optic cannula handpiece with an HeNe laser to provide a visible red aiming beam at 6.328 μ (Sunrise Technologies, Auburn, California). A hollow hood tip was placed over the cannula handpiece to maintain a defocused 3-mm diameter laser beam spot size when the tip of the hood was in contact with the tooth surface. All laser energy was exposed with the hood tip in contact with the root surfaces of the teeth. The laser power was measured before each exposure using a Joules meter (OPHIR Optics, Inc., Jerusalem, Israel) for energy produced at the opening of the hood tip.

The fluoride mixtures used for topical applications were a nonfilled resin urethane dimethylacrylate (UDMA)/sodium fluoride powder hand spatulated to produce a 4% fluoride mixture or a clinical 4% fluoride aqueous NaF gel (Emerson Laboratories, Houston, Texas). For each application, the resin-fluoride mixture was prepared fresh.

The 60 teeth were arbitrarily divided into four groups for root surface treatments. Two-thirds of the root surface of each tooth (apical to coronal) was embedded in a putty substance (Mo-tight Laboratories, LaPorte, Indiana) for each treatment

protocol. The teeth were mounted on a bracket and placed in a water bath at 37° Celsius. The water covered two-thirds of the root length, with all treatment sites above the water level. Each root surface area was air dried before treatment. Three-millimeter areas on the root surfaces apical from the dentinoenamel junction (one-half the circumference of each tooth) were used as the treatment sites with the remaining portion as the untreated control sites. Group 1 received an application of the mixture of nonfilled resin-NaF (4%) followed immediately by HO:YAG laser irradiation (RFL); group 2 received an application of an aqueous NaF (4%) gel only and was allowed to dry for 4 min (TF); group 3 was exposed to laser energy only (L); and group 4 received an application of nonfilled resin-NaF (4%) without laser exposure (RF). The thin layers of both fluoride mixtures were applied with a brush and allowed to dry for 4 min. The applications of nonfilled resin were not light-cured. Laser treatment sites were irradiated with a 3-mm defocused spot-sized beam at a power level setting of 2 W for 0.33 s (15 pps) with 20-s pauses between exposures. An area of 3 \times 5 mm was exposed per 0.33 s. The amount of laser energy delivered per area was 0.450 (+/-0.05) J with a fluence of 2.66 to 3.30 J/cm². This power level setting was tested before each exposure for the joules of energy delivered at the hood tip of the fiber-optic handpiece. One operator, using the cannula handpiece with the hood tip in contact with the tooth surfaces, made a slight forward and backward motion to irradiate the specimens. The operator exposed 3 \times 5 mm areas on photographic paper to standardize the slight movement with the cannula laser handpiece to cover the same area on tooth surfaces. This exposure technique was transferred to tooth surfaces and were evaluated by SEM examinations to confirm that the results could be reproduced. The technique involved surface areas which received 2.66 J/cm², with other areas receiving 3.30 J/cm² of energy density. All teeth were rinsed, brushed with a soft toothbrush with tap water, and stored in water after completion of designated treatments.

Before exposure to acid, five teeth from each group were arbitrarily selected for SEM examination for surface changes. They were fixed in neutral formalin and prepared for SEM examination. SEM photographs were made of representative areas of surface alterations for the various treatments versus their control sites.

Ten teeth from each group were placed in containers of 10 ml of 10% formic acid for 48 hr. Each tooth was washed ten times and stored in water after exposure to acid [Fig. 1(a)]. After exposure, each tooth specimen was cross-sectioned at the dentinoenamel junction and 3 mm apically on the root surface with a wet band saw [Fig. 1(b)]. The apical end of the cross sections was sealed with two layers of varnish and allowed to dry [Fig. 1(c)]. Each sample was placed in a petri dish 20 mm in diam-

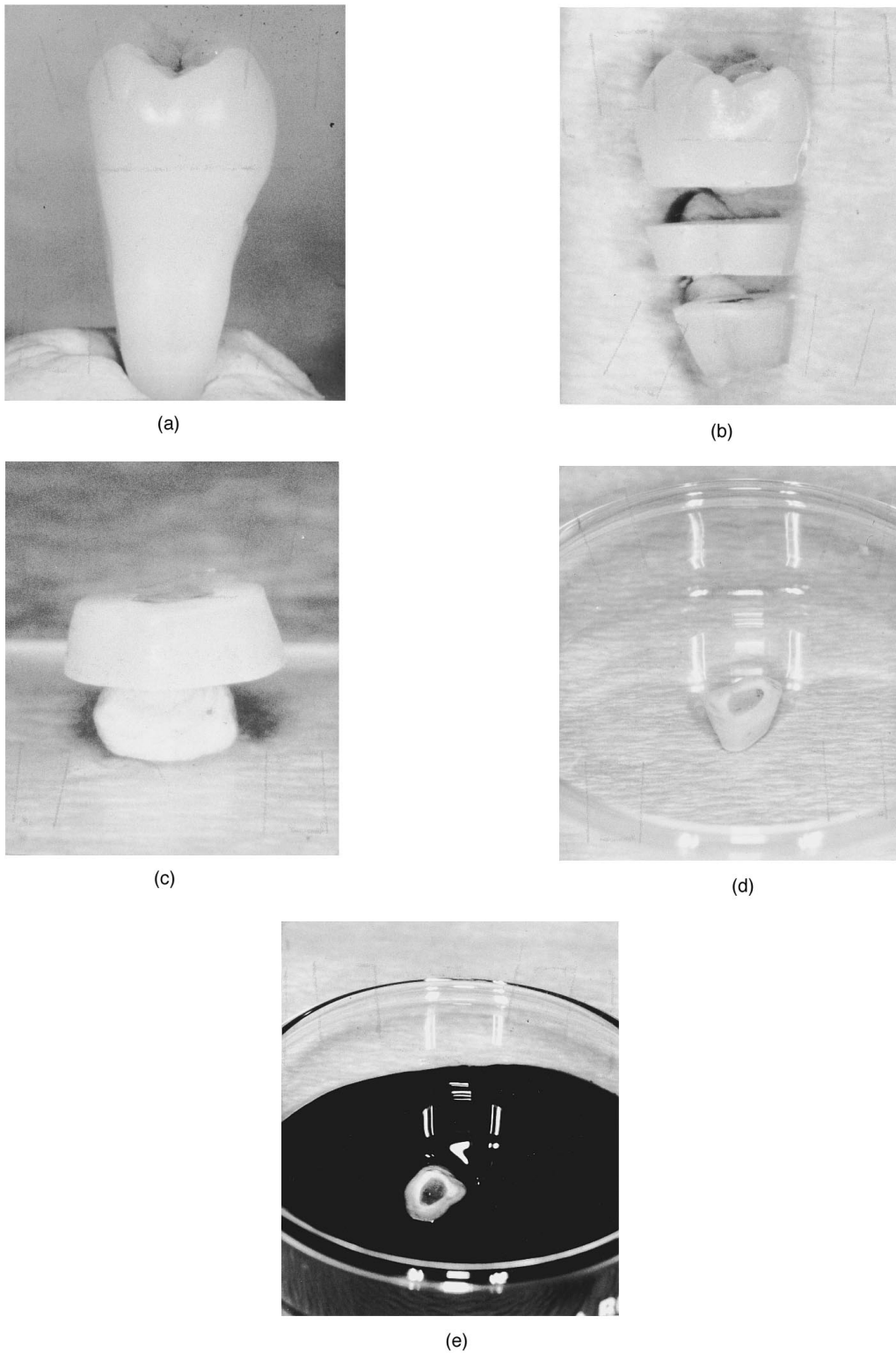


Fig. 1 (a) Example of tooth after exposure to acid for 48 hr. (b) After exposure to acid, tooth specimen cross-sectioned at the dentinoenamel junction and 3 mm apically on the root surface with a wet band saw. (c) Apical end of the cross-sections were sealed with two layers of varnish and allowed to dry. (d) Each tooth specimen was placed in a petri dish 20 mm in diameter with the sealed portion down. (e) Toluidine blue dye added to a level just below the top surfaces of the cross sections.

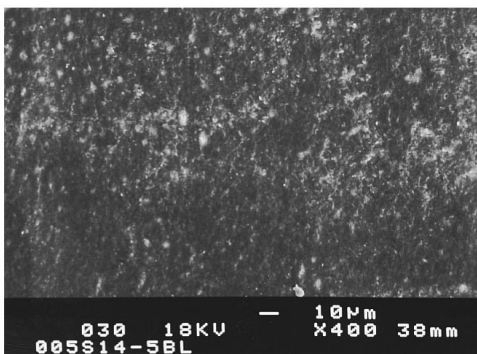


Fig. 2 SEM image of root surface after application of resin-NaF and HO:YAG laser exposure: Group 1 (RFL) showed increased surface smoothness and dentinal tubule closures compared with controls and other treated sites.

eter with the sealed portion down [Fig. 1(d)]. Toluidine blue dye was added to a level just below the top surfaces of the cross sections [Fig. 1(e)]. This setup allowed the dye to be exposed to the outer root surface areas of the treatment and control sides at the same time. The specimens were observed with a microscope using a camera mount for photographs. The amount of time for the dye to reach the pulpal wall on the treated and/or control sites was recorded in minutes. The depth of dye penetration from the outer root surfaces to the pulpal walls was recorded when the dye reached the pulpal walls on the treated and/or control sites for each tooth. If the dye had not reached the pulpal wall on the opposite side, treated or control, it was recorded as a percentage of depth from the outer surface to the pulpal wall. The specimens were photographed when the dye first reached the pulpal walls on the treated and/or control sides. The teeth were photographed under 3× magnification.

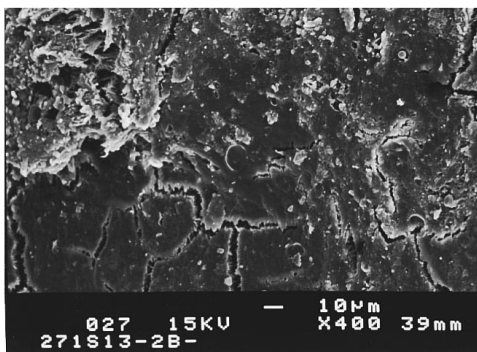


Fig. 3 SEM image of root surface after application of topical aqueous NaF only: Group 2 (TF) exhibited normal uneven surfaces with various amounts of tubule openings. All (untreated) controls showed uneven root surfaces and varying amounts of tubule openings consistent with teeth of different chronological ages.

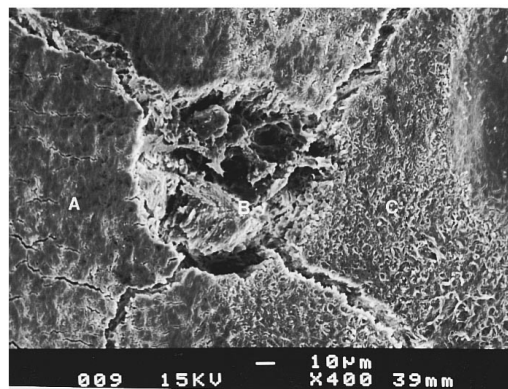


Fig. 4 SEM image of HO:YAG laser exposure only: Group 3 (L) showed various surface changes: (A) some areas exhibited some increased smoothness with tubule closures; (B) other surfaces had increased tubule openings with loss of surface integrity and/or crater formations; (C) still other areas appeared unaltered.

3 RESULTS

The criteria used for SEM evaluation of root surface changes or the lack thereof produced by the selected treatment regimens were (1) surface smoothing or glazing, (2) closure of dentinal tubules, and (3) loss of surface integrity and/or crater formations. The appearance of the root surfaces of the four treatment regimens were compared with their control sites and each other before exposure to acid. Group 1 (RFL) presented increased surface smoothness with dentinal tubule closures compared with its control sites and with other types of treated root surfaces (Fig. 2). Treated root surfaces of group 2 (TF) exhibited the same appearance as their control sites (Fig. 3). Control (C) areas of all groups presented uneven root surfaces with varying amounts of tubule openings consistent with teeth of different chronological ages (Fig. 3). Group 3 (L) showed various surface changes on the treated sites. Some areas exhibited increased smoothness with some tubule closures; other surfaces had increased tubule openings with loss of surface integrity and/or crater formations. Still other areas appeared unaltered with topographic features of their control sites (Fig. 4). Group 4 (RF) presented a somewhat glazed appearance compared with its controls, but tubule openings were still visible (Fig. 5).

The toluidine blue dye penetration test for permeability of the root surfaces after exposure to 10% formic acid for 48 hr presented significant differences in depth of penetration among the tested groups. The following variables were recorded and analyzed: (1) the percentage of the total depth of dye penetration from the outer root surfaces to the pulpal walls compared with their controls and other selected protocols, and (2) time in minutes necessary for the dye to reach the pulpal walls for either the treated or control sites (Table 1).

Analysis of the dependent variable (depth of penetration) for treatment sites versus their controls,

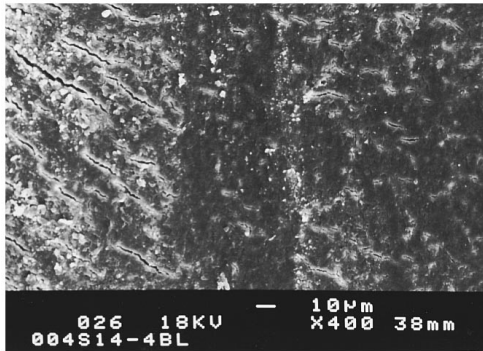


Fig. 5 SEM image of topical nonfilled resin-NaF mixture without HO:YAG laser exposure: Group 4 (RF) presented a somewhat glazed appearance compared with its controls, but tubule openings were still visible.

using the Student *t*-test, indicated a significant difference in depth of dye penetration among the four groups. Group 1 showed significantly less ($P > F$ at 0.0001) penetration into the root dentin than the controls and all other treatment modalities. Duncan's multiple range test indicated that group 1 was significantly different from groups 2, 3, and 4.

The Student *t*-test also proved that the control versus the treated sites were significantly different, with $P > F$ at 0.001. Duncan's multiple range test indicated significantly greater depth of dye penetration for the treated versus control sites of group 3 compared with the other groups. Groups 2 and 4

produced no significant difference between their control versus their treated surfaces for depth of dye penetration.

The times of dye penetration from the outer root surfaces to the pulpal walls varied per tooth in all groups from 1 to 5 min. Analysis of the variable (time of penetration) produced no significant difference in times of dye penetration among the various groups. Toluidine blue dye showed consistently more resistance to penetration into the dentin of all root surfaces treated with nonfilled resin-NaF and HO:YAG laser energy exposures than with control sites and all other treatment modalities.

4 DISCUSSION

The alterations of root surfaces produced with HO:YAG laser energy only appeared similar to Pashley et al.,⁶ who used the CO₂ laser. They found that CO₂ laser energy produced surface changes of partial loss of the smear layer and crater formation. Other areas showed glazed surfaces within the crater formations. White et al.¹¹ also reported that SEM examination of dentinal surfaces after exposure to Nd:YAG laser energy showed areas of dentinal tubule closures but other areas with dentin surfaces unmodified.

In this study, SEM examination of the root surfaces after an application of nonfilled resin-NaF mixture and exposure to HO:YAG laser energy showed consistently smoother surfaces and closure of dentinal tubules compared with controls and the

Table 1 Penetration of toluidine blue dye.

	Group 1		Group 2		Group 3		Group 4	
	Tx	C	Tx	C	Tx	C	Tx	C
	T/D	T/D	T/D	T/D	T/D	T/D	T/D	T/D
1	1.5/<.25	1.5/1.0	2.0/1.0	2.0/1.0	3.5/.75	3.5/1.0	3.0/1.0	3.0/1.0
2	2.0/<0.0	2.0/1.0	3.0/1.0	3.0/1.0	2.0/1.0	2.0/.50	5.0/1.0	5.0/1.0
3	3.0/<0.0	3.0/1.0	4.5/1.0	4.5/1.0	1.5/1.0	1.5/.75	1.5/.75	1.5/1.0
4	1.0/<.25	1.0/1.0	2.5/1.0	2.5/1.0	2.5/1.0	2.5/.75	2.0/.10	2.0/1.0
5	4.5/<0.0	4.5/1.0	1.5/1.0	1.5/1.0	4.5/.75	4.5/1.0	4.5/1.0	4.5/1.0
6	5.0/<0.0	5.0/1.0	3.0/.75	3.0/1.0	3.0/1.0	3.0/.75	3.5/1.0	3.5/1.0
7	2.5/<0.0	2.5/1.0	4.5/1.0	4.5/.75	1.0/.50	1.0/1.0	1.0/.75	1.0/1.0
8	3.0/<0.0	3.0/1.0	1.0/1.0	1.0/1.0	2.5/1.0	2.5/.75	2.5/1.0	2.5/1.0
9	1.5/<.25	1.5/1.0	3.5/1.0	3.5/1.0	3.5/1.0	3.5/.50	3.0/1.0	3.0/.75
10	2.0/<0.0	2.0/1.0	2.0/1.0	2.0/1.0	4.0/1.0	4.0/1.0	2.5/1.0	2.5/1.0

Note: T=time of dye penetration-minutes; D=depth of dye penetration from outer surface to pulpal wall (percentage); Tx=treatment site; C=control site, Group 1=Resin/NaF plus HO:YAG laser treatment; Group 2=Topical aqueous NaF only; Group 3=HO:YAG laser treatment only; Group 4=Topical resin-NaF treatment only.

other types of treatment. Previous research by the authors¹⁶ on the effects of HO:YAG laser energy with a topical resin-fluoride mixture on root surface dentin showed that 0.450 (+/-0.05) J with an energy density of 2.66 to 3.30 J/cm² would produce surface smoothing with the appearance of dentinal tubule closures in 3×5 mm areas. The use of a 3 mm diameter round exposure beam to completely cover the 3×5 mm area on a tooth surface resulted in some degree of overlapping with laser energy exposures to some areas. In group 3, this overlapping with its increased energy density caused opening of the dentinal tubules with crater formation (Fig. 4). Since the resin-fluoride mixture appeared to disperse the laser energy evenly to the tooth surface, the range of energy density at 2.66 to 3.30 J/cm² still produced consistent surface alterations to the tooth surface.

Initially, we did not observe the type of surface tissue reaction to the laser energy with and without the resin coating on the root surfaces. In further analysis, it appears that plasma formation was generated on the tooth surface without the resin-fluoride coating. Figure 4 clearly shows classic thermo-mechanical injury to the dentinal root surface. We suggest that the resin medium on the root surfaces allows the HO:YAG laser energy to be dispersed more evenly into the exposure areas thereby reducing plasma generation. Figure 2 suggests thermal reaction on the dentinal root surface that avoids crater formation. If clinical procedures such as root surface smoothing are to be attempted with a laser instrument, a standardized delivery of laser energy to tooth surface areas and a method to lessen plasma formation are necessary.

The resin-fluoride application without laser exposure showed the appearance of glazing on the surfaces but the dentinal tubules did not appear closed. Areas given aqueous topical fluoride without laser energy appeared no different than the control areas.

In this study, treatment of root surfaces with holmium:YAG laser energy only showed some areas that appeared more resistant to acid destruction, but generally the root surface dentin had increased permeability. Stern et al.⁶ (CO₂), Nelson⁹ (CO₂), Yamamoto and Sato^{7,8} (Nd:YAG), and Nammour et al.¹² (CO₂) found increased resistance to acid dissolution of enamel with a laser energy only treatment. Since the root surfaces were tested for permeability after acid exposure only in this study, comparing results is difficult, but these results agree with those of Pashley et al.¹⁰ that laser energy alone resulted in increased permeability in the dentinal surfaces. The application of nonfilled resin-NaF mixture followed by HO:YAG laser exposure consistently showed increased resistance to dye penetration into root surfaces, even after 48 hr in 10% formic acid solution. The results of this study also agree with those of Morioka et al.¹³ and Fox

et al.,¹⁴ who found increased resistance to decalcification of tooth surfaces with the combination of laser energy and chemical agents versus laser energy exposure only.

The effectiveness of higher fluorine content in teeth for the prevention of dental caries has been demonstrated in man and animals. Repeated topical fluorides have been used in clinical dentistry to increase the surface concentration of tooth fluoride to aid in the prevention of caries,²⁻⁴ but a topical application of fluoride (aqueous or resin-fluoride) without HO:YAG laser energy treatment did not appear to affect the resistance to acid destruction of root surfaces in this study.

5 CONCLUSIONS

Surface treatment with holmium:YAG laser energy after application of a nonfilled resin-NaF mixture on root surfaces of extracted human teeth produced increased surface smoothing with dentinal tubule closure. HO:YAG laser energy without a resin-fluoride application produced varying amounts of increased surface roughness, with opening of dentinal tubules. Topical fluoride mixtures without laser energy appeared to have no significant effect on root surface topography.

The surface treatment of nonfilled resin-NaF and HO:YAG laser energy also presented increased resistance to acid destruction of the root surfaces. The resin-fluoride and laser-treated surfaces were resistant to toluidine blue dye penetration into the root surfaces after 48 hr of exposure to 10% formic acid solution. Topical fluoride applications without laser energy treatments indicated no differences from their controls. HO:YAG laser energy without the application of resin-fluoride exhibited increased permeability of dye penetration of the root surface dentin. Since various methods of measuring the acid resistance of tooth surfaces after exposure to laser energy with and without chemical agents have been reported in the literature, it is difficult to compare results with various laser systems and methods of measurements. Toluidine blue dye penetration into the dentinal root surfaces demonstrated significantly decreased permeability of these surfaces after treatment with resin-fluoride applications and HO:YAG laser energy exposures compared with other selected types of treatment. The results of this study produced increased resistance to acid destruction and smoother surface texture. These findings suggest that this mode of treatment of root dentinal surfaces warrants further clinical investigation.

Acknowledgments

This study was supported in part by an unrestricted grant from Research to Prevent Blindness and in part by a grant from the OCAST Center for Laser Development and Applications, Noble Research Center, Stillwater, Oklahoma. The authors

wish to thank Steve Schafer for his valuable discussions of laser technology, Hanh Nguyen for her outstanding work with the SEM studies, and Marilyn Crawford and Helen Lowery for secretarial support with this document.

REFERENCES

1. B. Krasse, *Caries Risk*, Quintessence Publishing, Chicago (1985).
2. B. Kutler and R. L. Ireland, "The effect of sodium fluoride applications on the dental caries experience in adults," *J. Dent. Res.* **32**, 458-462 (1953).
3. G. S. Ingram and P. F. Nash, "A mechanism for the anticaries action of fluoride," *Caries Res.* **14**, 298-303 (1980).
4. H. R. Englander, J. P. Carlos, R. S. Senning, and J. R. Mellberg, "Residual anticaries effect of repeated topical sodium fluoride applications by mouthpieces," *J. Am. Dent. Assn.* **78**, 783-787 (1969).
5. M. A. Pogrel, D. F. Muff, and G. W. Marshall, "Structural changes in dental enamel induced by high energy continuous wave carbon dioxide laser," **13**, 89-96 (1993).
6. R. H. Stern, R. F. Sognnaes, and F. Goodman, "Laser effect *in vitro* enamel permeability and solubility," *J. Am. Dent. Assn.* **73**, 838-843 (1966).
7. H. Yamamoto and K. Sato, "Prevention of dental caries by Nd:YAG laser irradiation," *J. Dent. Res.* **59** (D II), 2171-2177 (1980).
8. H. Yamamoto and K. Sato, "Prevention of dental caries by acoustic-optically Q-switched Nd:YAG laser irradiation," *J. Dent. Res.* **59**(2), 137-139 (1980).
9. D. Nelson, M. Shariati, R. Glana, C. Shields, and J. Featherstone, "Effects of pulsed low energy infrared laser irradiation on artificial caries-like lesion formation," *Caries Res.* **20**, 289-299 (1986).
10. E. L. Pashley, B. S. Horner, M. Liu, S. Kim, and D. H. Pashley, "Effects of CO₂ laser energy on dentin permeability," *J. Endodont.* **18**, 257-262 (1992).
11. J. M. White, H. E. Goodis, and C. M. Rose, "Nd:YAG pulsed infrared laser for treatment of root surface," *CDA J.* (November) 55-58 (1991).
12. S. Nammour, C. Renneboog-Squilbin, and C. Nyssen-Behets, "Increased resistance to artificial caries-like lesions in dentin treated with CO₂ laser," *Caries Res.* **26**, 170-175 (1992).
13. Morioka, S. Tagomori, and Y. Nara, "Application of Nd:YAG laser and fluoride in the prevention of dental caries," in *Lasers in Dentistry*, pp. 55-61, Elsevier, New York (1989).
14. J. L. Fox, D. Yu, M. Otusuka, W. I. Higuchi, J. Wong, and G. Powell, "Combined effects of laser irradiation and chemical inhibitors on the dissolution of dental enamel," *Caries Res.* **26**, 333-339 (1992).
15. B. D. Goodman and H. W. Kaufman, "Effects of an argon laser on the crystalline properties and rate of dissolution in acid of tooth enamel in the presence of sodium fluoride," *J. Dent. Res.* **56**, 1201-1207 (1977).
16. R. A. Holt and R. E. Nordquist, "Holmium:YAG laser in dentistry: photoconditioning of dentinal surfaces," *Proc. SPIE* **2128**, 308-318 (1994).