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SCANNING ELECTRON MICROSCOPIC EXAMINATION OF INTRACANAL WALL DENTIN: HAND VERSUS LASER TREATMENT

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Abstract

Conventional cleaning and shaping of root canal spaces involves the use of hand and rotary instruments with irrigation. The procedure results in the formation of a smear layer consisting of dentin shavings, organic tissue remnants and microorganisms. The laser has been suggested as an aid in root canal preparation. In this study, pulsed and continuous wave 1.06 μm wavelength Nd:YAG lasers were used to compare their abilities to clean and shape root canal spaces to conventional methods. After preparation, the test teeth were sectioned longitudinally and examined by scanning electron microscopy. The results demonstrated that the laser was capable of removing the smear layer in its entirety and could occasionally alter dentin walls.

Key Words: Endodontics, dentin, lasers, scanning electron microscopy.

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Introduction

Various methods have been employed to alter the architecture (morphology) of root canal system dentin. These methods include the use of chemical (irrigants, chelating agents), physical (sonication, ultrasonics, lasers) and mechanical (hand, rotary instrumentation) or combinations of treatment modes for removal of organic tissue and microorganisms, as well as alteration of dentinal walls. Treatment objectives of root canal system preparation include the removal of all canal contents, sterilization of the root canal space and alteration of the shape of the space to receive a root canal filling material. The procedures used in root canal system preparation result in the creation of a smear layer and smear plug composed of organic tissue remnants, dentin shavings and microorganisms (McComb and Smith, 1975). The smear layer adheres to the prepared root canal walls while the smear plugs extend some short distance into the orifices of the dentin tubules. The tubules run from the inner dentin walls of the root canal space towards the outer root surface (Mader *et al.*, 1984; Kockapan, 1986). The primary irrigant used in root canal system preparation is sodium hypochlorite (NaOCl). It has been used alone and in combination with other chemical agents (Cohen and Burns, 1991).

Normal intracanal morphology has been characterized. Baumgartner and Mader (1987) found the architecture of intracanal wall dentin to consist of small globules called calcospherites, containing the orifices of dentin tubules. Delzangles (1989) confirmed that appearance. Marion *et al.* (1991) described the calospherites which gave a globular appearance to the circumferential root canal dentin at all levels of the root canal space. The calcospherites were evenly spaced in the coronal and middle thirds of the root canal space and more loosely spaced in the apical third of the canal with areas of flat dentin interspersed between them. Tubule density within the calcospherites decreased as the apical area of the root canal system was approached.

The treatment of root canal systems has been extensively studied. NaOCl alone or in combination with other chemical irrigants such as citric acid or ethylenediaminetetraacetic acid (EDTA), has been shown to be

effective in removing devitalized organic tissue (Baker *et al.*, 1975; Loel, 1975; Tucker *et al.*, 1976; Goldman *et al.*, 1982; Lifshitz *et al.*, 1983; Yamada *et al.*, 1983; Baumgartner *et al.*, 1984; Baumgartner and Mader, 1987; Gutierrez *et al.*, 1990). EDTA and its related compounds are effective in removing the smear layer, resulting in cleaner dentin walls (McComb and Smith, 1975; Goldberg and Abramovich, 1977; Ram, 1980; Goldman *et al.*, 1981; Berg *et al.*, 1986; Katsuumi *et al.*, 1986; Kockapan, 1986; and Alacam, 1987). EDTA decalcifies dentin to a depth of 50 to 70 μm after a 10 minute application (Katsuumi *et al.*, 1986) and erodes exposed calcospherites (Baumgartner and Mader, 1987). Other chemical irrigants found to be effective include Salvizol (Ravensberg GMBH, Konstanz, Germany) a quaternary ammonium-like compound with antibacterial activity (Kaufman *et al.*, 1978), tannic acid solution (Bitter, 1989), and tetracycline solutions (Barkhordar *et al.*, 1992). Koskinen *et al.* (1980) found that combinations of irrigants are necessary to cleanse canal walls of organic and inorganic remnants and debris. Combinations of hand or rotary instruments and chemical irrigants have been found to be superior to other methods of root canal preparation (Mizrahi *et al.*, 1975; Moodnik *et al.*, 1976; Rubin *et al.*, 1979; Ram, 1980; Bolanos and Jenson, 1980; Lev *et al.*, 1987; and Glaser *et al.*, 1989). More recently, ultrasonic techniques in combination with irrigants have been found superior to hand and rotary preparation methods (Cunningham and Martin, 1982; Cameron, 1983; Griffiths and Stock, 1986; Cameron, 1987a, 1987b, 1988; and Yamaguchi *et al.*, 1988). However, Cymerman *et al.* (1983), DeNunzio *et al.* (1989), and Mandel *et al.* (1990) found no difference in hand or ultrasonic techniques. Petschelt *et al.* (1987) found a thicker and less compact smear layer, while Ahmad *et al.* (1987) found no differences in surface debris created by hand or ultrasonic instrumentation.

The use of a laser to clean and shape the root canal space is the latest method employed. Dederich *et al.* (1984), used a continuous wave Neodymium:Yttrium-Aluminum-Garnett (Nd:YAG) laser and had variable results: from no effect, to disruption of the smear layer, and to melting and resolidification of the dentin. Dederich *et al.* (1988), found that a pulsed Nd:YAG laser was unable to glaze the dentin surface of the canal walls of split roots. In some cases, it tended to vaporize the dentin, resulting in craters and perforations. In a similar study, Dederich *et al.* (1989) found that a continuous wave CO_2 laser consistently created a glazed dentin surface with minimal cracking. Pini *et al.* (1989), used an excimer laser to remove root canal contents of extracted teeth, and demonstrated a sufficient degree of cleanliness on the canal walls without a significant removal of healthy dentin. Levy (1992) used a 200 μm fiber with a 35 W Nd:YAG laser and melted canal wall dentin with no debris. Goodis *et al.* (1992a) found that a Nd:YAG laser removed the smear layer created by use of hand instruments and NaOCl irrigation but did not alter the calcospherite appearance of the dentin walls. It is therefore apparent that no single method cleans and shapes root canal system dentin adequately. Most methods result in creation of a smear layer without alteration of the calcospherites, which are the most dominant feature of intracanal wall dentin. This study was undertaken to ascertain whether a pulsed or continuous wave 1.06 μm wavelength Nd:YAG laser could be effective in removing organic tissue and smear layer as well as in altering intracanal wall dentin.

Materials and Methods

Two lasers were used. The first was a pulsed, 3 watt, 1.06 μm wavelength Nd:YAG laser (Sunrise Technologies, Fremont, CA) with 200 and 320 μm quartz contact probes; the second, a continuous wave (CW) 20 watt, 1.06 μm wavelength Nd:YAG laser (Premier Laser, Irvine, CA) with 200 and 400 μm sapphire tipped contact probes. Forty single rooted teeth (upper central incisors, upper and lower cuspids and lower first bicuspids) were used. Ten teeth were prepared using hand files and a 5.25% NaOCl irrigation only with a stepback technique and served as positive controls. Thirty teeth were treated using a combination of hand and laser methods, 15 for each laser. They were accessed using a #4 round bur under water spray and each root canal was prepared in the following manner. Initial cleaning and shaping of the root canal system was accomplished with hand instruments using numbers 10, 15, and 20 files to the apex of each test tooth, which only affects the apical portion of the root canal space. Using the 3 W system, the 200 μm probe at 2 W and 20 Hz and pulse duration of 150 microseconds was placed in the canal space to within 1-2 mm of the apex. It was activated as it was removed slowly from the root canal space of each test tooth over a 10 second time period. Prior to use of the 320 μm probe, the body of the canal space was prepared to a number 40 file using the stepback technique. The 320 μm probe at 3 W and 30 Hz and pulse duration of 150 microseconds was inserted into the canal space 2-4 mm from the apex and again activated as it was withdrawn from the space over a 10 second time period. Using the 20 W system access and initial preparation was carried out as above. The 200 and 400 μm probes were used at 5 W and 10 W CW and at 5 and 10 W, 10 Hz and 50 millisecond pulsed duration (50% duty cycle - the laser is off 50% of the time and peak power equals the average power when the laser is on). The root canal spaces were irrigated between files and laser probes with 5 ml of a 5.25% sodium hypochlorite solution resulting in laser activation inside a wet canal space. The laser parameters for each laser system are given in Table 1. The use of files prior to each laser probe provided room for the laser probe in the root canal space so that it could move freely within the space without being curved, and thus would not become jammed in the canals or break when withdrawn from the canal space.

Table 1: 3 W Pulsed and 20 W continuous wave (CW) Nd:YAG laser parameters

	Laser Parameters				
	Power (W)	PPS[a] (Hz)	Pulse Width	Probe Size (μm)	Time (s)
3 W pulsed Nd:YAG	2	20	150 μsec	200	10
	3	30	150 μsec	320	10
20 W CW Nd:YAG	5	CW		200	10
	10	CW		400	10
	5	10[b]	50 msec	200	10
	10	10[b]	50 msec	400	10

[a]PPS = pulses per second [b]50% duty cycle

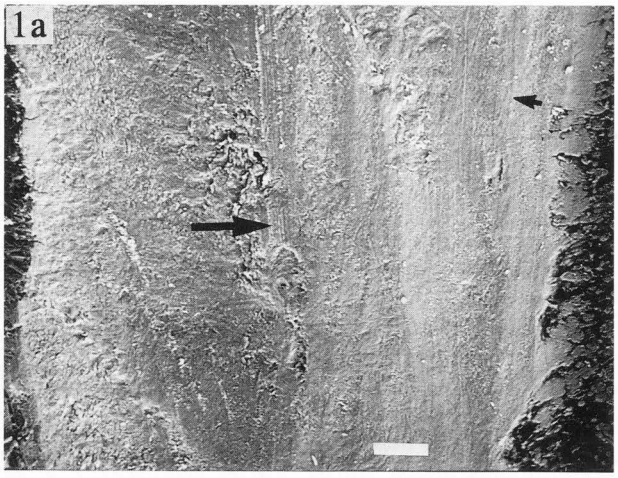
After hand instrumentation and laser application, the teeth were sectioned buccolingually using a water-cooled diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL). Each half of the tooth contained a section of the prepared root canal space from the orifice of the canal to the apex. One-half of each tooth was examined using backscattered scanning electron microscopy (Model SX-40A, International Scientific Instruments, Milpitas, CA) in the wet mode at 20 kV with specimen chamber pressures of 0.12-0.5 torr to reduce charging (Marshall *et al.*, 1989). Observations were made of the entire canal space for presence or absence of smear layer, organic tissue remnants, and microorganisms in the root canal systems as well as alteration of the architecture of the intracanal wall dentin. Three additional teeth were not accessed but sectioned longitudinally and examined as untreated controls.

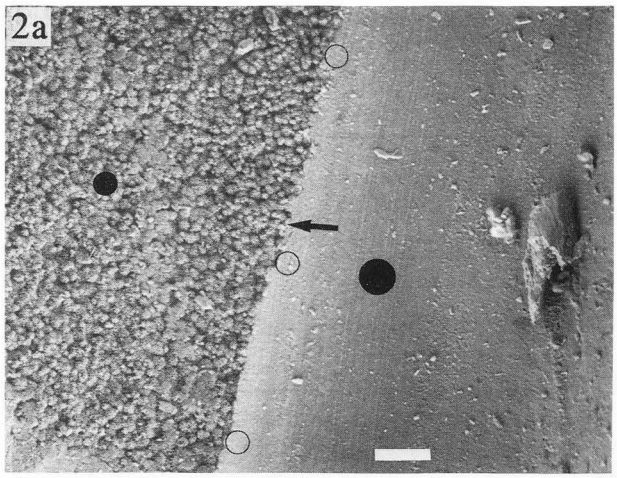
Results

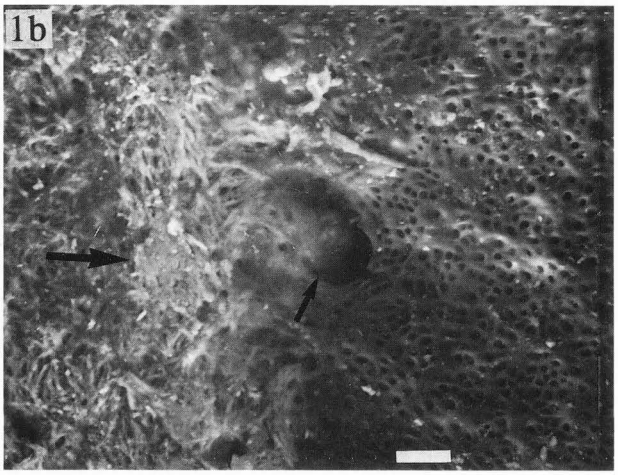
Scanning electron microscope (SEM) examination of the split longitudinal sections of the teeth prepared by conventional methods demonstrated the presence of a smear layer (Fig. 1a, large arrow). Striations in the smear layer were also evident, caused by the action of the endodontic files used to clean and shape the canal (small arrow). Organic tissue remnants alone were seen when it appeared that a portion of the canal wall was not reached by the files (Fig. 1b, large arrow). Also seen was the orifice of a lateral canal, surrounded by flattened calcospherites without the presence of tissue remnants, indicating debridement of that area of the root canal wall. Microorganisms were not seen within the root canal spaces as the teeth were not considered infected.

SEM examination of the longitudinal sections prepared with the combination of hand files and laser treatment demonstrated a general absence of both organic tissue remnants and smear layer with no microorganisms present. Where the probe was not in contact with the canal wall, the smear layer remained in place (Figs. 2a and 2b). Figure 2a (large circle) shows a segment of the root canal wall that has a smear layer in place. Striations from the files can also be seen. The area cleaned by the laser (small circle) is relatively free of smear layer. The open circles indicate the division between the smear layer and the portion of the canal affected by the laser. The small arrow indicates the area used for Figure 2b, which shows an area of smear layer and clean calcospherites at higher magnification. The circles in Figure 2b mark the division between untreated and treated root canal walls. Canal wall morphology depended on the laser system used. Both systems generally removed the smear layer and tissue remnants. Occasionally, there appeared to be some alterations occurring, with flattening of the calcospherites and some melting and resolidification of the dentin (Fig. 3). The entire area surrounding the black dot consists of melted and resolidified dentin. Prolonged contact of the probe caused alterations along the root canal space walls. Severe alterations of the canal walls occurred, including melting, ablation and general disruption of the root canal space as well as obliteration of the calcospherites (Figs. 4a and 4b). Cracks appeared in the area of destruction (large arrow) which were probably due to the action of the laser. The smaller cracks (small arrow) may be due to crack propagation during slow desiccation of the sample in the SEM chamber (Marshall *et al.*, 1989). Figure 4b is a higher magnification of the zone of maximum alteration. Where the calcospherites were not altered, smear layer and organic tissue remnants were absent. The pulsed 1.06 μm wavelength system removed the smear layer and tissue remnants, leaving the calcospherites.

Occasionally, alterations occurred with flattening of calcospherites and melting with resolidification. The 200 μm probe at 3 W and 20 Hz caused removal of the smear layer where the probe contacted the canal wall. At those laser parameters, no alteration of canal wall dentin occurred. The 320 μm probe used at 3 W and 30 Hz caused a complete removal of smear layer as well as melting and resolidification of canal wall dentin (Fig. 5, small arrows). There was destruction of dentin with cracking (large arrow) probably due to the laser. In one tooth, the apex of the root canal was severely altered,







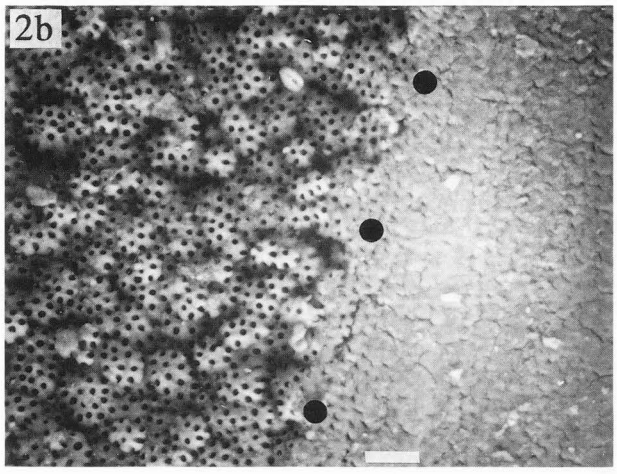


Figure 1. **a)** Longitudinal section, hand cleaned root canal space, smear layer. Large arrow: smear layer; small arrow: striations caused by endodontic instruments. Bar = 100 μm. **b)** Enlarged area, clean canal and adjacent organic tissue remnants (large arrow). Lateral canal exiting root canal wall (small arrow). Bar = 20 μm.

Figure 2 (at right). **a)** Combination hand and laser cleaning, smear layer partially removed due to contact probe, 200 μm probe 2 W, 20 Hz. Large dot: smear layer; small dot: area of wall affected by laser. Clear circles delineate division between treated and untreated canal walls. Small arrow shows the area magnified in b. Bar = 100 μm. **b)** Black dots delineate division between treated and untreated walls. Bar = 20 μm.

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with crater formation (Figs. 6a and 6b). There was melting and resolidification of the dentin with cracking (large arrow) while the apical opening shows complete obliteration of the apical opening (curved arrow). The small arrow is the area seen in Figure 6b; a higher magnification of the area showing melting, resolidification

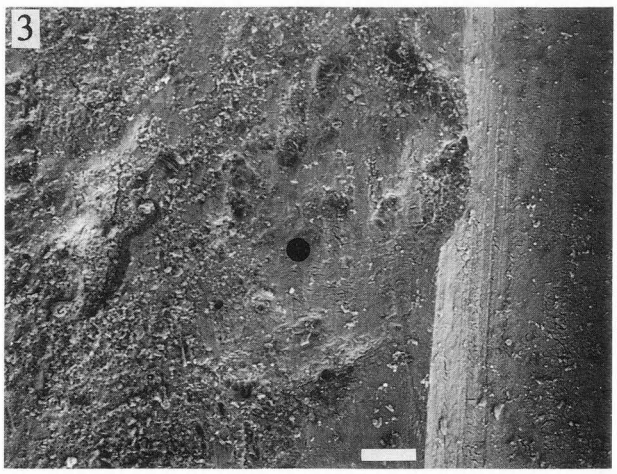

Figure 3. Combination hand and laser cleaning, flattened calcospherites with melting and resolidification, (circle) 200 μm probe, 2 W, 20 Hz. Bar = 100 μm.

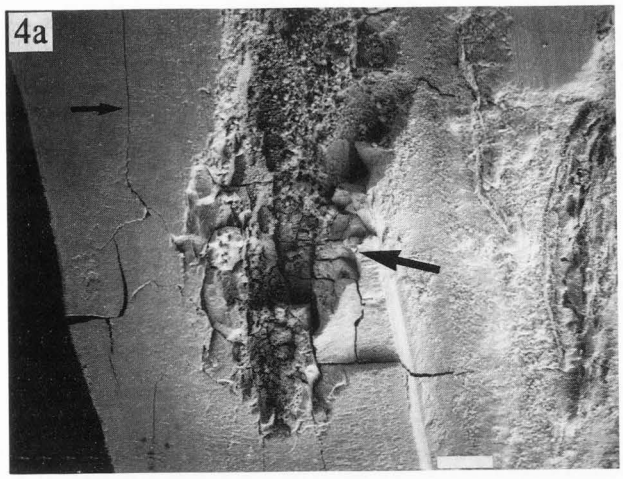

Figure 5. Combination hand and laser cleaning. Complete removal of smear layer, melting and resolidification (small arrows) with an area of destruction (large arrow). 3 W, 30 Hz. Bar = 100 μm.

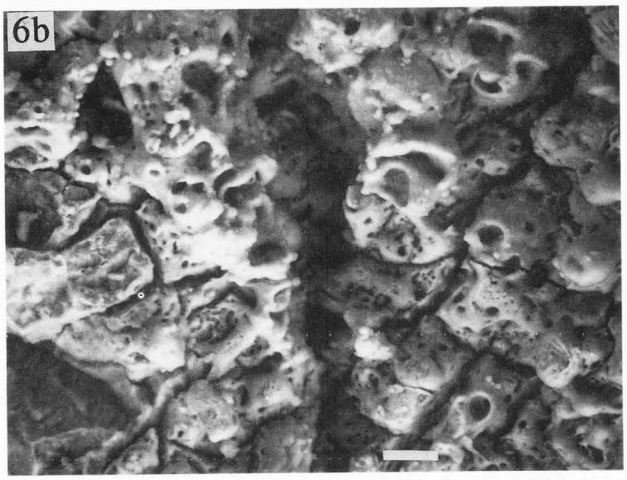

Figure 4 (at left). Combination hand and laser cleaning with probe outside of root canal space with melting and general disruption, 320 μm probe, 30 Hz. **a**) Small arrow: fracture lines thought to be due to slow desiccation in the SEM; large arrow: area of greatest destruction, fractures due to laser. Bar = 400 μm. **b**) Arrow indicates area of greatest destruction. Bar = 100 μm.

Figure 6 (above). Combination hand and laser cleaning, apex of root canal space. **a**) "Blast" appearance, melting, resolidification (large arrow). Curved arrow points to area of apex obliterated. Small arrow indicates region enlarged in b. 320 μm probe, 3 W, 30 Hz. Bar = 100 μm. **b**) Area of small arrow in a. Bar = 20 μm.

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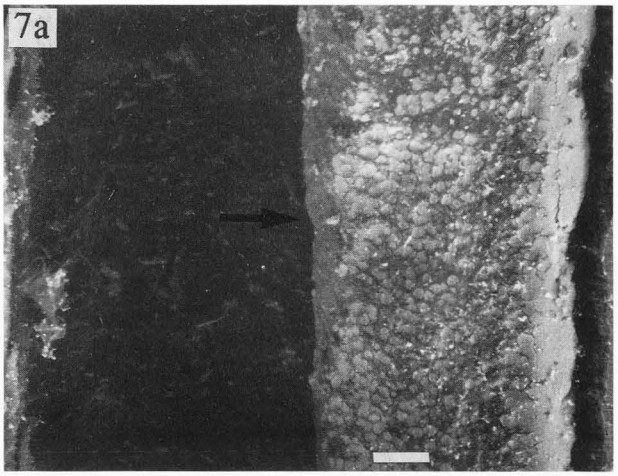
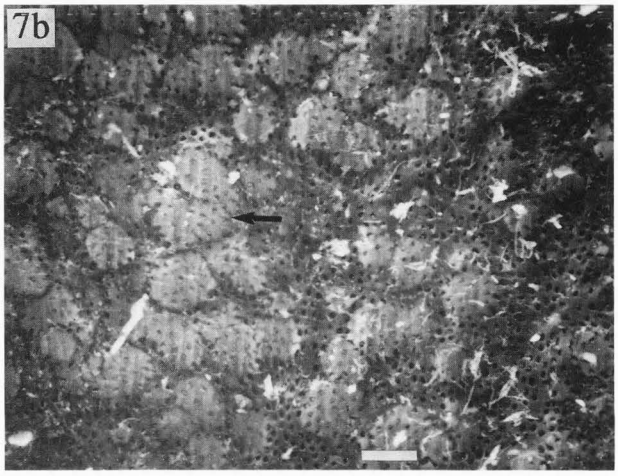
and cracking of the root canal wall. The continuous wave (CW) 20 W - 1.06 μm wavelength system resulted in various effects. At 5 W and 10 W with a 50 percent duty cycle (50 milliseconds) and a 200 μm fiber, the canal walls were generally free of smear layer with no alteration of canal wall dentin (Figs. 7a and 7b). Figure





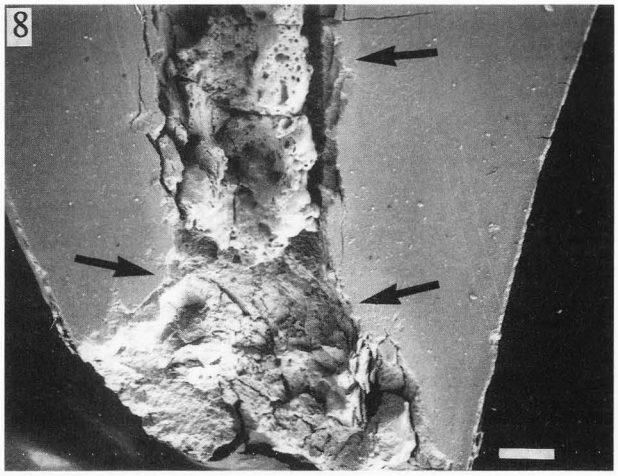


Figure 8. Combination hand and laser cleaning, apex of tooth melted and resolidified, blast effects, 200 μm probe, 10 W, CW. Arrows point to areas of greatest destruction with complete loss of apical anatomy. Bar = 400 μm.

Figure 7 (at left). Combination hand and laser cleaning, smear layer removed with debris remaining. Arrow indicates junction of affected root canal wall and longitudinal section of surface of tooth. 200 μm probe, 10 W, 50% duty cycle, (50 milliseconds). **a**) Bar = 100 μm. **b**) Higher magnification of the affected canal wall. Arrow points to dentinal tubules occluded with smear plugs. Bar = 20 μm.

7a (arrow) shows the division between the root canal wall and the longitudinal section of the tooth. Calcospherites with remnants of smear layer are seen. Figure 7b is a higher magnification of the calcospherites showing occlusion of the dentinal tubules with smear plugs. When 10 W CW system with a 200 μm probe was used, the canal walls were altered, with melting, resolidification and ablation (Fig. 8). There was complete obliteration of the apical opening with complete loss of the normal root canal anatomy (arrows).

Discussion

Cleaning methods employed in root canal preparation are often ineffective in totally removing organic tissue remnants as well as leaving the smear layer created during that preparation. A great number of irrigation solutions are used with either hand, motor-driven rotary, or ultrasonic instrumentation. NaOCl is effective in removing organic tissue remnants while EDTA is effective in removing the inorganic portion of the smear layer. EDTA also effects the inorganic content of the calcospherites. If left in root canal spaces for too long a time, EDTA may result in alteration of the intracanal walls that could compromise the success of the treatment (Katsuumi *et al.*, 1986). In fact, the methods employed to clean and shape root canal spaces create a smear layer which may harbor microorganisms that ultimately result in periapical pathosis.

We have confirmed that hand cleaning and shaping does, in fact, create a smear layer, which covers the orifices of the dentin tubules contained within the calcospherites. NaOCl was partially effective in removing organic tissue remnants from those areas of the canal wall that hand files had not contacted but had no effect in removing smear layer when compared to sections not treated with NaOCl. It, however, was not completely effective in removing those remnants, and particles of tissue remained. In the apical one third of the canal, there were areas of dentin that appeared to be flat surrounded by calcospherites. It is doubtful that the cleaning and shaping procedure produced those areas. Rather, it is more likely that the architecture of intracanal wall dentin is not uniformly covered by calcospherites but has flat areas resembling coronal dentin. Areas such as these were also present in the scanning electron micrographs of the Baumgartner and Mader (1987) study, but were not mentioned.

The Nd:YAG laser systems were effective in removing soft tissue on the root canal walls as the soft

tissue was on the surfaces of the walls. The laser interacts with the soft tissue and the water it contains rather than the hard tissue (dentin walls) beneath it.

With laser application in those longitudinal sections displaying orifices of accessory canals, only the areas around the orifice appeared affected by the procedure, if the laser probe was in contact with the surrounding dentin walls (Figure 1b). Contact with the walls was assessed based on tactile perception as in the use of hand instruments. The smear layer was also visible at the orifices of the accessory canals. Thus, there seemed to be no effect of the laser in the accessory canals. Since there almost certainly was reflected and/or transmitted light, contact of the laser probe and the dentin wall appears to be necessary for any effect to occur. There also appeared to be no alteration of the architecture of the calcospherites in hand cleaned canals when compared to the untreated controls, indicating that such treatment only resulted in the removal of organic tissue. This may occur due to the large size of the canal space prior to treatment precluding contact of hand instruments with canal walls. The action of the sodium hypochlorite, used as an irrigant, also may have aided in the removal of organic tissue. In small canals, it is more likely that the calcospherites would be altered. As regards the importance of removing the smear layer, it has been shown that such layers contain microorganisms (Brannstrom and Johnson, 1974) which, if the canal cannot be completely sealed, can result in subsequent pathologic conditions. However, since the smear layer covering dentin tubules in root canals reduces permeability (Fogel and Pashley, 1990; Tao *et al.*, 1991), the smear layer created in root canal preparation may protect against leakage and microorganism penetration following restoration. To date however, it has not been shown that the smear layer may be beneficial to the overall success of the treatment.

Both laser systems induced similar morphological changes. They removed the smear layer when in contact with canal walls, organic remnants, and only occasionally altered canal wall dentin. Microorganisms were not seen in any sections, either controls or treatment sections, but neither controls nor treatment teeth were infected. Only in teeth that could be judged to be infected would microorganisms be expected to be seen. Since these outcomes are thought to be desirable for endodontic treatment, both laser systems show promise in this area and deserve further evaluation. A preliminary study carried out in our laboratory showed that the laser was, indeed, effective in removing organisms contained in the root canal space (Goodis *et al.*, 1992b). With the laser parameters used and activating the probe as it was withdrawn from the root canal space, no alteration of the canal walls occurred. When the probe was left in place, destruction of the canal wall with complete obliteration of the normal architecture occurred (Figures 6a, 6b and 8). These results are in contrast to those reported by Levy (1992) who found melting and resolidification of root canal wall dentin and closure of the dentin tubules. He reported using a water cooling system to lower temperatures generated with use of his laser to temperatures well below those thought to cause irreversible damage to surrounding structures. Our results also differ from those of Dederich *et al.* (1984, 1988) who found varying effects using a continuous wave Nd:YAG laser system (10 to 90 W, 0.1 to O.9 seconds), from no effect to disruption of smear layer to melting and resolidification. Vaporization and crater formation or no effect occurred with a CW laser used at a 10% duty cycle. The constant movement of the laser probe within the canal space (in the present study) rather than holding the probe still results in no surface alteration. In this study, when the probe was allowed to remain in one position within the canal, ablation of dentin occurred with associated disruption peripherally and occasional melting, but the melting did not result in resolidification, rather resulting in a "blast" resolidification (complete ablation of the surface combined with melting and solidification of the underlying areas) with extreme crater formation and cracking. The amount of heat generated may also affect the surrounding periodontal ligament and supporting bone to the point that those tissues would become damaged. The fact that no destruction occurred (Figs. 2a and 2b) when the laser probe was continually in motion may indicate that temperatures generated with such a procedure may not be high enough to damage surrounding tissue.

It is apparent that more research is needed to determine the optimum effects of laser systems on root canal wall dentin as well as other application techniques. If a system can be developed such that the laser removes the smear layer and organic tissue remnants, sterilizes the root canal system in its entirety, as well as altering the intracanal walls to close dentin tubules by melting and resolidification, without damaging adjacent periodontal ligament and bone, then greater success with endodontic treatment will be achievable.

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Discussion with Reviewers

D.H. Pashley: How much heat was generated at the apex of the teeth in Figs. 6a and 8? Wouldn't that damage the PDL and periapical tissues?

Authors: In a related study using infrared thermography to measure outer surface root temperatures, the temperatures generated to cause such damage would be 200°-300°C. Those temperatures would damage the periodontal ligament (PDL) which is the soft tissue membrane that separates a tooth from the surrounding bone and is composed of connective tissue fibers that attach to both the tooth and bone. In this study, however, the absence of temperature measurements would cause difficulty in determining if the combinations of power over time would be clinically acceptable.

D.H. Pashley: Have the authors purposely contaminated root canals with bacteria and then attempted to sterilize them with lasers?

Authors: Yes, a preliminary study carried out in our laboratory showed that the laser was, indeed, effective in removing organisms contained in the root canal space.

D.H. Pashley: How far away from the apex should laser probes be positioned to avoid inadvertent roughening of the canal which might interfere with apical seals?

Authors: The laser probes should be positioned no closer than 2 mm from the apex. Also, the probe should not be left in any one position during root canal treatment, but should be continuously moved to avoid heat buildup which can cause the events shown in Figure 8. When such an event occurs, disruption of the canal walls interfere with apical seals and jeopardize the success of the treatment.