Cavitational Effects in Aqueous Endodontic Irrigants Generated by Near-infrared Lasers

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Abstract

Introduction: Laser-generated pressure waves may have application for removing debris and smear layers from root canals. Past work has employed middle infrared erbium lasers. The present study examined whether near infrared 940 and 980 nm diode lasers (Biolase Ezlase and Sirona Sirolaser, respectively) could induce cavitations in aqueous media. **Methods:** Laser energy was delivered into a capillary tube using a 200 μm fiber, and the formation of cavitations observed with a microscope. In the first part of the study, a range of laser parameters were trialled to establish conditions which form cavitations within 5 seconds of the commencement of laser irradiation. The second part of the study compared cavitation in distilled water, aerated tap water, degassed distilled water, ozonated water, 3 and 6% hydrogen peroxide using panel setting of 2.5 W/25 Hz for the Sirolaser, and 4 W/10 Hz for the Ezlase. **Results:** Both diode laser systems could induce cavitation in water-base media by the formation and implosion of water vapour. Laser power played a more important role than pulse frequency or pulse interval. Optimal laser-initiated cavitation occurred when weak (3%) peroxide solutions were used as the target irrigant, rather than water. **Conclusion:** This phenomenon has potential for enhancing debridement in endodontics. *(J Endod 2009;■:1–4)*

Key Words

Cavitation, debridement, endodontic treatment, irrigants, lasers, peroxide

It is well recognized that effective endodontic treatment requires the combination of physical and chemical agents to eradicate soft-tissue debris, smear layer, and microorganisms. The latter may be present both in planktonic forms and in multilayered biofilms that are physically robust. Although these resist mechanical instrumentation, they may be more amenable to disruption by pressure waves generated by pulsed lasers.

Cavitation is the formation of vapor-containing bubbles inside a fluid. This process results in the formation of pressure waves/shockwaves characterized by rapid changes in pressure and high amplitude (1). A forced collapse of bubbles causes implosions that impact on surfaces, causing shear forces, surface deformation, and removal of surface material (2). In the root canal environment, such shockwaves could potentially disrupt bacterial biofilms, rupture bacterial cell walls, and remove smear layer and debris. Shockwave generation can also enhance the breakdown of agents such as hydrogen peroxide and ozone dissolved in water and thereby enhance their disinfecting and debriding actions (3).

Shockwave generation with lasers is widely used in medical procedures such as lithotripsy for fragmenting renal and gall bladder calcifications. Past work has shown that solid-state laser systems with short pulse durations can induce pressure waves in water, including the near-infrared Nd:YAG laser (1) and more recently the middle infrared Er:YAG and Er,Cr:YSGG lasers (4, 5). These laser-generated pressure waves move at high speed, with different characteristics from waves induced by freely vibrating sonic and ultrasonic endodontic instruments, (1) and appear to enhance the action of endodontic irrigants in terms of smear layer removal (6). Because solid-state laser systems are large and relatively expensive, it was of interest to examine whether similar effects could be created with low-cost handheld diode lasers that have recently been introduced into clinical practice for soft-tissue surgery.

Within the near-infrared spectrum, 940- and 980-nm diode laser wavelengths are of particular interest because these are close to harmonics for water absorption and are much more strongly absorbed than other available near-infrared wavelengths such as 810, 830, and 1,064 nm (7). The present study was undertaken to establish whether cavitations could be generated in water using 940- and 980-nm diode lasers and, if so, which laser parameters and absorbing media would be optimal.

Materials and Methods

Laser Systems

Two diode laser systems were used: the Sirolaser (Sirona, Bensheim, Germany) system, which emits at 980 nm, and the Ezlase (Biolase, San Clemente, CA), which emits at 940 nm. Both systems have a maximum output power of 7 W and can deliver energy in pulsed or continuous wave modes into 200-μm plain ended fibers suitable for endodontic applications. The maximum pulse frequency for both lasers was 10 KHz.

Capillary Tube Model

A glass capillary tube model was used to allow direct viewing of cavitation in aqueous media. Capillary tubes 1 mm in diameter and 14 mm in length were used to establish threshold settings for generating cavitational bubbles in distilled water at

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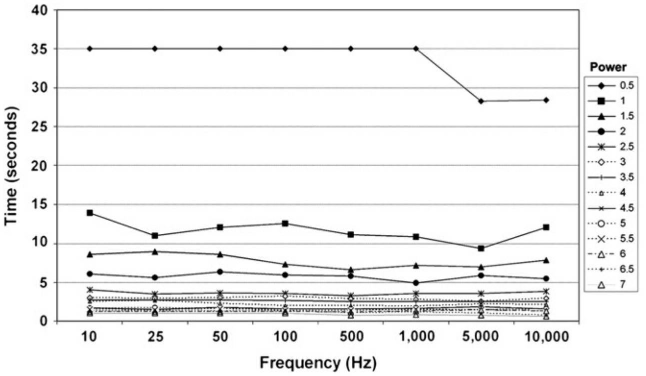

Figure 1. The effect of laser power and pulse frequency on the time taken for cavitation to be initiated in water using the Sirolaser. Each series is a different average laser power from 0.5 to 7 W in 0.5-W increments.

different settings. One end of the tube was securely sealed with adhesive (Blu-Tac; Bostic, Sydney, Australia) and mounted on a template that included a measuring ruler to achieve a standardized position of the laser fiber. The internal fluid volume of the capillary tube model was 11.0 μL. A stereo microscope (Olympus, Tokyo, Japan) fitted with a digital camera (CoolPix 4500; Nikon, Tokyo, Japan) was connected to a video monitor, and the capillary tube was viewed under a magnification of 18×. All studies were performed at an ambient room temperature of 25°C.

Thresholds for Cavitation

Both laser systems were tested in pulsed modes at average powers from 0.5 to 7.0 W using 0.5-W increments. A matrix design was used such that each power setting was used with a range of pulse settings as follows: for the Sirolaser, from 10 to 10,000 Hz in eight increments, and, for the Ezlase, combinations of pulse interval/pulse duration from 50 ms/50 ms through to 500 ms/500 ms in five increments (1- to 10-Hz pulse frequency).

Before each experimental trial, distilled water was introduced into the capillary tube using a 25-G needle attached to a 10-mL syringe; the tube was overfilled using a flushing action to ensure that the entire volume of the tube had been filled and no air bubbles were present. The laser fiber was then inserted into the capillary tube to a preset position 5 mm short of the closed end. The time taken from the commencement of lasing to the first sign of bubble formation inside the tube was recorded up to a maximum of 30 seconds. The entire study was repeated twice for reliability.

Cavitation in Different Fluids

Using laser settings determined from the preceding experiments that reliably caused cavitation within a 5-second period, other aqueous media were then tested. The panel settings were 2.5 W/25 Hz for the Sirolaser and 4 W/10 Hz for the Ezlase. The actual laser power emitted from the terminal end of the fibers when measured using a laser power meter was 1.35 and 1.68 W, respectively. The following media were used in the capillary tube model: distilled water, tap water that had been collected through a domestic aerator fitting, distilled water that had been degassed by treatment in an ultrasonic cleaner for 5 minutes, ozonated water generated by passing ozone-enriched air into water (OH DENT; Protec Dental, Melbourne, Australia), electrolytically ozonated water (C-7100 M; Biotek Ozone Australia, St Leonards, Australia), and hydrogen peroxide (3% and 6%, obtained from a dispensing pharmacy). Laser treatment of the seven liquids was undertaken with 15 replicates of each, and the average time for cavitation was calculated. The level of ozone in the water produced by the OH DENT and Biotek systems was measured by using a water ozone level meter (Biotek Ozone Model OM-1000). All datasets were tested for normality using the Kolmogorov and Smirnov test, and normality was confirmed for all groups. Because standard deviations were not comparable across groups, data were analyzed at group level using the Kruskal-Wallis nonparametric test with Dunn's multiple comparison tests for post hoc analyses.

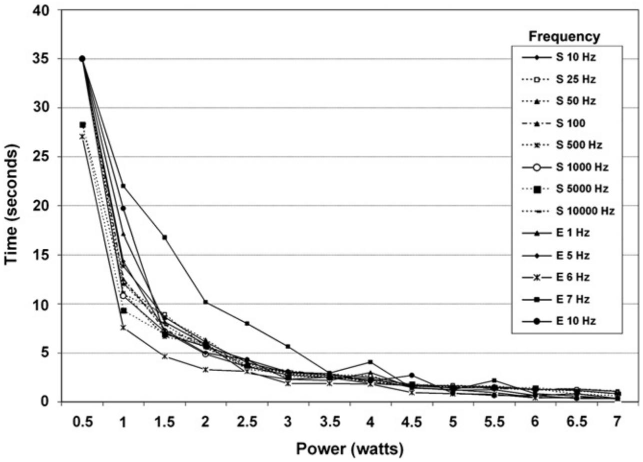

Figure 2. The effect of average laser power on the time taken for cavitation to be initiated in water using the Sirolaser and Ezlase. Data series are the pulse frequencies (in Hz) for the Sirolaser (s) and the pulse duration/pulse interval (in milliseconds) for the Ezlase (e).

Results

In distilled water, both laser systems could induce cavitational bubbles. The lowest panel settings that could achieve this within 5 seconds of the commencement of laser treatment were 2.5 W/25 Hz for the Sirolaser and 4 W/10 Hz for the Ezlase.

Varying the pulse frequency did not have a significant effect on the time taken to induce cavitations (Fig. 1). However, as the average power increased, with both lasers the time taken to induce cavitation decreased (Fig. 2).

Comparing different irrigants using the "minimal settings," there was a significant difference between fluids in the time to form cavitation bubbles ($p < 0.0001$). Hydrogen peroxide at both concentrations of 3% and 6% was significantly faster than all other fluids (Fig. 3), but there was no significant difference between the two peroxide concentrations. For other fluids, there were no significant differences between distilled water and degassed distilled water, aerated tap water, or ozonated water from either of the two systems used. The measured ozone level for the OH DENT treated water was zero, and for the Biotek treated water it was 3.66 ppm.

At the specified laser settings, cavitation in distilled water occurred more rapidly with the Sirolaser ($p = 0.0018$), whereas cavitation in both 3% and 6% hydrogen peroxide was faster for the Ezlase than the Sirolaser ($p < 0.0001$).

Discussion

The possibility of shockwave generation with dental lasers inside root canals and its role in smear layer removal have recently been suggested (4, 5, 6). George et al (6) showed that when water in root canals was activated using erbium lasers, laser-induced cavitations enhanced the removal of the smear layer. With the strong water absorption of the

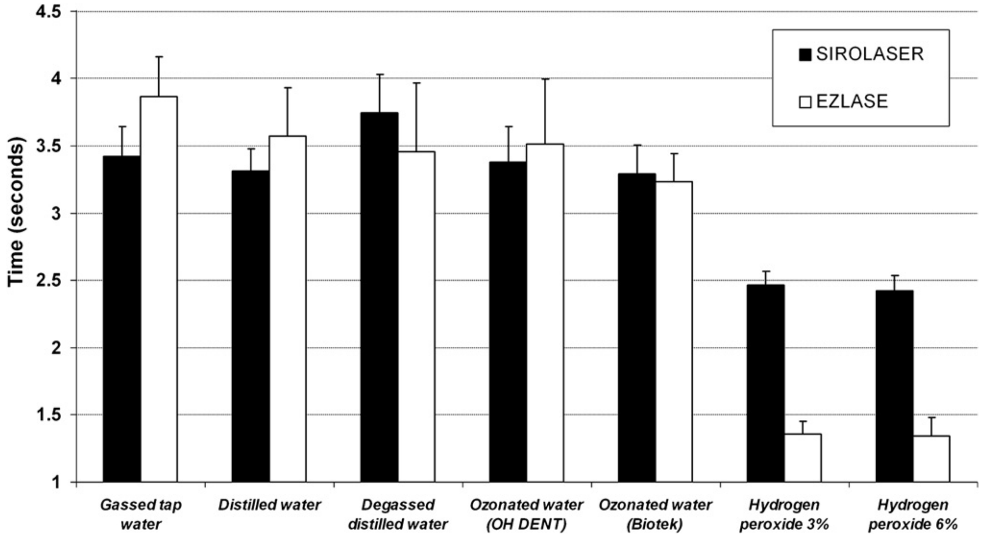

Figure 3. The time taken for cavitation to be initiated in different irrigants for the Sirolaser and Ezlase.

erbium laser wavelengths (2,780 and 2,940 nm), there was no difference between water and hydrogen peroxide irrigants in terms of smear layer removal.

The present study is the first to report laser-induced cavitations with near-infrared diode lasers at both 940- and 980-nm wavelengths. The minimum laser parameters required for this could induce cavitations in less than 5 seconds, which is a practical time for future clinical applications. Because the cavitations are the result of water vapor forming and then collapsing, increasing the average power was expected to reduce the time taken to form cavitations, and this was confirmed by the empirical data. On the other hand, increasing the frequency but keeping the same mark-space ratio (duty cycle or dwell) of 50% should not have a significant impact on the timing of cavitational bubble formation, and this was also found to be the case. In keeping with this, previous studies using 980-nm diode lasers have shown that altering pulse frequency at a constant duty cycle does not affect temperature changes within root canals (8).

An important part of the current study was exploring whether the bubbles forming in distilled water were water vapor or steam rather than dissolved air. By comparing aerated with degassed water, there was no difference found in the time taken to form cavitational bubbles, which formally excludes a significant contribution from dissolved air.

In a similar manner, it was expected that aqueous irrigants with oxygen-releasing potential would enhance cavitation formation through the generation of water vapor as well as oxygen. This was found for hydrogen peroxide at both concentrations of 3% and 6%, both of which showed more rapid induction of cavitation than water. These enhanced cavitations noted with diode lasers in weak solutions of hydrogen peroxide may result in better removal of debris compared with water alone if the relationships postulated between shockwave amplitude and debris removal in earlier work (4, 6) are shown to hold true empirically. The use of even higher concentrations of hydrogen peroxide may produce greater cavitational effects but may not be advisable because of irritancy should such materials be extruded through the apex.

Ozone-enriched water at the levels tested in this study did not have any effect on cavitation. The ozone system, which relied on gas dissolving into water, did not give detectable ozone levels in water despite ozone being identified in the gas produced by this unit using iodometry. The electrolytic system gave measurable dissolved ozone levels in the range known to be effective for water disinfection (9); however, there was no increase in cavitation. Nevertheless, laser activation of ozonated water may increase its disinfection capabilities because cavitation is known to decompose ozone, causing augmentation of the activity of oxygen-free radicals (10). During cavitation in ozonated water, ozone decomposes to hydroperoxyl and hydroxyl radicals but not to molecular oxygen (10). The latter point explains why there was no increase in cavitation noted in the ozonated water used in the present study.

When comparing the two laser wavelengths, 980 nm generated cavitations more readily in distilled water than 940 nm. This is consistent with the known near-infrared absorption characteristics of water because 980 nm is the more strongly absorbed wavelength of the two. The pattern was reversed when hydrogen peroxide was used, which can be explained by the differing absorption curves of water and hydrogen peroxide (11), with greater absorption at shorter wavelengths for the latter.

Conclusions

Both near-infrared diode laser wavelengths used in the present study can induce cavitation bubbles in water and weak hydrogen peroxide solutions. This phenomenon could have potential application in the root canal for enhancing the removal of debris and smear layer. Further studies of the application of laser-generated cavitations in endodontics are needed to explore the efficacy and safety of such an approach.

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