

# Selective removal of composite sealants with near-ultraviolet laser pulses of nanosecond duration

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**Abstract.** It is often necessary to replace pit and fissure sealants and composite restorations. This task is complicated by the necessity for complete removal of the remaining composite to enable suitable adhesion of new composite. Previous studies have shown that 355-nm laser pulses from a frequency-tripled Nd:YAG laser can selectively remove residual composite after orthodontic bracket removal on enamel surfaces. Our objective is to determine if such laser pulses are suitable for selective removal of composite pit and fissure sealants and restorations. Optical coherence tomography is used to acquire optical cross sections of the occlusal topography nondestructively before sealant application, after sealant application, and after sealant removal. Thermocouples are used to monitor the temperature in the pulp chamber during composite removal under clinically relevant ablation rates, i.e., 30 Hz and 30 mJ/pulse. At an irradiation intensity of 1.3 J/cm<sup>2</sup>, pit and fissure sealants are completely removed without visible damage to the underlying enamel. At intensities above 1.5 J/cm<sup>2</sup>, incident laser pulses remove the resin layer while at the same time preferentially etching the surface of the enamel. Temperature excursions in the pulp chamber of extracted teeth are limited to less than 5°C if air-cooling is used during the rapid removal (1 to 2 min) of sealants, water-cooling is not necessary. Selective removal of composite restorative materials is possible without damage to the underlying sound tooth structure. © 2005 Society of Photo-Optical Instrumentation Engineers.

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## 1 Introduction

Dental composites are used as adhesives and restorative materials for various dental procedures. They are composed of methacrylate resins combined with fused silica particles as a filler material. The most common application of composites is for restorative procedures, i.e., fillings. Composites are color matched to the tooth, making it difficult for the dentist to differentiate between the enamel and the restorative material. Frequently composite restorations and sealants fail and the composite must be removed and replaced. For adequate adhesion of the replacement composite, it is necessary to remove the existing composite to ensure the formation of resin tags in the exposed enamel. A system that can differentiate between the ablation of enamel and composite would facilitate the composite removal and minimize the inadvertent removal of healthy tissue structure.

Alexander and Fried<sup>1</sup> demonstrated that a *Q*-switched 355-nm Nd:YAG laser can be used to selectively remove residual composite left after the debonding of orthodontic

brackets without modification of the underlying enamel. Further studies by Wheeler et al.<sup>2</sup> demonstrated that if the incident laser fluence was increased to a level that resulted in the surface modification of the enamel, there is preferential etching of the interprismatic protein and lipid, increasing permeability and the uptake of fluoride for inhibiting tooth decay. Namely, the efficacy of subsequent fluoride treatments in inhibiting the susceptibility of enamel to acid dissolution was increased by over 400% due to the selective removal of the interprismatic protein and lipid. Subsequent studies by Wheeler et al.<sup>2</sup> also indicated that the laser-etched enamel surface was well suited for the adhesion of composite restorative material. Moreover, the shear-bond strength of the etched enamel surface bonded to composite exceeded 20 MPa without the necessity for further acid etching. These prior results suggest that *Q*-switched 355-nm laser pulses provide an ideal mechanism to facilitate the removal and replacement of composite sealants and restorations.

In this paper, we demonstrate for the first time that sealants and small composite restorations can be selectively removed from the tooth without undesirable damage to the surrounding

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healthy enamel. A novel optical imaging method, polarization-sensitive optical coherence tomography (PS-OCT) was used to acquire optical cross sections nondestructively before placement of sealants, after sealant placement, and after removal of the sealant to determine if the enamel topography was conserved during the procedure.

UV laser systems are finding increasing uses for the processing of organic polymers.<sup>3-6</sup> The new diode-pumped *Q*-switched 355-nm Nd:YAG laser systems can be used for the rapid processing of metals, polymers, and ceramic materials due to the increased absorption in the UV and the high pulse repetition rates.<sup>7</sup> Dental composites and sealants are principally composed of dimethacrylate resins and silica filler particles. We hypothesize that in dental composites, the combination of high scattering by the silica filler particles and increased absorption by the various components of the resin binder results in localized deposition of the laser energy near the composite surface followed by thermal modification of the composite matrix and subsequent removal. This hypothesis is supported by previous photoacoustic measurements that are indicative of a nonlinear increase in absorption in composite with increasing number of laser pulses.<sup>1</sup>

For the selective ablation of composite to be feasible, heat accumulation during laser irradiation must be maintained at a safe level. Zach and Cohen<sup>8</sup> determined that temperature excursions greater than 5.5°C may result in irreversible changes in the dental pulp at the center of the tooth. Therefore, thermocouple measurements were used to measure the temperature rise in the pulp chamber of extracted human teeth during the removal of the sealants at clinically relevant removal rates to determine if either air or water cooling was required for this procedure to avoid excessive heat accumulation.

Although we investigated the removal of both composite restorations and composite pit and fissure sealants in this study, we focused our efforts on pit and fissure sealants, since removing composite from the convoluted topography of the crown is clearly more challenging. Being able to show that the topography of the underlying enamel on occlusal surfaces is preserved completely intact, better demonstrates the high selectivity of this method.

## 2 Materials and Methods

In this paper, composite disks and bovine enamel blocks were initially ablated to determine the optimum laser conditions for composite removal. Once those laser conditions were established, small 1-mm<sup>3</sup> preparations were drilled in flat bovine blocks and filled with composite, and the laser was scanned over the tooth surface to selectively remove the composite. After successful removal of these small lesions, composite pit and fissure sealants were placed on the occlusal surfaces of 10 human third molars and the laser was scanned over the occlusal surface of each tooth to selectively remove the composite without removing the sound enamel underneath and with preservation of the topography of the crown. Selective removal was evaluated using optical coherence tomography. The temperature rise in the pulp chamber of 10 extracted human teeth was also monitored using microthermocouples during the removal of small composite restorations and occlusal sealants.

## 2.1 Sample Preparation

### 2.1.1 Composite disks

Composite disks were prepared from Z-250 composite (3M Minneapolis, Minnesota). Plastic test tubes were filled with composite, light cured, and subsequently sliced into sections approximately 1 mm thick and 1 cm in diameter.

### 2.1.2 Enamel sections (blocks)

Blocks (3×3 mm<sup>2</sup>) of human enamel were prepared from freshly extracted third molars provided by oral surgeons in the San Francisco Bay Area. Blocks (5×5 mm<sup>2</sup>) of bovine enamel were prepared from freshly extracted incisors acquired at a local slaughterhouse. The outer cementum layer was removed (bovine blocks) and the surfaces serial polished with 240-grit and 600-grit carbide paper followed by a 6- $\mu$ m diamond abrasive slurry. Small cavities were drilled to a depth of 1 mm with a #34 carbide burr in some of the blocks and composite was used to fill the hole to serve as model restorations.

### 2.1.3 Extracted human molars (whole teeth)

Composite sealants and restorations were placed in 20 freshly extracted human third molars. Five of the teeth were hemisectioned and 1×1×1-mm cavities were drilled on the buccal and labial surfaces with a high-speed handpiece and a #34 carbide burr. The cavities were acid etched and the bonding agent applied according to the manufacturers recommended protocol prior to placement of Z-250 composite (3M Minneapolis, Minnesota) to fill the cavity. Composites were light cured for 20 s.

The remaining 15 third molars had occlusal surfaces etched and the sealant Concise™ (3M Minneapolis, Minnesota) was applied according to manufacturers specifications before the placement of pit and fissure sealants. Sealants were also light cured for 20 s.

## 2.2 Laser Irradiation

The Tempest laser system (New Wave Research, Fremont, California) used for these studies is a *Q*-switched Nd:YAG laser (1064 nm) with a pulse duration (FWHM) of 5 ns equipped with nonlinear optics for third-harmonic generation (355 nm). The Tempest laser was equipped with a variable beam attenuator incorporating two linear polarizers with which to vary the incident intensity. Composite was selectively removed with 30 to 50 laser pulses per site at irradiation intensities of 0.75 to 3.0 J/cm<sup>2</sup>/per pulse and a fixed repetition rate of 30 Hz. The tooth containing the restoration or the sealant was irradiated by moving the specimen across the 355-nm laser beam using a computer-controlled ESP-300 motion control system (Newport Electro-optics, Irvine, California) with two 6-mm/s stages (model 850G-HS) interfaced to a computer (Fig. 1). A beam spot size of 1250  $\mu$ m was used and each ablation site was spaced a distance of 250  $\mu$ m apart to provide sufficient overlap to ensure uniform irradiation of the entire area.

## 2.3 PS-OCT and Optical Microscopy

An all fiber-based polarization-sensitive optical coherence domain reflectometer (OCDR) with polarization-maintaining (PM) optical fiber, high-speed piezoelectric fiber stretchers,

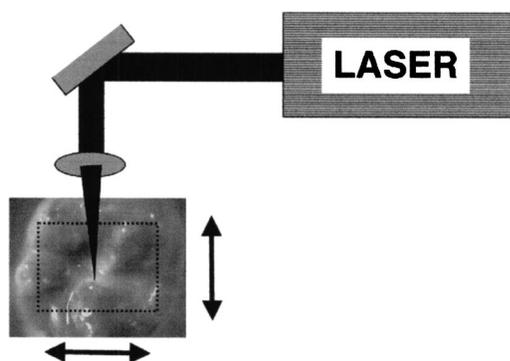


Fig. 1 Setup for laser irradiation of occlusal tooth surfaces.

and two balanced InGaAs detectors that was custom designed and fabricated by Optiphase, Inc (Van Nuys, California) was used to acquire images of the occlusal topography before placement, after placement, and after removal of the sealants. This two-channel system was coupled with a broadband 15-mW superluminescent diode (SLD) from ESL1320 (Exalos, Zurich, Switzerland) with a 30-nm bandwidth. A high-speed XY-scanning system with a ESP 300 controller and 850G-HS stages from (Newport Electro-optics, Irvine, California) was integrated with the system for *in vitro* optical tomography. The system has been described previously.<sup>9</sup> Linearly polarized light illuminated the tooth samples and the reflected/backscattered intensity in both orthogonal polarizations was coupled into the slow ( $\parallel$ ) and fast ( $\perp$ ) axes of the PM fiber of the sample arm. The signal intensity for each polarization state, defined as the parallel ( $\parallel$ ) axis and perpendicular ( $\perp$ ) axis, was measured from each detector channel after the signals were electronically demodulated. The PS-OCT system was completely controlled using Labview™ software from National Instruments (Austin, Texas). Two-dimensional OCT intensity plots were obtained by collecting a series of depth-resolved signals by laterally scanning the beam across the tooth.

Composite restorations were placed in cavities drilled in bovine blocks and hemisectioned human teeth as described. Ten human third molars were placed in cylindrical brass molds that were subsequently filled with dimethylacrylate resin, leaving the crown of the tooth and occlusal surfaces exposed. The composite was light cured in place and the tooth was removed from the mold, leaving each tooth embedded in a 1-cm<sup>2</sup> pedestal base of resin. Each tooth was subsequently scanned using PS-OCT (see Fig. 3 in Sec. 3.2) to measure the cavity depth and topography in the case of the 1-mm cubic cavities prepared on the smooth surfaces and the occlusal topography prior to placement of the sealants. Several parallel OCT scans were recorded across the center of the occlusal surface. Each embedded tooth specimen precisely fit into a brass jig mounted on the PS-OCT scanning assembly, enabling the teeth to be scanned repeatedly over the same coordinates of the tooth before sealant placement, after sealant placement, and after sealant removal.

The irradiated bovine enamel samples were also assessed visually at up to 500 times magnification using an Olympus BX50 optical microscope (Olympus America, San Jose, California) with an integrated digital camera, DVC 1300C (Digi-

tal Video Computing, Inc., Austin, Texas) and Image Pro Plus® software (Media Cybernetics, Silver Springs, Maryland).

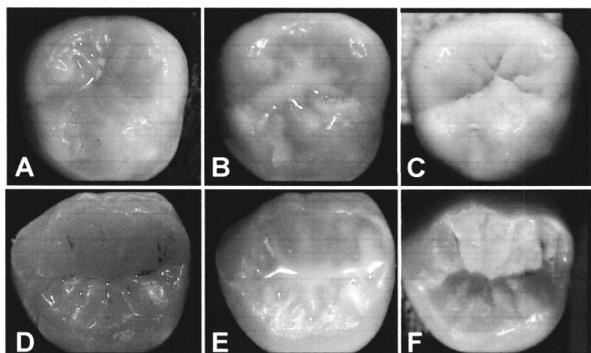
## 2.4 Thermocouple Measurements

Ten extracted human third molars were used for thermocouple measurements, five for pit and fissure sealants and five for small composite restorations, prepared as already described. The roots were left on each tooth and a small holes were drilled using a high-speed dental handpiece and a 1/4 round carbide burr into the pulp chamber. Prefabricated insulated thermocouples, type K Chromel-Alumel, 0.005-in. wire diameter (OMEGA Technologies, Stamford, Connecticut) were inserted inside the pulp chambers of the molars and the thermocouple tip made contact with the interior wall nearest the area of laser irradiation. A high-thermal-conductivity filled silicone paste OMEGATHERM 201 (OMEGA Technologies, Stamford, Connecticut) was placed on the thermocouple tip to ensure good thermal conduct with the dentin of the interior wall. The interpulpal temperature versus time was recorded from inside the tooth during the removal of composite from the surface. The thermocouple voltage was monitored with a digital oscilloscope. Thermocouple voltages were converted to temperatures using look-up tables. Teeth were continuously scanned across the 1250- $\mu$ m-diam laser beam at a repetition rate of 30 Hz. Forty laser pulses were delivered to each laser spot at a fluence of 1.7 J/cm<sup>2</sup> and the stage was moved 250  $\mu$ m for each pulse sequence. Measurements were performed with and without air cooling. Air cooling was provided by placing a nozzle with a 1/4-in. orifice 15 mm from the tooth surface. The flow rate from the nozzle was 60 standard cubic feet per hour (SCFH) in line with the air flow provided by a conventional dental high-speed handpiece.

## 3 Results

### 3.1 Ablation Measurements on Enamel Surfaces and Dental Composite Disks

The ablation rate (in micrometers per pulse) for the perforation of 200- $\mu$ m composite and enamel sections was published in our previous papers.<sup>1,2,10</sup> Although the ablation thresholds and relative ablation rates were determined for enamel and composite in earlier studies, it was necessary to repeat those measurements because the new laser used for these experiments had improved beam quality and a higher, more clinically relevant, repetition rate—30 versus 10 Hz. Composite disks and human enamel blocks were irradiated to estimate the appropriate irradiation intensities to be used on whole human teeth. At a threshold of 1.3 J/cm<sup>2</sup> with a spot size of 1250  $\mu$ m and a repetition rate of 30 Hz, there was visible superficial etching of the polished enamel blocks to a depth limited to 10  $\mu$ m, while 300  $\mu$ m of the composite was removed after scanning the surface with 30 pulses/spot. Above a fluence of 1.5 J/cm<sup>2</sup>, there was uniform etching of the enamel surface. The ablation threshold for composite ablation is below 1 J/cm<sup>2</sup>. The ablation rate exceeds 10  $\mu$ m/pulse at 1 J/cm<sup>2</sup> and reaches 15  $\mu$ m/pulse at an incident fluence of only 2 to 4 J/cm<sup>2</sup>. In contrast, the ablation threshold for enamel exceeds 1 J/cm<sup>2</sup> and the ablation rate for enamel saturates at only 2  $\mu$ m/pulse above 2 J/cm<sup>2</sup>. Therefore, in the fluence range of 1



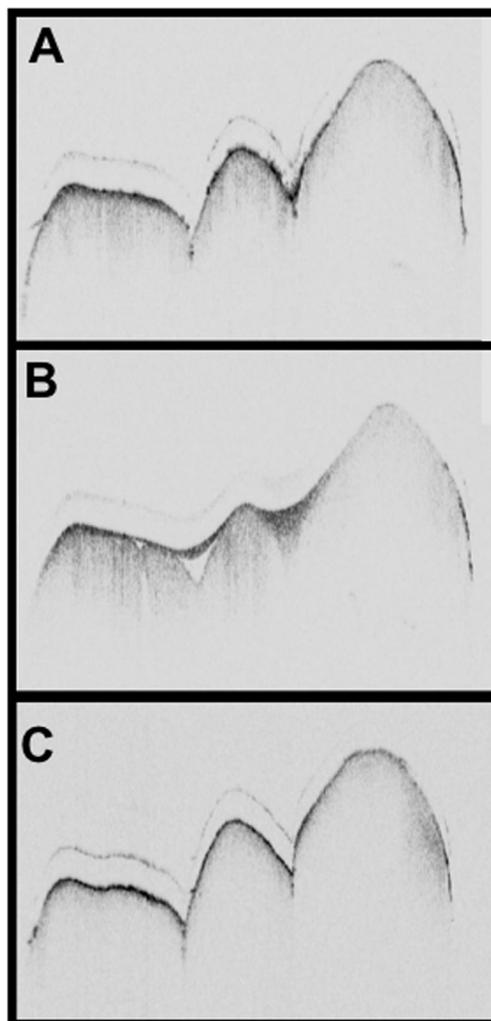
**Fig. 2** Two molars, the first tooth (a) before sealant placement, (b) after sealant placement, and (c) after sealant removal at a fluence of 1.3 J/cm<sup>2</sup>. The second tooth (d) before sealant placement, (e) after sealant placement, and (f) after sealant removal at a fluence of 1.7 J/cm<sup>2</sup>.

to 1.5 J/cm<sup>2</sup>, composite can be ablated at a relatively high rate—greater than 10 μm/pulse without damage to the underlying enamel.

### 3.2 Selective Removal of Small Restorations and Pit and Fissure Sealants

Selective removal of composite was initially tested on 1-mm<sup>3</sup> restorations placed on bovine blocks to determine number of laser pulses required to completely remove the composite. At fluence levels of 1 to 1.7 J/cm<sup>2</sup> we were able to remove the composite from the small restorations with only superficial etching of the peripheral enamel surface using only 30 to 50 laser pulses per irradiated position/spot with a 1.3-mm spot size and a 250-μm spacing between each adjacent spot.

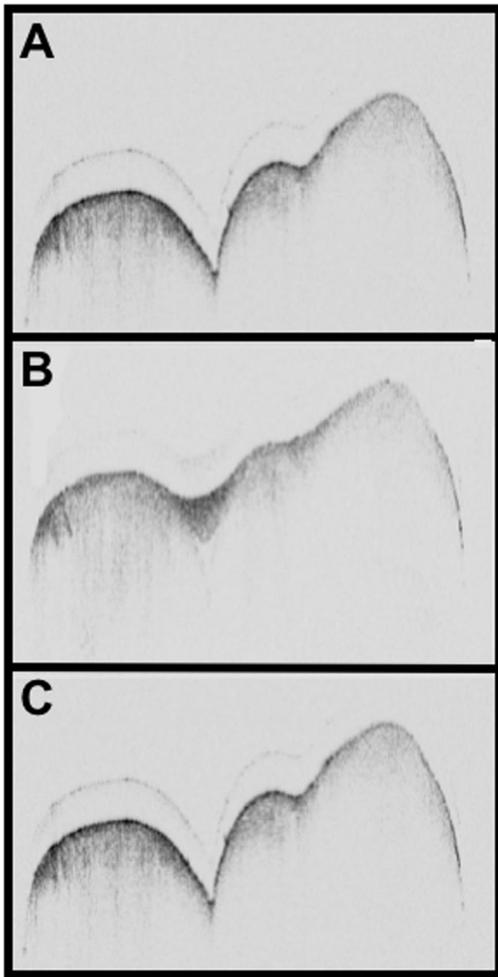
Composite pit and fissure sealants was selectively removed from the occlusal surfaces of 10 teeth. Figure 2 shows images of the occlusal surfaces of two molars before placement of the pit and fissure sealant, after placement of the sealant, and after the removal of the sealant with laser irradiation intensities of 1.3 and 1.7 J/cm<sup>2</sup>. The irradiated surfaces of the tooth irradiated at the higher fluence has a dull white appearance indicative of superficial etching of the enamel. Optical cross sections (OCT images) of the occlusal surfaces of three human molars are shown before placement of the pit and fissure sealant, after placement of the sealant, and after their removal of the sealant in Figs. 3, 4, and 5 for three different irradiation intensities. Ten teeth were used and irradiated at four incident irradiation intensities or fluence: 1.7 J/cm<sup>2</sup> ( $n=3$ ), 1.5 J/cm<sup>2</sup> ( $n=3$ ), 1.3 J/cm<sup>2</sup> ( $n=3$ ), and 1.0 J/cm<sup>2</sup> ( $n=1$ ). The enamel surface can be clearly differentiated from the sealant in all of the images. The PS-OCT scans also show whether or not the sealants were placed successfully without air pockets. This is clearly illustrated in both Figs. 3(b) and 5(b), where the shallow fissures peripheral to the principal fissure have large air pockets under the sealant. The PS-OCT scans show that the sealant was removed completely for irradiation intensities exceeding 1.3 J/cm<sup>2</sup>, and the PS-OCT scans show that the occlusal topography is not significantly altered and matches the surface topography before placement of the sealant.



**Fig. 3** PS-OCT scans across the fissure of a molar (a) before sealant placement, (b) after sealant placement, and (c) after sealant removal at a fluence of 1.3 J/cm<sup>2</sup>.

### 3.3 Thermocouple Measurements During Composite Restorations and Sealant Removal

During laser irradiation, the thermocouple temperature reached a maximum or plateau after the rate of heat accumulation in the tooth equilibrated with the convective and conductive heat losses. That temperature was recorded for each of the five teeth with pit and fissure sealants and the other five teeth with the small composite restorations. The mean and standard deviation (SD) is recorded for each sample group in Table 1. The temperature rise was also measured without the sealant present to determine if a significant amount of the deposited thermal energy was carried away by the ablated material, which can be significant for higher irradiation intensities.<sup>11</sup> However, we found that there was no significant difference in the temperature excursions with or without the sealant. For most of the samples the temperature rise exceeded 10°C without application of air or water cooling. However, after application of air cooling at a rate similar to

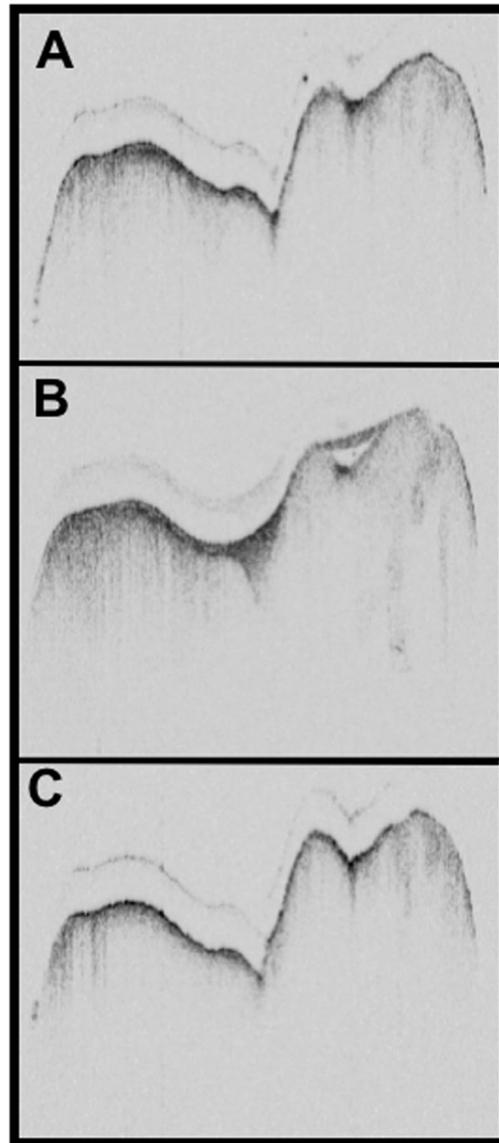


**Fig. 4** PS-OCT scans across the fissure of a molar (a) before sealant placement, (b) after sealant placement, and (c) after sealant removal at a fluence of 1.5 J/cm<sup>2</sup>.

that of a dental handpiece, peak temperature excursions fell to a safe level of less than 3°C, and water cooling was not necessary.

#### 4 Discussion

These measurements demonstrate that a Nd:YAG laser operating at  $\lambda=355$  nm with laser pulses of 5-ns duration can be used for the selective removal of composite restorations and pit and fissure sealants without peripheral damage to the underlying healthy enamel. To the best of our knowledge, this is the first study of any kind to demonstrate the selective removal of pit and fissure sealants from occlusal surfaces. Other laser systems such as the Food and Drug Administration (FDA) approved free-running (100 to 300- $\mu$ s) erbium lasers designed for hard tissue ablation are not well suited for selective ablation of composite, since they ablate enamel and composite at similar rates.<sup>12</sup> Moreover, the fluence required to ablate composite using free-running Er:YAG laser pulses is two orders of magnitude higher than for the 5-ns, 355-nm laser pulses used in this study and requires water cooling to avoid excessive heat deposition. We have shown<sup>12</sup> that damage to the underlying enamel can be avoided with 355-nm



**Fig. 5** PS-OCT scans across the fissure of a molar (a) before sealant placement, (b) after sealant placement, and (c) after sealant removal at a fluence of 1.7 J/cm<sup>2</sup>.

laser pulses using irradiation intensities in the range of 1 to 1.3 J/cm<sup>2</sup>. Higher irradiation intensities of the order of 1.3 to 2 J/cm<sup>2</sup> result in etching of the enamel surface without substantial removal of tissue. Such etching can be desirable for removal of the interprismatic protein and lipid for increasing the efficacy of topical fluoride application uptake for inhibiting subsequent decay and demineralization, and for increasing adhesion of composite resin.<sup>2</sup> Thermocouple measurements indicated that heat accumulation was sufficiently low to avoid risk of pulpal inflammation if air cooling was employed. In contrast to the conventional high-speed dental handpiece, a water spray was not required during the procedure. In future studies, we will investigate the use of reverse flow (suction) for simultaneous removal of the ejected composite debris and convective cooling. Temperature excursions were limited to 2 to 3°C with air cooling. Previous studies<sup>8</sup> of excessive heat accumulation in the tooth indicated that irreversible changes

**Table 1** Thermocouple temperature rise (in degrees celsius) after composite removal ( $n=5$  per group).

Sample Irradiated Group <sup>a</sup>	Mean	SD	
Small restoration	13.9	2.5	a
Restoration with air	1.4	0.26	b
Sealant	11.6	3.1	c
No sealant	11.7	2.5	c
Sealant with air	3.2	1.0	d
No sealant with air	2.4	0.92	d

<sup>a</sup> Groups with same letter are not statistically significant  $P>0.05$ .

to the pulp may occur for temperature excursions greater than 5.5°C. Note also that with living teeth embedded in bone with the peripheral blood perfusion, temperature excursions would be expected to be lower than those recorded in this paper.

A laser operating at 30 Hz with a spot size of ~1.3 mm took less than 1 min to remove the small composite restorations and 1 to 2 min to remove the pit and fissure sealants. Larger restorations would take a proportionally longer time. Diffractive beam shaping, namely, converting the Gaussian spatial beam profile to a flat-top beam shape would reduce the necessity of overlap of the laser pulses and speed up the composite removal rate for larger volume removal. There is some concern about the risk of using UV photons in the oral cavity. Near-UV, 355-nm photons lie within the UV-A band, which can potentially cause hyperpigmentation (tanning) and erythema at high exposure levels. The risk of skin cancers due to UV-A radiation exposure is generally several orders of magnitude less than for the shorter wavelength, UV-B, and the permitted exposure levels are relatively high compared to those of the shorter wavelength excimer lasers that fall within the UV-B and UV-C bands, respectively.

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