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The use of the erbium, chromium:yttrium-scandium-gallium-garnet laser in endodontic treatment
The results of an in vitro study

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One objective in endodontic therapy is to sanitize the root canal and the three-dimensional network of dentinal tubules. Bacteria from infected pulp tissue can penetrate into the deeper layers of root dentin and propagate periapical inflammation with subsequent destruction of the adjacent connective tissues.[1-3]

The local microenvironment of the root canal system favors the selection of a few bacterial species that can survive and proliferate when they are out of reach of the host's immune response.[4-8] Rinsing solutions used during conventional root canal treatment affect those bacteria only partially. The pathogenic microorganisms are able to penetrate the root dentin up to more than 1 millimeter, whereas rinsing solutions reach a depth of around only 100 micrometers.[9,10] In addition, bacteria such as *Enterococcus faecalis* are able to form intra- and extraradicular biofilms, which makes it even harder to con-

A B S T R A C T

Background. The use of the erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser has become accepted in the field of cavity preparation. The development of miniaturized and flexible fiber tips has allowed this device to be used in endodontics. The authors conducted an in vitro study to assess the effects of Er,Cr:YSGG laser irradiation on root canals.

Methods. The authors inoculated root canals with two bacteria, laser irradiated them at two power settings and subjected them to a quantitative microbiological evaluation. They used scanning electron microscopy (SEM) to assess morphological changes in endodontically processed and laser-irradiated root canal walls. They measured temperature increases on the root surface to determine possible thermal side effects.

Results. The bacteriological evaluation revealed a disinfecting effect in the root dentin samples that was dependent on the output power but not specific for the bacterial species investigated. SEM showed the removal of the smear layer from the root canal walls and the exposure of dentinal tubules. The temperature rise during irradiation was moderate when standardized power settings were used.

Conclusions. The Er,Cr:YSGG laser can be used to eliminate bacteria in root canals. It also effectively removes smear layer and debris from the canal wall.

Clinical Implications. Practitioners can use the Er,Cr:YSGG laser to prepare root canals for endodontic therapy.

Key Words. Endodontics; root canal; laser; bacteriology; scanning electron microscopy.
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trol them.[11-13] These facts often are the reasons for cases that are resistant to therapy from the beginning or end up as long-term failures after endodontic treatment.

Considering this, disinfecting the root canal—including the most distant areas of the tubular system—is a major challenge in endodontic treatment and is of fundamental importance for the prolonged preservation of endodontically treated teeth. The use of lasers in the field of endodontics is an innovative approach for meeting these requirements. In general, dental lasers provide access to formerly unreachable parts of the tubular network, owing to the fact that they penetrate dental tissues better than rinsing solutions.[14-16]

Since the early 1980s, several studies on the impact of different laser systems on the root canal and the surrounding dentin have been published. The carbon dioxide (CO_2) laser, which emits a wavelength of 10,600 nanometers, has been used in surgery for a long period. In 1986, Zakariasen and colleagues[17] showed for the first time that this wavelength could be used in endodontics with a good bactericidal effect. In 1995, Moritz and colleagues[18] achieved a partial closure of dentinal tubules using the CO_2 laser on root canal surfaces. Owing to the fact that the emitted long wave infrared radiation (10,600 nm) can be transmitted into the root canal exclusively by using a rigid hollow wave guide, the canal lumen must be well-prepared and the laser can be used only in straight root canals.

An in vitro study by Pini and colleagues[19] focused on the use of the xenon chloride (XeCl) excimer laser, which emits ultraviolet radiation at 308 nm. This low wavelength leads to a satisfactory removal of hard tissues and a bactericidal effect with only limited thermal side effects. The requirements of technical resources are tremendous and, therefore, the use of the XeCl excimer laser remains restricted primarily to basic research.

Moshonov and colleagues[20] demonstrated the efficacy of the argon laser in removing intracanal debris by means of computerized scanning electron microscopy (SEM), whereas Blankenau and colleagues[21] illustrated this procedure's safety regarding the temperature rise at the root surface when they used an argon laser at power settings of 1 and 2 watts.

The most widely used laser in endodontics is the neodymium:yttrium-aluminum-garnet (Nd:YAG) laser, which emits a wavelength of 1,064 nm. Owing to the wavelength's being in the near infrared range, flexible conductors can be used in narrow and curved root canals. This laser yields a bactericidal effect on root canal surfaces and in the deeper dentin layers. Studies by White and colleagues,[22] Rooney and colleagues,[23] Gutknecht and colleagues[24] and Moritz and colleagues[25] showed the high bactericidal effect of the Nd:YAG laser.

The diode laser is comparable to the Nd:YAG laser in terms of effectiveness. It emits at a wavelength of 810 nm and has comparable bactericidal capabilities.[26]

For the removal of dental hard tissue, the erbium:yttrium-aluminum-garnet (Er:YAG) and the erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers provide suitable wavelengths. Emitting at 2,940 nm and 2,780 nm, respectively, these lasers act through photoablation since their wavelengths correlate closely with the absorption maximum of hydroxyapatite. When irradiated, water contained in the dental hard tissue evaporates instantaneously and ablates the surrounding tissue with only minimal thermal side effects.[27]

Although used primarily for the preparation of dental hard substances, the erbium lasers also can be used in endodontic treatment. The development of superior light-conductive materials allows for the irradiation of narrow or curved root canals. Hibst and colleagues[28] proposed that Er:YAG lasers be used in endodontics; later studies by Schoop and colleagues[29,30] confirmed Er:YAG laser's qualification.

Some articles focused on caries removal and cavity preparation using the Er,Cr:YSGG laser,[31-33] while Yamazaki and colleagues[34] and Kimura and colleagues[35] described the morphological changes encountered in irradiated root canal walls.

In our in vitro study, we examined the bactericidal, morphological and thermal effects of the Er,Cr:YSGG laser when it is used in addition to root canal treatment. To evaluate the antimicrobial effect of the laser, we performed bacteriolog-

ABBREVIATION KEY. CO₂: Carbon dioxide. **Er,Cr:YSGG:** Erbium, chromium:yttrium-scandium-gallium-garnet. **Er:YAG:** Erbium:yttrium-aluminum-garnet. **ESEM:** Environmental scanning electron microscope. **Nd:YAG:** Neodymium:yttrium-aluminum-garnet. **SEM:** Scanning electron microscopy. **XeCl:** Xenon chloride.

ical experiments in vitro with two different bacterial species. We used an environmental scanning electron microscope (ESEM) to record morphological alterations on dentinal surfaces, and we used a thermocouple to measure the thermal effects caused by laser irradiation.

MATERIALS AND METHODS

Sample preparation. We stored 60 extracted human teeth with one root each in physiological saline solution (that is, saline of the same concentration as that in the human body). We then performed trepanation and orthograde enlargement of the root canal to International Organization for Standardization standard 70. We assigned the prepared teeth to six experimental groups.

Bacterial inoculation. We steam-sterilized the samples at 134 C for 10 minutes to remove all pre-existing bacteria. We then inoculated the root canals with 10 microliters of either of the two test bacteria—*Escherichia coli* (American Type Culture Collection 10536) or *E. faecalis* (American Type Culture Collection 29212)—by means of a micropipette. The initial bacterial count was 10^8 colony-forming units per milliliter (CFU/mL). We sealed the inoculated teeth with wax and placed them into sterile microcentifuge tubes containing 100 µL of physiological saline solution. After incubating the teeth for four hours at 35 C, we took them out of the microcentifuge tubes and removed the wax seals.

Laser irradiation. One investigator (U.S.) performed all of the irradiations to ensure comparability between the test samples in our study and those of preceding investigations.[29,30] He performed laser irradiation in the root canals by using an Er,Cr:YSGG laser that emitted a wavelength of 2,780 nm. The pulse energy of the Er,Cr:YSGG laser varied between 25 and 300 millijoules at a fixed repetition rate of 20 hertz, which resulted in an output power of 0.5 to 6 W. The laser was equipped with exchangeable fiber tips that had a diameter of 300 µm. The investigator measured the laser power emitted at the fiber tip by using a wattmeter before each irradiation to ensure stable and standardized power outputs.

For each test bacteria, he used the following experimental protocol. He treated one group of 10 samples with the laser set at 180 mJ as indicated at the display of the laser unit, with an output power of 1 W measured directly at the end of the fiber tip. He treated a second group of 10 samples

with the laser set at 250 mJ, with an output power of 1.5 W. He used a pulse rate of 20 Hz for both groups. He treated each sample with one lasing cycle, which consisted of five irradiations of five seconds each with a 20-second break in between. For irradiation, he inserted the optical tip as far as the apex. Then he activated the laser and continuously radiated the root canal from the apex to the crown in slow, circular movements. By using this procedure, he could ensure that he irradiated the entire root canal. For each test microorganism, 10 samples served as a control group. He treated these control samples the same way he treated the test samples, but when he introduced the laser fiber into the canal, he did not activate the laser device.

Bacteriological evaluation. Immediately after the laser treatment we rinsed the root canal with 1 mL of physiological saline solution and collected the eluate in a microcentifuge tube.

To determine the bacterial count, we diluted the eluate in log 10 steps (that is, a dilution was made to the 10th part of the initial concentration, then to 100th part, the 1,000th part and so forth). We applied 20 µL of each dilution to sheep blood agar culture plates and incubated them for 24 hours at 37 C. We counted the colonies and assessed the total number of bacteria (CFU/mL of the extraction fluid). The lowest detection level of bacteria we found was 5×10^2 CFU/mL.

Temperature measurements. To assess the thermal impact of the irradiation using Er,Cr:YSGG lasers, we took temperature measurements, using five samples for each power setting. We mounted the teeth on an even thermocouple measuring 10 mm $\times$ 10 mm that used a silicon-based heat-conductive compound. During the irradiation procedure, which we conducted the same way as we did for the inoculated samples, we recorded the maximum temperature increase starting from a room temperature of 21 C by using a digital thermometer. We calculated the average value and the standard deviation of the five measurements from each laser and setting.

ESEM. We divided the remaining 20 samples in two equal groups (those irradiated with an output power of 1 W and of 1.5 W) and prepared them as described above, except we did not inoculate them with bacteria. We cut the samples longitudinally with a diamond-coated band saw and submitted them to SEM to evaluate the morphological changes induced by laser irradiation. We

TABLE

Bacterial counts of *Escherichia coli* and *Enterococcus faecalis,* by test group.

BACTERIA (LOG STEP OF COLONY COUNT)	TEST GROUP (NO.)		
	Control	Er,Cr:YSGG* (1 Watt)	Er,Cr:YSGG (1.5 W)
***Escherichia coli* (CFU/mL†)**			
Below detection level	—‡	8	10
10^3	—	—	—
10^4	—	2	—
10^5	5	—	—
10^6	5	—	—
10^7	—	—	—
***Enterococcus faecalis* (CFU/mL)**			
Below detection level	—	8	8
10^3	—	2	2
10^4	—	—	—
10^5	4	—	—
10^6	6	—	—
10^7	—	—	—

* Er,Cr:YSGG: Erbium, chromium:yttrium-scandium-gallium-garnet.
† CFU/mL: Colony-forming units per milliliter.
‡ —: Not applicable.

assessed the specimens using an ESEM, which works with comparatively small negative pressure compared with SEM, and the samples did not sputter, which facilitated our assessment of the samples and the minimization of artifacts. We took micrographs at different magnifications.

RESULTS

Bacteriology. The table shows the results of the bacteria counts of *E. coli* and *E. faecalis.* We rated samples in log steps of the colony counts and applied the specific radiation power.

The control group results for both test bacteria showed colony counts ranging between 10^5 and 10^6 CFU/mL, demonstrating a decrease of two to three log steps through the inoculation and incubation processes and the further processing of the samples.

The Er,Cr:YSGG laser succeeded in reducing the amount of *E. coli* at the lower output power setting of 1 W. The higher output power setting of 1.5 W yielded a reduction of the bacteria to below the detection level.

The Er,Cr:YSGG laser was effective in eliminating the gram-positive *E. faecalis.* At an output

power of 1 W, it removed the bacterium three to four log steps compared with the control group. At an output power of 1.5 W, the use of the laser did not result in any significant difference in terms of disinfecting effectiveness when compared with the 1 W group.

Temperature measurements. When we chose the output power setting of 1 W, the irradiation of the samples resulted in an average temperature rise of 2.7 C at the root surface. When we chose the output power setting of 1.5 W, the average temperature rise at the root surface was 3.2 C. We took all the measurements at a base room temperature of 21 C; thus, the value 3.2 C stands for a temperature rise to 24.2 C. Although a higher irradiation power resulted in a stronger temperature increase at the sample surface, the temperature stayed within safe borders.

Environmental scanning electron microscopy. Figure 1 shows a longitudinal cut through a root that had been irradiated with the Er,Cr:YSGG laser at an output power of 1 W. The cut surface of the periluminal dentin can be seen at the right margin. The root canal surface exhibits the typical rough structure after the removal of the adhering smear layer.

Figure 2 gives a detailed view of the root canal wall at 1,000-fold magnification after irradiation with the laser set an output power of 1 W. The exposed dentinal tubules are clearly discernible, since the smear layer resulting from manual preparation had been removed by laser irradiation.

When we increased the output power to 1.5 W, we could see some areas with partially closed dentinal tubules (Figure 3, page 954). Partial melting and recrystallization of dentin could have caused this effect. A significant number of dentinal tubules stayed open.

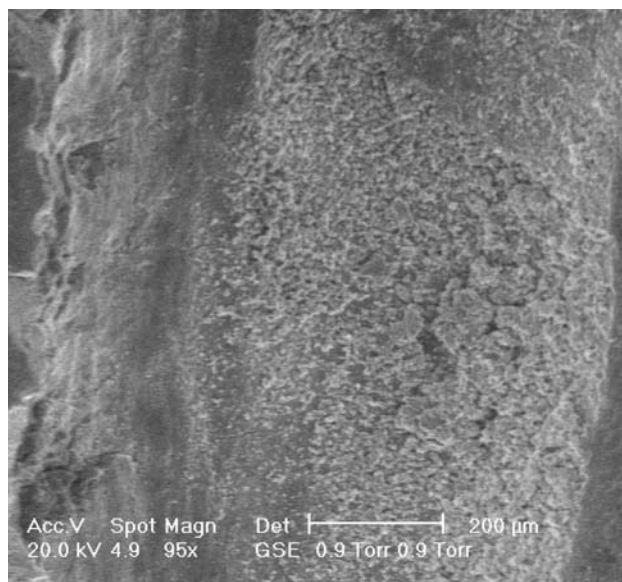Figure 4 (page 954) shows a detail of a root

Figure. 1. Scanning electron micrograph of a root canal irradiated at an output power of 1 watt. Magnification ×95.

Figure 2. Scanning electron micrograph of a root canal irradiated at an output power of 1 watt. Magnification ×1,000.

canal irradiated at an output power of 1.5 W. The closed dentinal tubules can be seen alongside the open ones.

DISCUSSION

Successful endodontic treatment relies to a great extent on completely cleaning the root canal, as infected dentin and pulpal tissue can endanger therapy outcome. In conventional endodontic treatment, practitioners aim to remove infected pulp and dentin layers by using mechanical techniques and bactericidal irrigants. One treatment method, bactericidal rinsing, can be ineffective. Kouchi and colleagues[9] show that bacteria colonize the periluminal dentin up to a depth of 1,100 μm, while another study found that chemical disinfectants penetrate the dentin to a depth of only 100 μm.[10] Curved root canals or side branches also can be obstacles in conventional root canal treatment. The use of lasers helps overcome these problems. The high penetration depth of the laser beam in the dentinal tissue seems to be the best explanation of the satisfying bactericidal effect of different laser wavelengths. Vaarkamp and colleagues[15] and Odor and colleagues[16] provide a possible explanation for this kind of light propagation; they describe the ability of enamel prisms and dentin tubules to act as optical fibers. Moritz and colleagues[36] demonstrate the effect of Nd:YAG laser irradiation on bacteria through indirect irradiation.

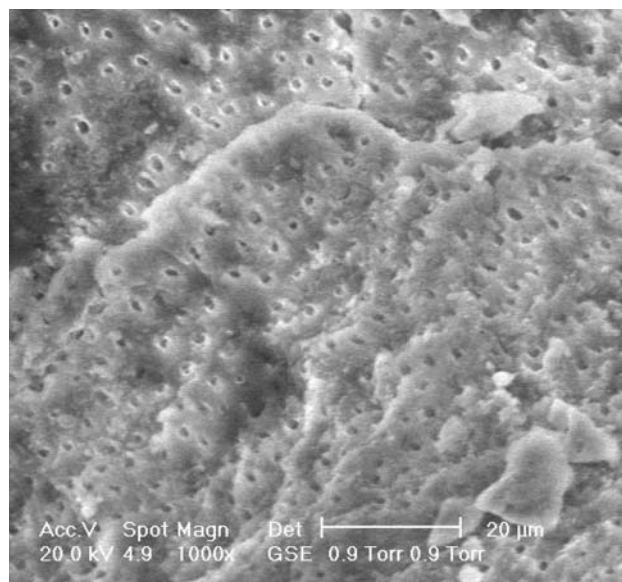The use of laser wavelengths suitable for the preparation of dental hard substances could add another aspect to the field of root canal cleaning. In an in vitro study, Schoop and colleagues[29] described the effects of Er:YAG laser irradiation on root canal walls and the bactericidal effect of its wavelength, which emits at 2,940 nm.

We conducted our study to evaluate the effectiveness of a similar wavelength, that of the Er,Cr:YSGG laser, which emits at 2,780 nm. Even at the lower output power of 1 W, we observed a distinct reduction in bacterial counts, although we could not achieve bacterial reduction below 10^2 CFU/mL in all the samples. When we used the laser at an output power setting of 1.5 W, the CFU/mL level fell below the detection level in all samples. We found no significant difference between the effects of laser irradiation on the two test microorganisms. In another study, the authors stated that *E. faecalis* was harder to eradicate than *E. coli* and explained that this was due to differences in cell wall structures.[36] In a preceding study that focused on the Er:YAG laser, the investigators noticed no complete eradication of *E. faecalis*.[30]

The temperature rise at the root surface did not exceed 3.2 C; therefore, we discounted excessive heating of the entire sample as a reason for the antibacterial effect. We also regarded the maximum temperature rise at the root surface as innocuous for the surrounding periodontal tissues.

Owing to the high absorption rate of the Er,Cr:YSGG laser's radiation in water, the penetration depth in dentin should be restricted,
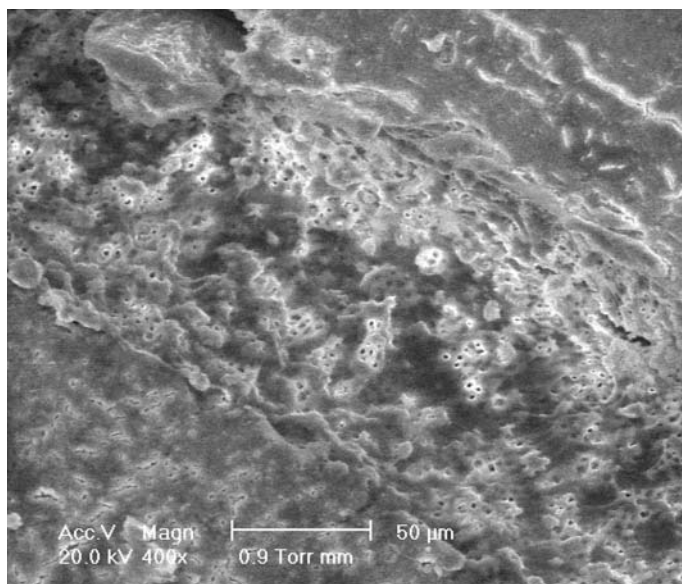
Figure 3. Scanning electron micrograph of a root canal irradiated at an output power of 1.5 watts. Magnification ×400.

Figure 4. Scanning electron micrograph of a root canal irradiated at an output power of 1.5 watts. Magnification ×1,000.

unlike with other lasers such as the Nd:YAG or the diode. One explanation for the laser's positive bactericidal effect on *E. faecalis* in our study could be that the test bacteria did not penetrate the dentinal tubules. However, we incubated the samples for four hours before laser irradiation, which should have been sufficient to allow for propagation of the test bacteria into the tubular network. This method's reliability has been demonstrated in other studies.[24,30,36] Another explanation for the Er,Cr:YSGG laser's positive effect on *E. faecalis* could be that a certain degree of the laser's light conduction within the dentinal tubules results in a higher penetration depth. Other factors such as shock waves or cavitation effects have been reported for other laser devices[37,38] and could be a further explanation for the actual effects of Er,Cr:YSGG laser irradiation. Further investigations are necessary to clarify the exact interactions of laser light and bacteria.

Through SEM, we found that the Er,Cr:YSGG laser could remove the smear layer and debris from the root canals' walls and could open up the dentinal tubules' orifices. This should help practitioners seal the root canal tightly. We used the laser as an adjunct to the conventional root canal preparation technique. Although we did not observe excessive ablation, we think that using the laser to enlarge the canal could lead to unwanted effects such as perforating the root canal wall or local overheating.
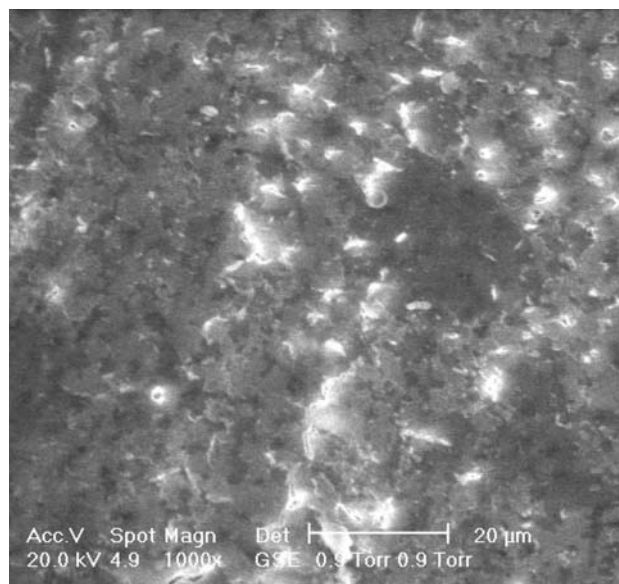
When we used the laser at the higher output power setting (1.5 W), we found slight traces of melting and recrystallization. This might be due to the fact that we used the laser without using the air-water delivery system so as not to impair our bacteriological evaluation. Since the device is equipped with an adjustable air-water delivery system, using the water spray probably could reduce those effects. We are conducting a study on the effects of the water spray and the rinsing solutions on the laser's effectiveness.

Regarding the ability of the Er,Cr:YSGG laser system to remove debris and the smear layer from the root canal walls and to reduce the presence of viable bacteria, we found that it yielded results equivalent to those of lasers with different wavelengths.[17-36]

CONCLUSION

The laser wavelength we tested in our study may be suitable for cleaning and disinfecting root canals and can be used safely if the common precautions for using lasers are observed and the energy and irradiation time are within the proposed range. Clinical studies are necessary to confirm the results and to investigate the laser wavelengths under in vivo conditions. ∎

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