Laser-aided degradation of composite resin

Brian W. Thomas, DMD; Charles R. Hook, DMD; Robert A. Draughn, DSc

Implications for the use of lasers (light amplification by stimulated emission of radiation) in the practice of clinical dentistry have been suggested for over three decades. In 1990 the U.S. Federal Food and Drug Administration recognized the Nd: YAG (Neodymium: Yttrium Aluminum Garnet) laser for limited use involving intraoral soft tissue procedures.[1] There are still many questions concerning the practical application of dental lasers on hard tissue and numerous concerns about the detrimental effects to the tooth, patient, and practitioner.[2] However, the potential for clinical use is significant.

Other studies have demonstrated the effect of lasers on the debonding of ceramic brackets.[3,4] This paper addresses the use of the Nd: YAG laser in degrading residual resin after orthodontic bracket removal. The most common current techniques of resin removal involve the use of bond-removing pliers,[5,6,7] hand-scalers,[5,8,9,10] green rubber wheels,[5,8,9] ultrasonic scalers,[11,12] or handpieces with suitable burs.[7,8,10] Studies have shown that these techniques can produce surface scratches, enamel loss, and enamel tearouts.[6,9,10,13,14] If the resins used in bonding could be selectively degraded with a dental laser, these problems might be eliminated. Furthermore, the techniques developed for orthodontic

Abstract

The removal of residual composite resin after debonding orthodontic brackets often creates surface scratches, enamel loss, and enamel tearouts. If the Nd: YAG laser could selectively degrade the resin without damaging the underlying tooth structure, these problems might be eliminated. The purpose of this study was to determine the effectiveness of the Nd: YAG laser in degrading composite resin within a time frame that will not cause pulpal damage. Minimal lasing times and optimum frequencies were determined by testing the compressive strengths of resin cylinders exposed to laser radiation for 2, 3, 5, 10, or 15 seconds at frequencies of 60, 80, or 100 Hz. The optimum condition was determined to be a 3 second lasing time at a frequency of 100 Hz. Cylinders of composite resin were divided into four groups consisting of: (1) resin, (2) resin with a laser enhancing dye, (3) resin lased for 3 seconds at 100 Hz, and (4) resin with the dye which was lased for 3 seconds at 100 Hz. The compressive strengths of the four groups were statistically compared. The resin groups that were lased for 3 seconds at 100 Hz showed a 75% reduction in compressive strength. The results of this study demonstrate that dual wavelength pulsed Nd: YAG laser energy, when used within the parameters described here, will degrade the mechanical properties of composite resin, thereby offering the potential for a quick and efficient method of removing residual composite resin.

Key Words

Laser • Nd: YAG • Composite resin • Dental enamel • Orthodontic brackets

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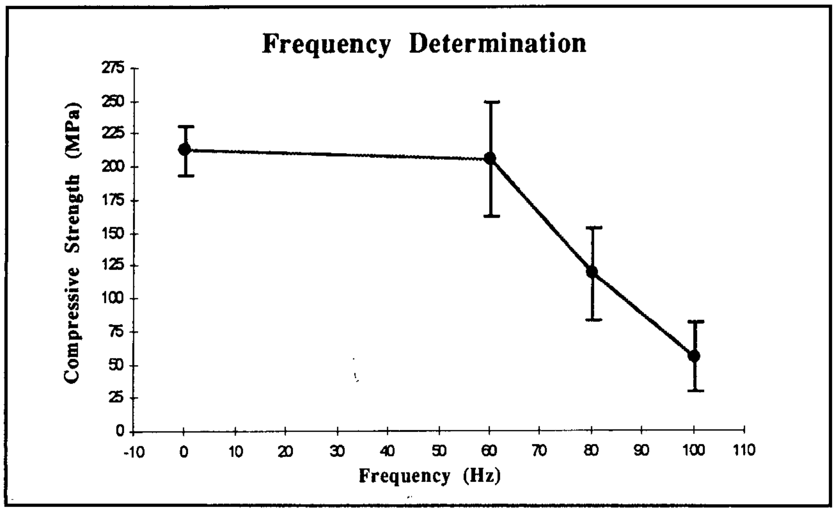

Figure 1

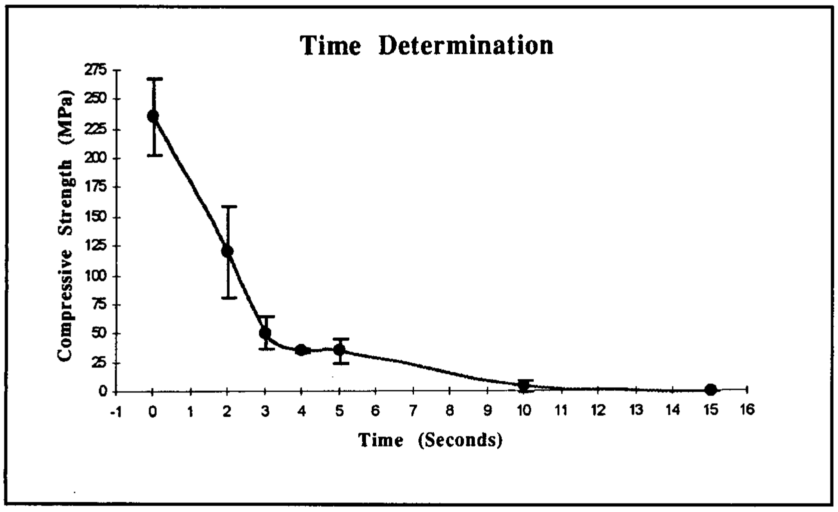

Figure 2

Figure 1
Mean compressive strengths of composite resin cylinders as a function of pulse frequency with an exposure time of 3 seconds; bars indicate one standard deviation of the mean.

Figure 2
Mean compressive strengths of composite resin cylinders with increasing exposure times and a pulse frequency of 100 Hz; bars indicate one standard deviation of the mean.

purposes could have significant applications in restorative dentistry.

One of the early problems associated with the application of laser technology to dental hard tissues was that laser irradiation of teeth generates too much heat.[15,16,17] A temperature rise of 6° Celsius may result in an irreversible pulpal reaction which can lead to pulpal necrosis.[18] More recent research has shown that laser-induced temperature increases are a function of time of laser use and power output from the laser.[19,20,21] Although the results of these studies regarding pulpal effects are somewhat conflicting, it can be concluded that shorter lasing times and lower powers result in minimal temperature changes within the tooth. Therefore, before lasers are to be used clinically for hard-tissue procedures, particular attention must be given to the precise lasing times and power output of the laser used.

The purpose of this investigation was to test the effectiveness of a dual wavelength Nd:YAG laser in degrading composite resin within a time and power range that should not cause pulpal damage. The compressive strengths of cylinders of composite resin were tested before and after lasing at different times and frequencies.

Materials and methods

The laser used in this study was the Nd: YAG laser model-K14 (Kiger Inc, Hilton Head, SC). It is unique in that it simultaneously emits two wavelengths with energy outputs of 60% 532 nm and 40% 1064 nm. A laser beam is delivered to a pen-sized handpiece through an optical fiber that has a focal spot of 300 microns diameter. Energy pulse frequency can be varied from 40 to 100 pulses/second (Hertz). The laser affects the surface by direct contact or by holding the handpiece at a short distance and pointing a red L.E.D. (light emitting device)-aiming beam at the target. A laser-enhancing dye (acid red dye #52 in propylene glycol), similar in composition to red food dye #102, was mixed with some of the resin specimens and tested for effectiveness. This dye has been used to enhance the absorption of laser light upon carious dental tissues because it readily stains organic pathogens[22] and its absorbance wavelength is similar to the laser's wavelength.[23] The resin material used in this study was Prisma-fil APH high density composite (LD Caulk Co, Dentsply, Milford, Del).

Cylindrical specimens (1.56 mm diameter x 2.45 mm length) were prepared by injecting composite resin into a multicompartment clear acrylic mold. Composite material was uniformly injected into the holes, excess was removed, and the mold was placed into a visible light curing instrument (Schultz-Dental PLC 400) for 10 minutes. After curing, the top and bottom surfaces of the mold were ground to a 400 grit finish with silicon carbide abrasive paper, and the specimens were gently pressed from the mold.

Groups of five specimens were used to determine the optimum frequency and lasing times. The laser handpiece was mounted on a bracket so that the tip of the fiber was 1 mm from the cylinder sample, which was held by a small clamp. The cylinders were lased at 60, 80, or 100 Hertz for 2, 3, 4, 5, 10, or 15 seconds. Mechanical properties were measured by testing the specimens in compression using a mechanical test system (MTS System 810). The test apparatus was operated in the displacement control mode with a ramp function and displacement rate of 1 mm/min. The values for compressive strengths were calculated by dividing the maximum applied load by the cross-sectional area of the specimen.

The optimum frequency (Figure 1) and mini-

Table 1
Statistical comparison of various conditions using a 2-tailed paired t-test.

Conditions	Paired t-value	Prob.
Composite (199 +/- 37.2 MPa) x composite with dye (195 +/- 29.1 MPa)	0.52	0.6047
Composite (199 +/- 37.2 MPa) x composite and laser (48.0 +/- 11.6 MPa)	14.7	0.0001
Composite with dye (195 +/- 29.1 MPa) x composite, dye, and laser (43.2 +/- 14.6 MPa)	19.9	0.0001
Composite and laser (48.0 +/- 11.6 MPa) x composite, dye, and laser (43.2 +/- 14.6 MPa)	0.95	0.3553

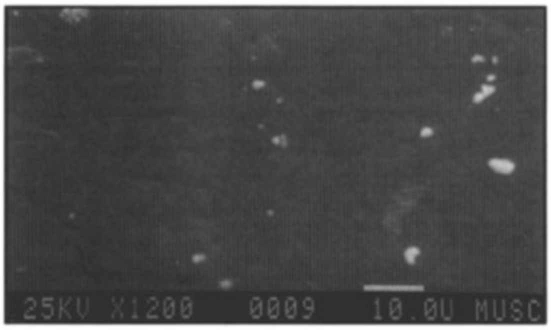

Figure 3A

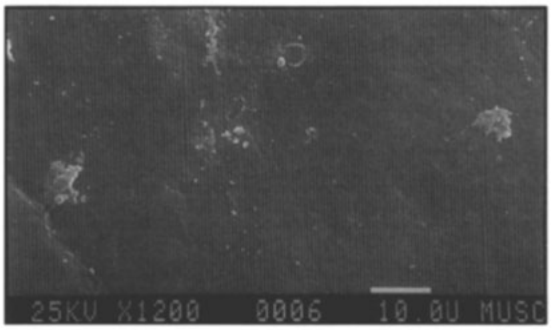

Figure 3B

Figure 3A
Enamel surface at 1200x magnification without being lased.

Figure 3B
Enamel surface at 1200x magnification after being lased for 3 seconds at 100 Hz at a distance of 1 mm.

mal lasing times (Figure 2) were established by statistical analysis (two-tailed paired *t*-test at 2 degrees of freedom). Comparison of the mean compressive strengths of the 60 Hz (205.8 +/- 21.4 MPa), 80 Hz (119.0 +/- 25.4 MPa), and 100 Hz (56.4 $\pm$ 24.5 MPa) groups with the control group reveals that the 100 Hz group demonstrated the greatest decrease in compressive strength, thus the 100 Hz frequency was chosen. At this frequency the laser delivers a power of 3.0 watts and an energy density of 30 joules/cm^2. The compressive strengths between 2 seconds (140.8 +/- 38.7 MPa), 3 seconds (51.0 +/- 13.8 MPa), 4 seconds (36.4 +/- 2.0 MPa), 5 seconds (35.7 +/-9.9 MPa), 10 seconds (4.7 +/- 4.8 MPa), and 15 seconds (0.0 MPa) were compared. The interval with the greatest significant difference was between 2 seconds and 3 seconds, with smaller decreases with increasing time, thus a 3-second lasing time at 100 Hz was chosen as the optimum parameter to use.

To study the effectiveness of the laser in degrading the composite resin at the optimum parameters (100 Hz for 3 seconds) four groups of 20 cylinders were constructed. The groups consisted of (1) unlased composite, (2) composite lased for 3 seconds at 100 Hz, (3) composite mixed with a laser-enhancing dye, and (4) composite mixed with dye and lased for 3 seconds at 100 Hz. The specimens with the laser-enhancing dye were mixed in a ratio of .02 ml to .25 gm composite on a glass slab prior to curing. Each cylinder was compressed on the MTS machine and the compressive strengths were determined following the same procedures used in determining the optimal parameters. The compressive strengths were averaged and statistically compared (Table 1) using a two-tailed paired *t*-test.

Potential damage to tooth structure was assessed by performing scanning electron microscope studies on four human mandibular first premolars. The extracted teeth were disinfected in 2% chlorhexidine digluconate for 24 hours and then stored in distilled water. The crowns were sectioned off and three were irradiated at 100 Hz and 3 watts of power for 3 seconds at a distance of 1 mm. The specimens were prepared and examined according to the techniques described by Fuerenstein et al.[24] The specimens were attached with epoxy resin to aluminum stubs, then sputter-coated with a 200 angstrom-thick layer of gold palladium. Examination was done with a JEOL JSM 35C S.E.M. at 25 kV and micrographs of the tooth surface were examined at 1200X magnification (Figures 3A and 3B).

Results

Results of statistical analysis of compressive strengths are shown in Table 1. Mean values of compressive strength are shown in Figure 4. The results of the lased composite group show a 75% reduction of compressive strength in comparison with the control group. Statistical analysis comparing the lased composite group to the composite, dye, and laser group showed no significant difference ($P \leq .05$). Thus, mixing the dye with

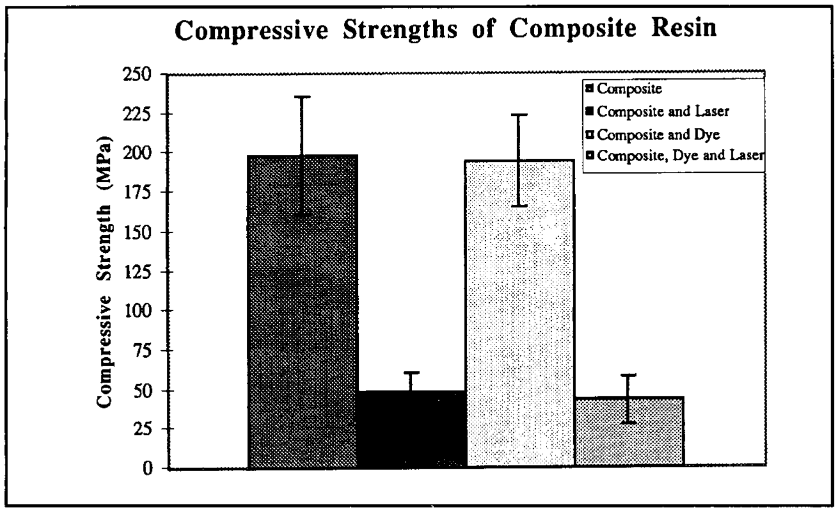

Figure 4
Mean compressive strengths of composite resin cylinders; bars indicate one standard deviation of the mean.

the composite did not decrease the compressive strength and did not enhance the laser's ability to degrade the resin.

Upon lasing the test cylinders, a rough damaged surface with a deep crater and carbon deposits was instantly produced. During the 3-second interval the composite crackled and an odor of burnt plastic was evident. A plume of smoke arose from the burnt surface. The specimens did not feel hot to touch immediately after lasing, but they would glow during the lasing procedure

Scanning electron microscopy showed the control enamel surface, without laser irradiation, (Figure 3A) to be relatively structureless enamel with rod ends, particles, and transverse wave-like grooves, perikymata, believed to be the external manifestations of the Striae of Retzius. The laser-treated surface (Figure 3B) showed very little change. The perikymata were still visible and the outer prism layer and the rod boundaries still intact. The rod ends seemed more defined but clearly did not resemble an etching pattern resulting from an acid treatment of enamel in which the rod periphery would be heavily eroded leaving a prominent rod core.

Discussion and conclusion

The decrease in ultimate compressive strength of the lased composite shows that the Nd: YAG laser is effective in degrading dental resin materials. The similarity of the dye and nondye groups reveals that the dye is not more effective in reducing the composite's strength by lasing. The strength values of the control group fall within the range reported in previous studies,[24] demonstrating that the techniques used in this study are consistent with those of other researchers.

Previous studies indicate that pulpal damage from lasers occurs as a result of temperature increases within the tooth of 6° C or more,[18] and temperature changes are a function of lasing powers and times.[19-21] These studies have demonstrated that lasing times of less then 5 seconds would not increase pulpal temperature more than 1°C.[20,21] Current data from Kigre Inc suggest that exposure times of less than 45 seconds, using the same laser used in this study, result in pulpal temperature increases of less than 5° C.

From these conclusions we infer that using a laser for only 3 seconds will place any temperature changes well below the time-power limit at which pulpal damage would occur. Furthermore, the results from our study demonstrate that as lasing times exceeded 3 seconds, the laser's degrading ability did not improve (Figure 2). However, as the laser's frequency was increased to the maximum setting of 100 Hz, a trend was noted as the compressive strength of the resin cylinders continued to decrease.

Laser-initiated degradation is hypothesized to take place as a result of: (1) thermal softening, (2) thermal ablation, which comes about when the rate of heating is fast enough to vaporize the resin, or (3) photoablation, which occurs when laser light energy, being absorbed by the resin, increases molecular vibration causing chemical bonds to disassociate.[26] The Nd:YAG laser used in this study emits light in the infrared ranges of 532 nm and 1064 nm. It is hypothesized that light in the 532 nm range is highly absorbed by the resin and produces immediate carbonization. The 1064 nm wavelength is efficiently absorbed by the darkened material and results in increased efficiency of ablation.

The results of this study demonstrate that dual wavelength pulsed Nd: YAG laser energy, when used within the parameters described here, will degrade the mechanical properties of composite resin. From these findings, it is proposed that the Nd: YAG laser can facilitate the removal of bonded resin without damaging tooth structure. Further research is needed before the laser can be used clinically for composite resin removal. Closer examination of the enamel-resin interface, laser enhancing dyes, thermal effects of the laser, and patient comfort are some of the topics that require additional investigation.

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