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Authors

Fried, William A
Chan, Kenneth H
Darling, Cynthia L
[et al.](#)

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Selective removal of dental composite with a diode-pumped Er:YAG laser

William A. Fried, Kenneth H. Chan, Cynthia L. Darling, and Daniel Fried*

University of California, San Francisco, San Francisco, CA 94143-0758

Abstract

Selective removal of dental composite with high precision is best accomplished using lasers operating at high pulse repetition rates focused to a small spot size. Conventional flash-lamp pumped Er:YAG lasers are poorly suited for this purpose, but new diode-pumped Er:YAG lasers have become available operating at high pulse repetition rates. The purpose of this study was to compare the ablation rates and selectivity of enamel and composite for a 30 W diode-pumped Er:YAG laser operating with a pulse duration of 30–50- μ s and evaluate its suitability for the selective removal of composite from tooth surfaces. The depth of ablation and changes in surface morphology were assessed using digital microscopy. The fluence range of 30–50 J/cm² appeared optimal for the removal of composite, and damage to sound enamel was limited to less than 100- μ m after the removal of composite as thick as 700–800- μ m. Future studies will focus on the use of methods of feedback to further increase selectivity.

Keywords

Er:YAG laser; dental composite; selective laser ablation

1. INTRODUCTION

Dental composites and glass ionomers are used as restorative materials for filling cavities, shaping, and covering teeth for esthetic purposes, and as adhesives. Dentists spend more time replacing existing restorations that fail due to microleakage and secondary caries than they do placing new restorations. [1, 2] Tooth colored restorations are difficult to differentiate from the surrounding tooth structure and adhere strongly to the underlying enamel and dentin making them challenging to remove without damaging tooth structure. Hence, the clinician frequently removes excessive amounts of healthy tooth structure to ensure complete removal of the composite.[3, 4] Therefore, a system that can rapidly and selectively remove composite from tooth surfaces while minimizing the inadvertent removal of healthy tooth structure would be a significant improvement over current methods.

Previous studies have shown that high ablation selectively can be achieved using laser pulses at $\lambda=355$ -nm of nanosecond duration.[5–7] However, the frequency tripled Nd:YAG laser is poorly suited for the removal of sound and demineralized dental hard tissues and

*Contact Author: daniel.fried@ucsf.edu.

utilizes UV radiation. It is safer and more economical to utilize a laser that can be used for multiple applications. The pulsed CO₂ laser can be used to ablate composite selectively if spectral feedback is employed. [8] Studies have shown that free-running and Q-switched Er:YAG lasers can be used to remove composite restorative materials but a high degree of selectivity has not been observed. [9–11]

The Er:YAG has been used recently to remove residual composite from tooth surfaces but the damage to the underlying enamel created a rough surface that was rougher than after conventional removal.[12, 13] Recent studies employed the Er:YAG laser to remove ceramic brackets, veneers, and crowns due to thermal action and the higher absorption of water between the tooth surface and the adhesive. [14–20]

We demonstrated that composite can be selectively removed from tooth buccal and occlusal surfaces at clinically relevant rates using a CO₂ laser operating at 9.3- μ m with high pulse repetition rates with minimal heat deposition. [8] The selective removal of composite from the smooth buccal surfaces is more challenging than removing composite from other tooth surfaces since it is particularly important to minimize enamel loss from these highly visible tooth surfaces for esthetic reasons.

For selective removal, low energy pulses and small spot sizes must be used to minimize the amount of tissue removed per laser pulse, therefore the laser has to be operated at high pulse repetition rates for practical removal rates. Until recently the only lasers that met this criteria were CO₂ lasers operating at the highly absorbed 9.3 and 9.6- μ m wavelengths and we have demonstrated that enamel and dentin can be most efficiently ablated using laser pulses of 10–15- μ s duration. [21–23] The flash-lamp pumped erbium solid-state lasers presently being used for dental hard tissue ablation are not suitable for this approach since they utilize high energy pulses and relatively low pulse repetition rates. Diode pumped solid-state (DPSS) Er:YAG lasers are now available operating with pulse repetition rates as high as 1–2 kHz and initial studies have been carried out demonstrating their utility for the ablation of dental hard tissues and bone. [24–26]

Last year we explored the potential of the diode pumped Er:YAG laser for the image guided ablation of caries lesions. [27] The purpose of this study is to explore the potential of using the DPSS Er:YAG laser for the selective removal of composite.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Blocks approximately 10 \times 2 mm with the enamel at least 500- μ m thick were prepared from bovine incisors. Composite discs at least a mm thick were prepared from Z250 composite (3M, Minneapolis, MN) by sectioning a block of the cured composite. Layers between 400–800 μ m thick of GrenGloo™ (Ormco, Orange, CA) composite were applied to the bovine blocks as shown in Figure 1 for the composite removal samples. The Ortho Solo™ (Ormco) adhesive, and 37% phosphoric acid etchant were used according to the manufacturer's instructions. Grengloo™ composite changes color and appears green below body

temperature. This helps to identify any residual composite missed by the laser. It also has similar composition to other standard composites such as Z250.

2.2 Laser Setup and Parameters

Samples were irradiated using a DPSS Er:YAG laser, Model DPM-30 from Pantec Engineering, (Liechtenstein) operated at a pulse duration of 50- μ s and a pulse repetition rate of up to 100-Hz. The laser energy output was monitored using a power meter EPM 1000, Coherent-Moletron (Santa Clara, CA), and the Joulemeter ED-200 from Gentec (Quebec, Canada). A high-speed XY-scanning system, Model ESP 301 controller with ILS100PP and VP-25AA stages from Newport (Irvine, CA) was used to scan the samples across the laser beam. Designated sound and lesion areas (boxes) on each tooth were irradiated by the laser. The laser was focused to a spot size of \sim 150- μ m using an aspheric ZnSe lens of 25 mm focal length. A pressure air-actuated fluid spray delivery system consisting of a 780S spray valve, a Valvemate 7040 controller, and a fluid reservoir from EFD, Inc. (East Providence, RI) was used to provide a uniform spray of fine water mist onto the tooth surfaces at 2 mL/min.

2.3 Digital Microscopy (DCDM)

Tooth surfaces were examined after laser irradiation using an optical microscopy/3D surface profilometry system, the VHX-1000 from Keyence (Elmwood, NJ). Two lenses were used, the VH-Z25 with a magnification from 25 to 175 \times and the VH-Z100R with a magnification of 100–1000 \times . Depth composition digital microscopy images (DCDM) and 3D images were acquired by scanning the image plane of the microscope and reconstructing a depth composition image with all points at optimum focus displayed in a 2D image. The Keyence 3-D shape measurement software, VHX-H3M, was used to correct the tilt of the sample and measure the variation in depth over the enamel and composite in the ablated areas.

2.4 Relative Ablation Rate Measurements

Relative Er:YAG ablation rates were assessed using bovine enamel samples and Z250 composite sections. Incisions were produced by scanning the laser beam at a rate of 5 mm/sec with the pulse repetition rate fixed at 100 Hz. Each incision was produced by two passes in one direction. The ablation depths were analyzed using DCDM. A range of fluence was assessed starting with the highest achievable fluence and progressively reducing the fluence using glass attenuators. Six incisions were produced for each fluence on six samples of bovine enamel and three samples of composite.

2.5 Composite Removal from Enamel Surfaces

A rectangular box was cut across the applied composite on the bovine enamel samples with the cut extending approximately a mm beyond the composite on each side as shown in Fig. 1. The laser was scanned in one direction and twenty scans were carried out separated by 25- μ m for each iteration. The iterations were repeated until the composite was completely removed along the center of the box. The axial focus position was adjusted manually to avoid stalling. The composite thickness and the damage to the underlying enamel was measured using DCDM as shown in Fig. 2. The lateral and transverse damage measurements

were averaged for each fluence. The reported values represent the measurements on one sample.

3. RESULTS AND DISCUSSION

3.1 Relative Ablation Rate Measurements

Two digital 3D images of incisions produced in enamel and composite at the same fluence are shown in Fig 3. The composite incisions were typically deeper, cleaner and more uniform for the same fluence. For irradiation intensities below 15 J/cm^2 digital microscopy showed that the enamel surface was actually raised after irradiation. For an incident fluence of 35 J/cm^2 the rate of composite removal was three times the rate of enamel removal. A plot of the ablation depth versus fluence is shown in Fig. 4. The range of fluence between 25 and 50 J/cm^2 appears to offer the highest selectivity with a 3–5 times higher ablation rate for composite versus enamel. The ablation depth is also quite variable with a fairly high standard deviation.

3.2 Composite Removal from Enamel Surfaces

Digital images of some of the samples are shown in Figs. 5 & 6 for the areas where the composite was ablated. In Fig. 5 the center of the composite area is shown (position CT in Fig. 2) highlighting the thickest area of composite. A fluence of 29 J/cm^2 was used and a clean incision is visible through $\sim 800 \mu\text{m}$ of composite.

Typically the underlying enamel had a rough appearance and enamel was lost. However, in some cases the enamel was left intact even at a relatively high intensity. A couple of examples are shown in Fig. 6 for incident fluence of 10 and 17 J/cm^2 . Areas of variable enamel damage are indicated both in the irradiated areas that were originally covered by composite and the exposed enamel adjacent to the composite. Many craze lines are visible in the area of irradiated enamel.

The respective enamel loss measurements and the composite thickness are plotted in Fig. 7 for nine samples of varying incident fluence from 7 to 70 J/cm^2 . The enamel loss appears similar from 10 to 50 J/cm^2 and is limited to less than $100\text{-}\mu\text{m}$ even though $500\text{--}700\text{-}\mu\text{m}$ of composite was removed. The rate of composite removal was lower for lower fluence, therefore the number of laser pulses incident on the exposed enamel was greater. The number of scans required to completely remove the composite was not recorded. The GrenGloo composite is colored green and any residual composite was clearly visible. Moreover, the magnetic sample holder could be removed so that the samples could be closely inspected to ensure that the composite was removed at the base of the laser cuts. From Fig. 7 it appears that the fluence range of $30\text{--}50 \text{ J/cm}^2$ is best suited for selective composite removal.

It is interesting that some of the enamel surfaces remained intact without any enamel loss. Even for an incident fluence as high as 50 J/cm^2 there was intact enamel in the laser irradiated areas. Absorption at the interface and delamination can explain how the composite is removed while the enamel remains intact as has been observed for ceramic brackets, veneers, and crowns due to thermal action and the higher absorption of water between the

tooth surface and the adhesive. [14–20] However, this does not explain how the exposed areas are preserved. It is likely that the enamel surface lay outside the depth of focus with the focal plane at the composite surface.

In summary, the high degree of selectivity achieved in this pilot study is encouraging with a much greater degree of selectivity than was previously observed with either free-running or Q-switched laser pulses. It appears that thermo-mechanical transients play an important role in both composite and hard tissue removal and the smaller spot size and lower single pulse energies are advantageous for minimizing damage to enamel and increasing selectivity.

Future studies will focus on the use of methods for feedback for further increasing selectivity and for identifying when the composite has been removed. Spectral feedback has proved successful for UV [5–7] and carbon dioxide laser systems [8] for the removal of composite from tooth surfaces, however it may be difficult to use spectral feedback with the small spot size combined with the small plume produced with water-mediated ablation. Other possibilities include image guided ablation or acoustic guidance. In conclusion, these studies indicate that the diode-pumped solid state Er:YAG laser with its high pulse repetition rate holds great potential for the selective removal of dental composites.

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Fig. 1. Bovine enamel block 10×2 mm with GreenGloo composite applied. For the composite removal studies the laser was scanned across the center of the composite and the incision was expanded to cover the enamel only areas on each side of the composite.

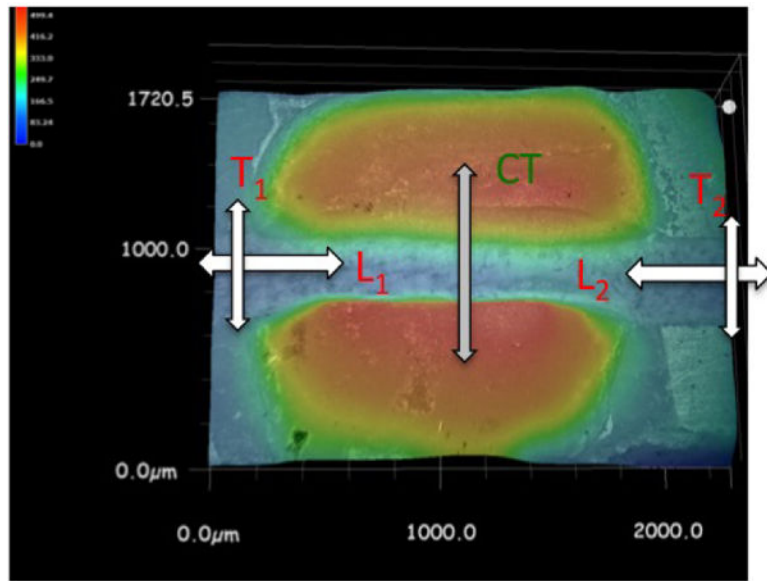


Fig. 2. Digital microscopy was used to measure the amount of enamel lost and the thickness of composite ablated. The enamel loss was calculated as the mean of the four measurements, T1, T2, L1 & L2. The thickness of the composite removed was measured along CT.

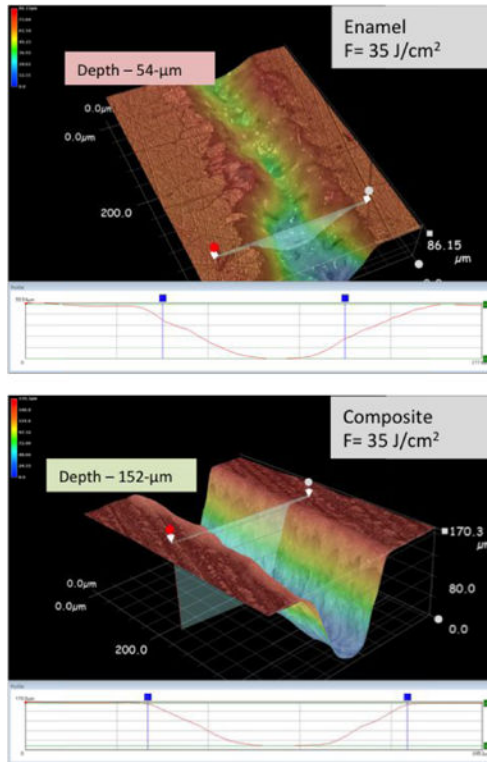


Fig. 3. 3D digital images of incisions produced in enamel and composite at an incident fluence of 35 J/cm^2 . Depth profile shown at bottom of each image.

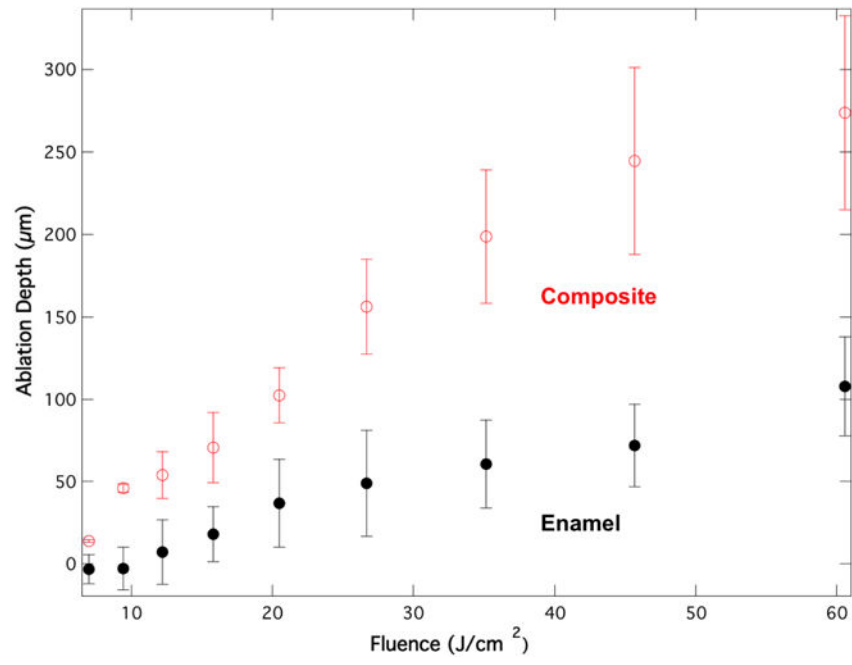


Fig. 4. Relative incision depth for enamel versus composite. The mean \pm s.d. are shown with 6 measurements per point.

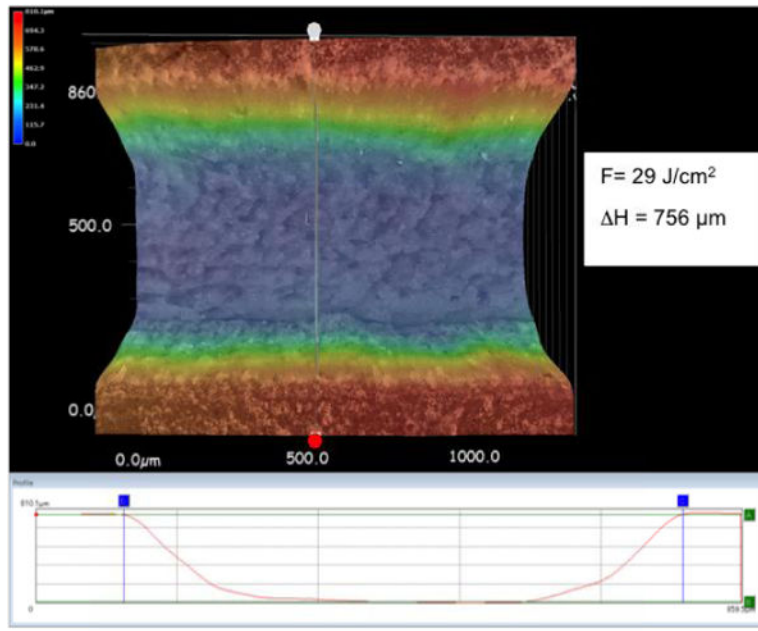


Fig. 5. 3D digital image of the center of the incision at the maximum composite thickness (position CT) at an incident fluence of 29 J/cm². Depth profile is shown at the bottom.

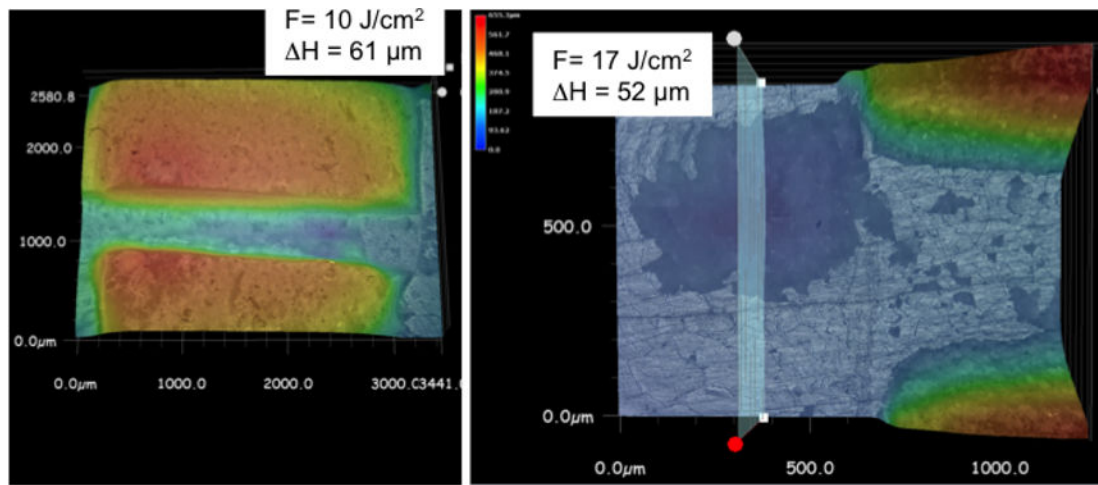


Fig. 6.
3D digital images showing the varying degree of damage to the adjacent and underlying enamel for two samples at different fluence.

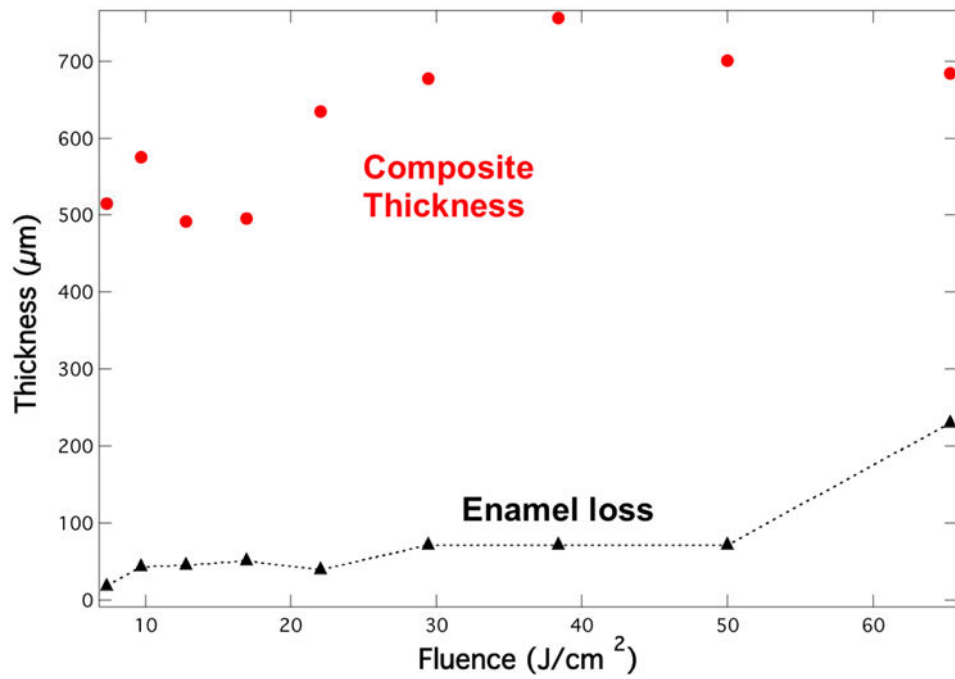


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