In Vitro Study of a Nd:YAP Laser in Endodontic Retreatment

Pierre Farge, DDS, PhD, Paul Nahas, DDS, and Philippe Bonin, DDS, PhD

Nd:YAP laser is a dental laser with a 1340 nm wavelength. The laser beam is carried by a 200 to 300 μm fiberoptic and is suitable for endodontic therapy. We used the Nd:YAP laser in an in vitro experiment to study its effectiveness in endodontic retreatment. Temperature measurements and irradiation parameters were first defined. Then Nd:YAP laser irradiation was used, alone or in combination with hand instruments, to remove various canal sealers and broken instruments. Clinical parameters were monitored and scanning electron microscopic observations were conducted. When used at 200 mJ—with a pulse duration of 150 ms, an exposure time of 1 s and a frequency of 10 Hz—Nd:YAP laser preserved the dentinal walls of the root canal and enabled root canal retreatment without thermic elevation harming periodontal tissue. It is concluded that, in combination with hand instruments, the Nd:YAP laser is an effective device for root canal preparation in endodontic retreatment.

Since the first attempts with lasers in the field of dentistry, a number of experiments have been conducted on the effects of laser exposure on dental hard tissues. Recently, the potential of this technology has been emphasized, and several experiments have been conducted in endodontics. The possible use of laser in root canal therapy relies on the physical properties of laser irradiation that enables the removal of tissue debris, microorganisms, and other components of the root canal.

Laser characteristics include their wavelength, their dissipated energy, and the use of a fiberoptic technology that gives access to the root canal system. When used for dentin and root canal therapy, the absorbed energy of laser causes an intended effect. This energy can go up to 4 × 10^5 W/cm^2 using an Nd:YAG laser of 100 W, whereas solar energy is estimated at 5 × 10^3 W/cm^2 (1). Dentinal permeability modifications and antibacterial effects of laser irradiation have been studied. Stabholz et al. (2) showed a reduction in the permeability of the resected root end using Nd:YAG beam to seal teeth after apicoectomy and retrofill. Miserendino et al. (3) demonstrated that the permeability of Nd:YAG laser-treated teeth was significantly less than untreated specimens. The Ar:F excimer laser can cause significant removal of peritubular dentin, melting, and resolidification of the dentinal smear layer with laser fluence of 5 and 15 J/cm^2. Deeper and wider cracks are noted with higher laser fluence (4).

Using a CO₂ laser, Bonin et al. (5) showed a decrease in dentin permeability after laser exposure in the dog model. Paghdidiwala (6) demonstrated that erbium:YAG can transform the mineral constituents of the tubules that melt and fuse into amorphous particles. After irradiation, the smear layer usually found with rotary cutting instruments was not present. Tewik et al. (7) indicated that dentin might become more permeable after lasing with KTP/532.

Mashida et al. (8) compared the presence of the smear layer at different power settings used for the KTP/YAG and found that the smear layer might either disappear or remain, depending on the parameters used.

Moss et al. (9) have demonstrated the potential of the excimer laser radiation at 248 nm wavelength for precision machining dental hard tissue, with a resulting clean appearance of the irradiated zone.

Other studies have been conducted on the antibacterial effects of intracanal Nd:YAG laser irradiation. Stevens et al. (10) found that the Nd:YAG beam with water was an effective inhibitor of the growth of B. stearothermophilus, compared with hand instrumentation and ultrasonic groups. Hardee et al. (1) noted a reduction in colony-forming units when using a Nd:YAG laser. Onal et al. (11) described the use of a 9.6 μm CO₂ laser delivered by an AgCl fiber of 900 μm diameter into the root canal to treat the dentinal surface and demonstrated bactericidal effects.

Regarding endodontic retreatment, a variety of techniques have been described to remove insufficient root canal filling (12). The elimination of debris remains essential for nonsurgical treatment; in particular, the removal of a metallic obstruction is tedious and may lead to unsuccessful results (13).

The purpose of this study was to find out if a Nd:YAP laser could improve the retreatment of the root canal system. Changes that might occur on the dentinal walls during laser irradiation without harming periodontal ligaments were investigated according to the clinical parameters.

MATERIALS AND METHODS

Laser Device

We used a Nd:YAP laser apparatus in which yttrium aluminium perovskite is a synthetic crystal serving as a matrix for the
neodyme ions. The wavelength is 1340 nm, and the absorption spectrum in water is 20 times the Nd:YAG laser spectrum (Lokki Co., Vienne, France).

The laser beam is carried by a 200 μm or a 300 μm diameter fiberoptic that can be switched and swapped easily from a hand-piece. The fiberoptics are made of quartz and coated with silicon and polystyrene. Thus, the external diameters are, respectively, 240 and 380 μm.

The device characteristics are the following: energy per pulse is adjustable at 170 or 200 or 300 mJ; length of pulse is preset at 150 ms; frequency is adjustable at 5 or 10 or 30 Hz; mean power is 6 W; and mean peak power is 2 kW. Because the Nd:YAP wavelength is invisible, the beam is visualized using a visible red helium-neon laser with a 635 nm wavelength. For the following experiments, the 200 μm fiberoptic was used.

Tooth and Root Canal Preparation

Thirty-three freshly extracted straight and single-rooted teeth were randomly selected. Eight of them were used to specify laser parameters, and 25 were prepared for the study of laser impact in endodontic retreatment.

Three groups of five teeth were manually prepared by a standardized step-back serial technique. Canals were enlarged to a #25 file, coupled with a 10 ml of 2.5% NaOCl irrigation and divided into four groups. Three groups were filled with either gutta-percha by lateral condensation, zinc oxide-eugenol, and silver cones. Two other groups contained broken instruments; a #10 file or a #15 file was fractured into the root canal system during root preparation.

SEM Evaluation after Laser Irradiation

All irradiated teeth considered for scanning electron microscopic observation were split in half with a chisel, after their buccal and lingual surfaces were vertically grooved.

The specimens were dehydrated in a graded series of aqueous ethanol (60, 70, 80, and 90%) for 10 min at each concentration. The specimens were then dried under a vacuum at room temperature. After that, they were mounted on scanning electron microscopic stubs and sputter-coated with silver. All specimens were viewed using a scanning electron microscope JEOL CF 35 at 15 kV tension.

RESULTS

Temperature Measurements

Temperature elevation was first measured in empty root canals to minimize the heat absorption by the root obturation material. Frequencies (5 and 10 Hz) were used at three energy levels (170, 200, and 300 mJ) in eight teeth.

On average, the temperature rose from 2.2°C to 6.6°C, and the cooling time at room temperature ranged from 1.20 to 2.14 min after one set of laser irradiation. As expected, higher energy levels generated greater temperature elevation.

Similar experiments were conducted when irradiating filled root canals with either gutta percha, zinc oxide past, or silver cones. Using the same experimental conditions as in empty canals, the temperature elevation never rose above 5.2°C.
Retreatment Parameters

On behalf of the preliminary determinations of the laser irradiation, the 200 mJ energy level was used either with a 5 Hz or 10 Hz frequency, to study the removal of endodontic obstacles.

In the first set of teeth, laser irradiation alone was used and could not allow for complete removal of debris and obturation materials in the canal. In the second set of teeth, laser irradiation was used in combination with hand instrumentation. Retreatment could be completed in all cases, and a #8 file could reach the apical foramen. In the case of broken instruments, the files could never be removed but were all bypassed with the #8 file. No perforation or ledge of the apical foramen was noted either clinically or on the radiographs. The times required to complete the procedures on the 20 teeth considered are shown in Table 1.

Experimental observations showed that the average progression in a canal after one irradiation is approximately 0.5 mm with a 5 Hz/200 mJ/1 s impact and 1 mm using a 10 Hz/200 mJ/1 s impact.

At 5 or 10 Hz, canal patency was obtained equally at both frequencies, but the procedure tends to be faster at a higher frequency. No major time difference was noted between gutta-percha and zinc oxide pastes in all cases. The procedure was quicker with silver cones and broken instruments that are both of metallic nature and seem to be modified or removed with the help of the laser irradiation.

Scanning Electron Microscopic Evaluation

External irradiation with a single impact at 200 mJ and 10 Hz resulted in a large circular crater on the dentin surface. Inside the crater, holes in the fused area are considered as residuals of gas bubbles that are generated during the melting and recrystallization process of the hydroxyapatite. Larger spheric structures are seen and appear disconnected from the fused dentinal walls (Fig. 1).

Canal irradiation leads to similar observations. The melting of the dentin occurs at the laser impact, and disconnected spheres of fused dentin increase in number and size proportionally to the energy levels. Separated and crystallized dentin projections appear at an energy level of 300 mJ (Fig. 2).

However when used at 200 mJ, the laser activity remains superficial and does not alter the deepest part of the dentinal walls. This is demonstrated in Fig. 3, in which deep unlased dentin and superficially lased dentin are seen.

Using laser irradiation, irrigation, and manual instrumentation, the prepared root canal demonstrates a clean and regular appearance. Calcipherite debris is scattered over the melted dentin that covers the dentinal tubules (Fig. 4).

The effect of the laser beam transmitted through the 200 μm diameter fiberoptic can be seen on a zinc oxide canal filling. The laser impact is clearly demonstrated in Fig. 5. The laser impact seems quite innocuous to adjacent structures, and the imprint of the optic fiber is marked on the root filling material with a 200 mJ, 10-Hz impact.

Figure 6 demonstrates the bypass of a broken file with the help of laser irradiation and hand instrumentation. In this straight canal, the apical foramen has been reached with the help of the laser irradiation. The demarcations of the optic fiber and the files are seen.

**DISCUSSION**

A successful endodontic treatment requires the complete elimination of all debris from the root canal; this is conventionally performed using hand or mechanical instrumentation with chemical irrigation. Studies (14) have shown that endodontic instruments produce organic and mineral debris and are unable to remove them totally. Friedman et al. (12) compared four techniques that used combinations of hand or ultrasonic instrumentation with

<table>
<thead>
<tr>
<th>Laser Parameters</th>
<th>Gutta Percha</th>
<th>Zinc Oxide</th>
<th>Silver Cone</th>
<th>Broken Files</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Hz, 200 mJ (5 teeth)</td>
<td>80 min</td>
<td>70 min</td>
<td>40 min</td>
<td>15 to 20 min</td>
</tr>
<tr>
<td>10 Hz, 001 mJ (15 teeth)</td>
<td>49 min</td>
<td>35 min</td>
<td>20 min</td>
<td>4 to 26 min</td>
</tr>
</tbody>
</table>

Fig. 1. Perpendicular irradiation to the dentin surface with the Nd:YAP laser. The resulting crater demonstrates the melting and recrystallization of the dentin surface. (Original magnification ×1000.)

Fig. 2. Root canal dentin surface after an intracanal irradiation with the fiberoptic. (Original magnification ×900.)
heat and chloroform, and concluded that neither technique removed all debris and no removal technique was superior.

In endodontic retreatment, these procedures are often tedious and time-consuming. One of the main difficulties is the removal of insufficient root canal filling or obstacles. The common endodontic rule is that instruments should not be forced inside the canal.

Fracture of root canal instruments is not an uncommon incident; evaluations of endodontic recall radiographs have indicated that the frequency of remaining fragments ranges from 2 to 6% (13). Silver cones, which are no longer a conventional root canal filling material, account for a large amount of indications of endodontic retreatments.

Hulsmann (13) described the most useful methods for removing obstructions from the root canal. Chemical dissolution by specific solvents is used in combination with manual instrumentation or ultrasonic energy to remove pastes and other cones.

For elimination of silver cones or broken instruments, manual retrieval techniques involve the attempt to pull out silver cones with a plier. The Canal Finder systems, the Masseran kit, and ultrasonic devices have also been tried. No statistical data on the success rate of these techniques have been documented; the estimated time for these procedures ranges from a few minutes to several hours.

Root canal preparation versus laser methods were compared by Goodis et al. (15). When viewed by scanning electron microscopy, root canal preparation done by combined laser and hand instrumentation showed a general absence of smear layer, with no remaining tissue remnants. The architecture of the dentin along the walls of the root canal was modified by an increase in the appearance of the calciospherites.

Compared with conventional procedures, the Nd:YAP laser irradiation must be undertaken in a dry root canal. Chemical dissolution must not be considered simultaneously.

Whereas the manual retrieval technique works most successfully on fragments broken in the coronal third of the root, the Nd:YAP laser fiberoptic with a 200 μm diameter can work in the apical third. The Nd:YAP laser can also be used when a fragment of the broken instrument is firmly blocked inside the canal and cannot be dislodged by an ultrasonic method. Similarly, laser can
be considered for a broken silver cone, which cannot be reached or grasped with peet splinter forceps.

As for temperature elevation, Arcoria et al. (16) suggested that injury to pulp and supporting periodontal structures may occur with wavelength ≥390 nm. Eriksson and Albrektsson (17) found that injury to bone could occur when the local temperature increased by 10°C for 5 min; a 47°C temperature elevation for 1 min was the border temperature for the occurrence of morphologically evident bone tissue damage. Using a Nd:YAG laser, Mashida et al. (8) observed a maximum temperature increase of 10.3°C in the irradiated zone during 5-s exposure at 2 W, 5 Hz. In a monkey model, Zach and Cohen (18) reported that a 5°C increase of temperature would cause necrosis.

When using a Nd:YAP laser (10), all results were within a 5° to 7°C limit and seem acceptable in regard to periapical structures. Similar results were obtained with a 245 μm optic fiber and a Holmium:YAG laser.

Higher temperature elevations appear only when using the 10-Hz, 300 mJ combination that is not set for intracanal use, but for gingival and soft tissue surgeries. The Nd:YAP laser is preset and operated on a pulse mode with a period of rest of 1 min between consecutive pulses. This rest period was of great importance in the prevention of temperature build-up in the canal system and thermal damages to the surrounding tissues. The laser carried through an optic fiber of an adequate diameter can destroy the sealer by staying in contact with it, without affecting the dentinal walls. Hand instrumentation eliminates the carbonized part of the sealer and enlarges the canal laterally without any vertical progression. To allow for this progression, the fiber-optic has to stay in contact with the filling material.

When looking at the scanning electron microscopic results, the lased dentin has a comparable appearance to a Nd:YAG-lased dentin surface. The scattered calciospherites at the dentin surface indicate that the laser irradiation is an aid to passing obstacles or eliminating endodontic materials, but does not prepare the dentinal walls for refilling.

Using the Nd:YAP laser, retreatment must be accomplished with hand instrumentation to avoid carbonized parts of dentin accumulating in the central part of the root canal. The resulting apical plug does not permit proper disinfection and reobturation.

Dentin permeability modifications need to be further studied. Dederich et al. (19) obtained a melted, recrystallized dentin after Nd:YAG lasing. These surface modifications depend on the magnitude of the irradiation energy. With these results, he suggested that none of the wavelengths were suitable for endodontic use. With the Nd:YAP laser, scanning electron microscopic observations indicate that the 300 mJ energy level can result in important dentin projections and possible recrystallization; using the 200 mJ energy level, the underlying dentin is not modified, and no crater-like structures are seen.

Although heat convection is recognizable, the heterogeneous nature of tissue types makes it difficult to detect the depth of the penetration and the total result of laser ablation. Further characterization of the reflecting properties versus the penetration potential will be helpful.

Multiple factors influence the various types of laser tissue interactions for each wavelength of emission. Most types of interactions are strongly dependent on the inherent optical absorption properties of various materials and tissues. In endodontic retreatment, the laser light interaction with matter may not be energy-dependent because of the heterogeneous nature of the root canal material or obstacles. Therefore adequate control of energy, density, and pulse duration in regard to the canal environment must be achieved. Future developments involve the use of Nd:YAP for the retreatment of curved canals and the study of dentin permeability modifications.

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References