Title

Root canal preparation using the second harmonic KTP:YAG laser: A thermographic and scanning electron microscopic study

Journal

Journal of Endodontics, 21(2)

ISSN

0099-2399

Authors

Machida, T
Wilder-Smith, P
Arrastia, AM
et al.

Publication Date

1995-02-01

DOI

10.1016/s0099-2399(06)81102-7

0099-2399/95/2102-0088/$03.00/0
JOURNAL OF ENDODONTICS
Copyright © 1995 by The American Association of Endodontists

Printed in U.S.A.
VOL. 21, NO. 2, FEBRUARY 1995

Root Canal Preparation Using the Second Harmonic KTP:YAG Laser: A Thermographic and Scanning Electron Microscopic Study

Takashi Machida, DDS, Petra Wilder-Smith, Dr. med dent, BDS, LDS RCS, Anna M. Arrastia, DDS, Lih-Huei L. Liaw, MS, and Michael W. Berns, PhD

Thermal and microstructural events resulting from KTP laser use during root canal preparation were investigated in 30 extracted single-rooted human teeth. In the first section of this study, thermal events occurring on the root surfaces of 18 teeth during and after exposure of the root canal were measured using thermography. A variety of parameters were used to determine settings that would be effective without causing thermal damage to the periodontal ligament. In the second section of the study, root canals of 12 teeth exposed to KTP laser irradiation at parameters derived from section 1 were evaluated using Scanning electron microscopy. KTP laser application at a power setting of 3 W, an exposure time of 2 s, and a frequency of 5 Hz, applied five times, removed smear layer and debris from the root canal surface at temperatures below the thermal injury threshold for periodontal tissue.

One of the main requirements for successful endodontic treatment is complete elimination of all debris from the root canal before root canal filling. Conventionally, this procedure is most widely performed using hand instrumentation and chemical irrigation. However, some studies have shown that these techniques do not remove all debris from the root canal (1). A residual smear layer is left behind on the root canal walls, with the consequence that root canal filling materials are unable to seal the root canal completely. As a result, leakage may ensue between the root canal walls and the filling materials (2).

Lasers were first used in basic dentistry by Goldman et al. (3) and Stern and Sognnaes (4) in 1964. Since that time, lasers have been investigated for a wide range of applications in dentistry. The main areas of clinical dental laser use that have been studied include soft tissue applications (5, 6), removal of dental caries (7, 8), cavity preparation of teeth (9), and altering the physicochemical characteristics of tooth substance (10). One of the main barriers to endodontic application of lasers has been the problem of adequately delivering light into the narrow root canal. Some wavelengths cannot at present be delivered by fiberoptic systems, others are excluded from endodontic use by the lack of availability of sufficiently narrow fibers to introduce into the root canal. At the present time, fiberoptic systems sufficiently small in diameter to permit delivery of laser energy to the root canal are being developed for a rapidly increasing range of wavelengths.

Several recent studies have investigated endodontic applications of lasers (11, 12). Melcer and Chaumette (13) and Miserendino et al. (14) reported crystalline structures on extracted human teeth as a result of CO_2 laser irradiation. Using an Nd:YAG laser to irradiate root canal wall dentin, Dederich et al. (15) obtained a melted, recrystallized surface. Neev et al. (16), Matsumoto et al. (17), and Arima and Matsumoto (18) demonstrated smooth dentin walls on coronal surfaces of human extracted teeth using ArF excimer lasers. However, none of these wavelengths are currently suitable for clinical endodontic use. The CO_2 laser is not appropriate for this type of endodontic treatment, because it cannot be delivered through a suitable fiberoptic system and because of the high temperatures it generates in adjacent tissues. No suitable fibers are currently available for application of most excimer lasers to endodontic therapy. Furthermore, these lasers are still too unwieldy and expensive for clinical use.

The KTP:YAG laser has been investigated for a variety of surgical applications, but it has not been applied in dentistry. The KTP:YAG laser emits at a wavelength of 532 nm and can be delivered through a wide range of fibers in a constant or a pulsed mode.

The purpose of this study is to evaluate use of the KTP:YAG laser as an adjunct to conventional endodontic techniques for removal of debris and smear layer. Root surface temperatures were measured in human extracted teeth during laser irradiation at several parameters, and laser-induced structural changes were observed using scanning electron microscopy (SEM).

MATERIALS AND METHODS

Laser Device

The KTP laser used in this study was the KTP/YAG Surgical Laser system (Laserscope, San Jose, CA) emitting at a wavelength of 532 nm with a maximum output of 20 W. Pulse durations were adjustable from 0.1 to 1.0 s; pulse intervals were adjustable to 0.1 or 0.5 s. A 0.3-mm diameter bare fiber (Endostat, San Jose, CA) was used with an irradiation spot diameter of 0.3 mm. The power emitted at the fiber tip was reduced to 30% of the value indicated on the laser controls, due mainly to the very thin fiber used.

Sample Preparation

Thirty extracted human straight and single-rooted teeth were selected and stored in demineralized water with a small amount of thymol. Conventional access to the root canal was prepared through the crowns, and a #15 reamer was passed into the canal until a working length could be established visually at a point 1 mm short of the apical foramen. The canals were then instrumented to this working length by conventional methods up to size #45 using only demineralized water for irrigation. The 30 teeth were then randomly divided into two experimental groups. Group 1: 18 teeth were prepared for temperature measurement during exposure as described herein. Group 2: 12 teeth were exposed as described herein, then prepared for SEM.

Temperature Measurement During KTP Laser Irradiation (Group 1)

Eighteen teeth were randomly divided into three subgroups of six teeth each. Before exposure, all root canals were slightly moistened using demineralized water. The teeth were exposed either at 1 W (total energy density, 13.6 J/cm^2), 2 W (27.3 J/cm^2), or 3 W (40.9 J/cm^2) at 5 Hz for 10 s. To obtain accurate and consistent thermography results, the fiber tip was fixed at the working length, 1 mm short of the apical foramen. Thermal camera measurements (Inframetrics model 600, with a scan speed of 60 Hz) were taken during and after exposure to determine ongoing thermal events and provide information on possible heat effects of this treatment on periodontal tissues surrounding the root surface.

SEM Evaluation Following KTP Laser Irradiation (Group 2)

Results from temperature measurements conducted on group 1 samples indicated maximum irradiation times that could be used at each power setting before reaching a threshold temperature rise above which thermal damage might occur in adjacent structures. From these results, the following parameters were selected: 4 samples from group 2 were irradiated at 1 W for 6 s, 4 samples at 2 W for 3 s, and 4 samples at 3 W for 2 s. The fiber was moved up and down slowly in the apical third of the root canal during irradiation. This procedure was repeated five times on each sample with 10 s cooling time between each irradiation. Thus, total energy delivered to each sample was 30 J (total energy density, 40.9 J/cm^2). Upon completion of the irradiation procedures, the specimens were sectioned parallel to the long axis of the root canal. After dehydration in a graded series of aqueous ethanol (30, 50, 70, 90, and 100% ethanol) for 10 min at each concentration, samples were mounted on stubs using colloidal silver liquid (Ted Pella, CA) and gold-coated on a PAC-1 Pelco advanced coater 9500 (Ted Pella, CA). Micrographs of the root canal walls were taken on a Philips 515 (Mohawk, NJ) SEM.

RESULTS

Temperature Measurement

The temperature distribution on the root surface was examined from the time immediately before laser irradiation at a room temperature of 20.0°C to 10 s after cessation of irradiation. A maximum temperature increase of 10.3°C was recorded in the central region (absolute maximum temperature, 30.3°C), during exposure at 2 W, 5 Hz, for 5 s. The heat spread in concentric circles from the site adjacent to the fiber tip. Figure 1 represents the mean temperature increase at powers of 1, 2, and 3 W as a function of irradiation time. In general, apical root surface temperature increased proportionally with power and time. Table 1 shows the mean temperature and standard deviation at each power and time combination. A temperature rise threshold of 7°C was used to select the following parameter conditions: 1 W × 6 s, 2 W × 3 s, and 3 W × 2 s.

SEM

Figures 2 to 5 illustrate typical examples of the appearance of the root canal walls at the different power settings used for group 2. The following observations were noted. (a) *Exposure at 1 W, 5 Hz, for 6 s × 5 times*: In all samples, wall dentin appeared totally covered by a smear layer at every level of the root canal (Fig. 2). (b) *Exposure at 2 W, 5 Hz, for 3 s × 5 times*: Generally, lower levels of smear layer and debris were apparent than in samples exposed at 1 W. A few open tubules were visible in the apical area (Fig. 3). (c) *Exposure at 3 W, 5 Hz, for 2 s × 5 times*: The root canal surfaces generally appeared clean and free of smear layer and debris in the apical area (Fig. 4). A few isolated localized patches of melting and fusion were also visible (Fig. 5).

DISCUSSION

In the first section of this study, thermography was performed to determine temperature rises on the root surface

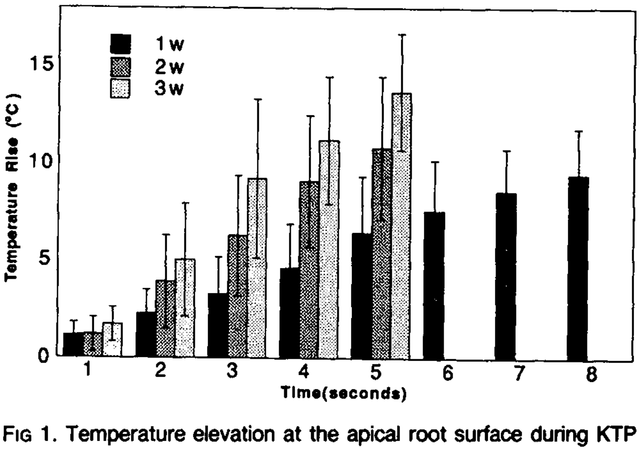

FIG 1. Temperature elevation at the apical root surface during KTP laser irradiation.

Table 1. Temperature elevation caused by KTP laser irradiation at the apical root surface

Time	Power					
	1 W	*t* test	2 W	*t* test	3 W	*t* test
1	1.15 ± 0.67	4.2	1.18 ± 0.88	3.29	1.70 ± 0.87	4.75
2	2.25 ± 1.2	4.59	3.88 ± 2.4	3.96	5.00 ± 2.9	4.22
3	3.25 ± 1.9	4.19	6.25 ± 3.1	4.94	9.20 ± 4.1	5.5
4	4.58 ± 2.3	4.88	9.08 ± 3.4	6.54	11.2 ± 3.3	8.32
5	6.43 ± 2.9	5.43	10.8 ± 3.7	7.15	13.7 ± 3.0	11.2
6	7.57 ± 2.6	7.13				
7	8.57 ± 2.2	9.54				
8	9.43 ± 2.4	9.63				

Temperature rise (°C); mean ± SD ($n = 6$) and *t* test; 5 Hz (duration 0.1 s, interval 0.1 s); $p < 0.05 = 2.44$, $p < 0.01 = 3.7$.

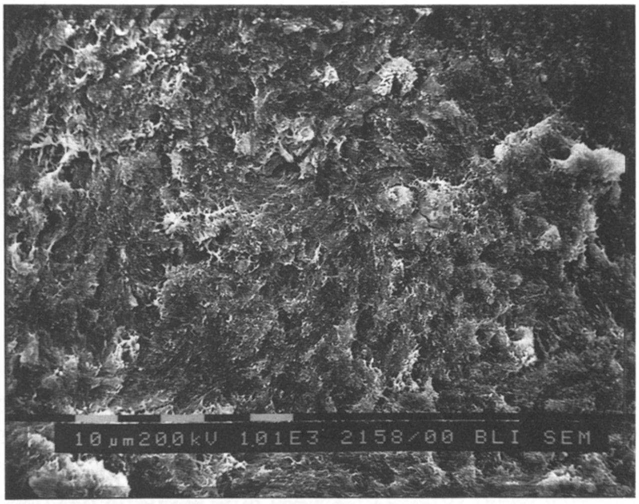

Fig 2. SEM micrograph of lased root canal surface using 1 W, 6 s, 5 Hz. Original magnification ×1010.

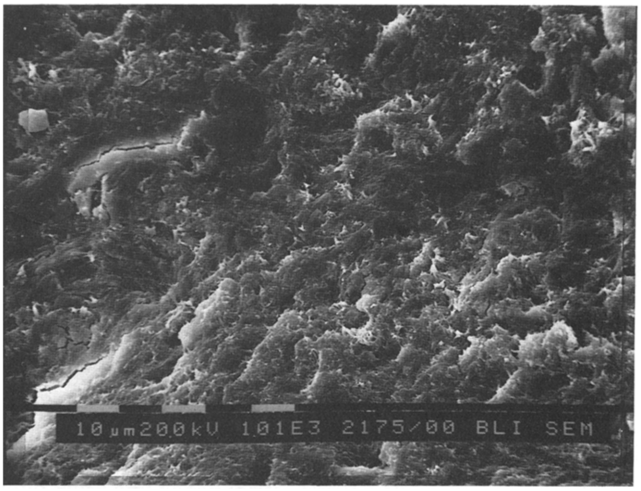

Fig 3. SEM micrograph of lased root canal surface at 2 W, 3 s, 5 Hz. Original magnification ×1010.

Fig 4. SEM micrograph of lased root canal surface using 3 W, 3 s, 5 Hz. Original magnification ×1010.

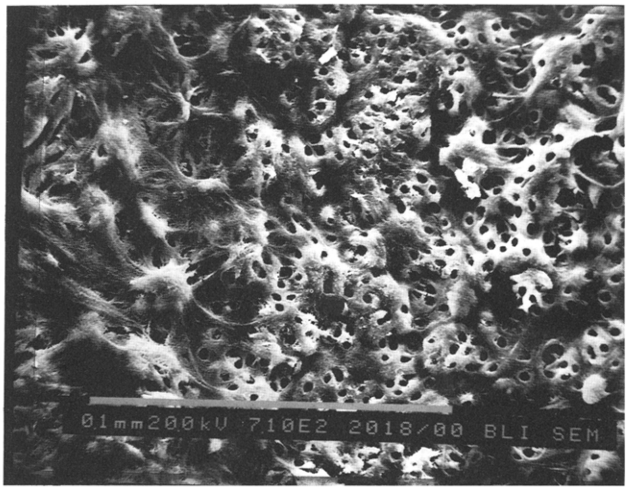

Fig 5. SEM micrograph of lased root canal surface using 3 W, 2 s, 5 Hz. Original magnification ×710.

induced by KTP laser irradiation of the root canal in relation to exposure time and power levels. Figure 1 shows apical root surface temperatures increasing linearly in proportion to power and exposure time.

In this study, we measured temperature rises at the apical root surface, where in a clinical situation the tooth would be surrounded by the periodontal ligament. Previous studies dealing with laser applications for dental hard tissue have usually measured temperature changes at the hard tissue surface or within the root canal. However, in this study, we were particularly concerned about possible thermal effects on the periodontal ligament. Especially in the apical region, the root canal wall tends to become very thin after root canal preparation, leaving the periapical area particularly susceptible to thermal damage of the periodontal ligament or of the surrounding alveolar bone. Thus, we recorded thermal events at the apical root surface to determine what power levels and exposure times might safely be used in a clinical situation.

Eriksson and Albrektsson (19) reported that the critical temperature for bone injury lies at 47°C, only 10°C above human body temperature. Using histological evaluation of the effect of heated gutta-percha root canal obturation, Saunders (20) demonstrated that, in 28% of cases, surface resorption of cementum occurred as a result of an 18°C temperature rise. In this situation the time factor is significant in addition to temperature elevation, and recovery may occur more rapidly in vivo than in vitro, because of the heat-dispersing effects of a vital circulation and of adjacent structures. Taking these factors into account to provide a generous safety margin for a clinical situation, the following parameters were selected from the results of part 1 of this study for further investigation in part 2: 1 W × 6 s, 2 W × 3 s, and 3 W × 2 s. In this study, the observation was made in all samples that maximal temperature rise occurred in a very small area in the central region of the root canal, at the site of the fiber tip within the root canal. Intersample differences in thermal measurements can be attributed to several factors. Because most root canals are not completely straight, it was not possible to place the fiber in the canal in such a way as to be completely parallel to the root canal axis. In these samples, the laser beam impinged excessively on one area of the root canal wall. Furthermore, the fiber did not permit delivery of the laser beam perpendicular to and thus directly onto the canal walls. Therefore, real power densities delivered to the root canal surfaces were lower than the calculated value and somewhat dependent on root canal configuration. Because of these considerations, the fiber was slowly moved up and down in the apical third of the root canal during irradiation of group 2 samples for SEM evaluation. Many studies have reported a melting, glazing, or recrystallization effect on the dentin wall after exposure to a variety of lasers. In our study, no significant microstructural changes were observed using parameters of 1 W × 6 s, 5 Hz, repeated 5 times and at 2 W × 3 s, 5 Hz, repeated 5 times. However, after irradiation at 3 W × 2 s, 5 Hz, repeated 5 times, SEM examination demonstrated successful removal of smear layer and debris with a few localized patches of melting. Exposed dentin tubule orifices were clearly visible in the exposed apical area, whereas smear layer and debris remained apparently higher up the root canal where no exposure had occurred. The successful debridement of the root canal and smear layer removal achieved using this technique should significantly improve preparation methods, root canal seal, and tooth longevity in a clinical situation.

The argon laser has wavelength peaks at 488 and 514 nm. Thus, its effects often resemble those of the KTP:YAG laser emitting at a wavelengths of 532 nm. However, in dentistry, the argon laser has mainly been used to cure dental resins. Because favorable results were obtained in this study using the KTP:YAG laser, use of the argon laser in root canal preparation should be investigated, as argon lasers are becoming increasingly accessible for a wide range of clinical applications.

Thorough cleaning of the apical area of the root canal is one of the most demanding procedures during endodontic treatment. In this study, we have demonstrated that KTP laser irradiation can be used to remove debris and smear layer from root canal walls to obtain significantly better results than those achieved by conventional methods only. During exposure at appropriate parameters, temperature rises were maintained below a safety threshold level of 7°C. Bacteriological evaluation of this technique is currently underway. Future research needs to address the issue of laser light delivery to the root canal walls in a nonaxial fashion, to permit direct and localized, well-quantified irradiation of root canal walls with minimal exposure of the apical foramen.

This research was supported by DOE Grant DE-FG03-91ER6227, ONR Grant N00014-91-C-0134, and NIH Grant 5P41 RR0192.

We are also indebted to Mr. Tri Pham, Mr. Tejas Desai, and Mr. Huynh Pham for their assistance in this study.

Dr. Machida is affiliated with the Department of Endodontics, Showa University School of Dentistry, Tokyo, Japan. Drs. Wilder-Smith, Arrastia, Berns, and Mrs. Liaw are affiliated with Beckman Laser Institute and Medical Clinic, University of California, Irvine CA. Address requests for reprints to Dr. Takashi Machida, Department of Endodontics, Showa University Dental Hospital, Ohta-ku Kitasenzoku 2-1-1, Tokyo, Japan.

References

1. Fairbourn D, McWalter G, Montgomery S. The effect of four preparation techniques on the amount of apically extruded debris. J Endodon 1987;13:102-7.
2. Bystrom A, Sundquist G. The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy. Int Endod J 1985;18:35–40.
3. Goldman L, Hornby P, Meyer R, Goldman B. Impact of the laser on dental caries [Abstract]. Nature 1964;203:417.
4. Stern RH, Sognnaes RF. Laser beam effect on dental hard tissues. J Dent Res 1964;43:873.
5. Fisher SE, Frame JW. The effects of the carbon dioxide surgical laser on oral tissues. Br J Oral Maxillofac Surg 1984;22:414–25.
6. Nakamura Y, Watanabe H, Matida T, Matsumoto K, et al. The effect of ArF excimer laser on the rat's tongue. J Show Univ Dent Soc 1990;10:241-5.
7. Goldman L, Gray JA, Goldman B, Meyer R. Effect of laser beam impacts on teeth. J Am Dent Assoc 1964;70:601-6.
8. Sugawara N. The change of dental enamel to ruby laser radiation: observation with the scanning electron microscope. J Oral Pathol 1974;61:161-171.
9. Gordon TE. Single surface cutting of normal tooth with ruby laser. J Am Dent Assoc 1967;74:398-402.
10. Frentzen M, Koort HJ, Thiensiri I. Excimer lasers in dentistry: future possibilities with advanced technology. Quint Int 1992;23:117–33.
11. Levy G. Cleaning and shaping the root canal with a Nd-YAG laser beam: a comparative study. J Endodon 1992;18:123-7.
12. Pini R, Clauser G, et al. Laser dentistry: a new application of excimer laser in root canal therapy. Laser Surg Med 1989;9:352-7.
13. Melcer J, Chaumette MT. Treatment of dental decay by CO_2 laser beam: preliminary results. Laser Surg Med 1984;4:311–21.
14. Miserendino LJ, Neiburger EJ, Valia H. The thermal effects of continuous wave CO_2 laser exposure on human teeth: an in vitro study. J Endodon 1989;15:383-6.
15. Dederich D, Zachariensen K, Tulip J. Scanning electron microscopic analysis of root canal wall dentin follow Neodium Yttrium Garnet laser irradiation [Abstract]. J Endodon 1984;10:428.
16. Neev J, Liaw L-HL, Ranney DV, Fujishige JT, Ho PD, Berns MW. Selectivity and efficiency in the ablation of hard dental tissues with ArF pulsed excimer laser. Laser Surg Med 1991;11:499-510.
17. Matsumoto K, Nakamura Y, Wakabayashi H, Arima M, Yamada Y, Kikuchi K. A morphological research on the cavity preparation by ArF excimer laser. Jpn J Conserv Dent 1990;33:1139-42.
18. Arima M, Matsumoto K. Effects of ArF excimer laser irradiation on human enamel and dentin. Laser Surg Med 1993;13:97-105.
19. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital microscopic study in the rabbit. J Prosthet Dent 1983;50:101-7.
20. Saunders EM. In vivo findings associated with heat generation during thermomechanical compaction of gutta-percha. 1. Temperature levels at the external surface of the root. 2. Histological response to temperature elevation on the external surface of the root. Int Endod J 1990;23:263-74.