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Selective removal of esthetic composite restorations with spectral guided laser ablation

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Abstract

Dental composites are used for a wide range of applications such as fillings for cavities, adhesives for orthodontic brackets, and closure of gaps (diastemas) between teeth by esthetic bonding. Anterior restorations are used to replace missing, diseased and unsightly tooth structure for both appearance and function. When these restorations must be replaced, they are difficult to remove mechanically without causing excessive removal or damage to enamel because dental composites are color matched to teeth. Previous studies have shown that CO_2 lasers have high ablation selectivity and are well suited for removal of composite on occlusal surfaces while minimizing healthy tissue loss. A spectral feedback guidance system may be used to discriminate between dental composite and dental hard tissue for selective ablation of composite material. The removal of composite restorations filling diastemas is more challenging due to the esthetic concern for anterior teeth. The objective of this study is to determine if composite spanning a diastema between anterior teeth can be removed by spectral guided laser ablation at clinically relevant rates with minimal damage to peripheral healthy tissue and with higher selectivity than a high speed dental hand-piece.

Keywords

caries removal; near-IR reflectance imaging; 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. 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. [1, 2] 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. Anterior restorations are used to replace or cover missing, diseased, and unsightly tooth structure for both appearance and function and the

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removal or replacement of such restorations is particularly sensitive to aesthetic damage to the underlying enamel.

During laser ablation, a luminous emission plume is produced that is unique to each tissue or material. The luminous plume generated during hard tissue ablation by the CO_2 laser consists of electronically excited atoms, ions, and molecules ejected from the site of ablation. The plume can be spectrally interrogated to reveal the chemical composition of the ablated material as described in previous studies. [3–5] We have shown that distinctive high intensity calcium emission lines can be used to differentiate between the ablation of composite and dental hard tissues at several laser wavelengths. [3–5] Individual peaks can be identified with wavelength tables of elemental spectra. [6] Therefore, it is possible to differentiate enamel and composite spectra by their distinct component peaks. Dumore et al showed [5] that the spectral analysis of dental enamel possesses distinct calcium emission lines that are strong between 580 and 650-nm, giving the plume a distinct red appearance. Since dental composites contain no calcium, this spectral region can be used to differentiate enamel from composite.

We demonstrated that composite can be selectively removed from tooth buccal and occlusal surfaces at clinically relevant rates using a CO_2 laser operating at 9.3-μm with high pulse repetition rates with minimal heat deposition. [3] The selective removal of composite from the smooth 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.

The objective of this study is to determine if composite spanning a diastema between anterior teeth can be removed by spectral guided laser ablation at clinically relevant rates with minimal damage to peripheral healthy tissue and higher selectivity by a laser than with a high speed dental hand-piece.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Twenty noncarious incisors were cleaned, sterilized with gamma radiation, and stored in a 0.1% thymol solution to prevent bacterial growth. The incisors were placed in PVS molds and mounted in dental stone after the roots were notched for extra retention. The incisors were paired by shade and shape to create a 1.0–1.5 mm diastema. Composite Z250 from 3M (Minneapolis, MN) was placed to fill the diastema after the 37% phosporic acid etch gel and bonding agent were applied according to manufacturer"s instructions.

2.2 Laser Irradiation

Samples were irradiated using an industrial marking laser, Impact 2500 from GSI Lumonics (Rugby, United Kingdom) operating at a wavelength of 9.3 μm. The laser was custom modified to produce a Gaussian output beam (single spatial mode) and a pulse duration between 10–15-μs. The laser energy output was monitored using a power meter EPM 1000, Coherent-Molectron (Santa Clara, CA), and a Joulemeter, ED-200 from Gentec (Quebec, Canada). Computer-controlled XY galvanometers 6200HM series with MicroMax Series

671 from Cambridge Technology, Inc. (Cambridge, MA) were used to scan the laser beam over the sample surfaces. A repetition rate of ~110-Hz was used, and the laser beam was scanned point to point over a 150-µm grid using a ZnSe scanning lens of f=90-mm. The laser spot size was ~450-µm (note 150-µm spacing between pulses for high overlap) and the incident fluence was 4.2 J/cm^2 (6.7 mJ per pulse). An 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. Composite was selectively removed from the facial surfaces of the filled-diastema samples using the spectral guidance system mentioned below. In order to ensure complete removal, samples were turned over and re-irradiated on its lingual side with the same laser conditions and scanning algorithm.

2.3 Depth Composition Digital Microscopy (DCDM)

Tooth surfaces were examined before and 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× and the VH-Z100R with a magnification of 100–1000×. Depth composition digital microscopy images (DCDM) 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. Images of the samples were acquired before and after ablation at 25× and 50× magnification. 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 in the ablated areas.

2.4 Spectral Guidance (Description of Procedure)

The laser was scanned from point to point over a 5 mm square area for enamel surface damage measurements and removal rate measurements with the computer-controlled XY Galvanometer scanning system. A laser spot size of 450-µm was used with a spot to spot separation of 150-µm.

The plume produced from laser irradiation of each spot was captured using a USB2000+ fiber optic spectrometer from Ocean Optics (Dunedin, FL) incorporating a 2048 element CCD detector that was used in conjunction with a 1-mm bare silica-fiber to acquire spectra as previously described. [3] Distinct calcium emission lines only present in enamel were used to differentiate between the ablation of enamel and composite. Both composite and enamel spectra contain the strong sodium D emission line near 580-nm. The composite spectrum is similar to the emission spectrum of ablated glass and quartz. [4] Dental hard tissues have a very strong emission line centered at 605-nm. The ratio and intensities of the 580 and 605-nm peaks were used to differentiate between composite and enamel.

The algorithm used to remove the composite is described by the flowchart provided in reference [3]. The laser beam was scanned from point to point over a matrix defining a specific area. The plume emission ratio from each irradiated spot was subsequently used to determine if that spot was enamel or composite and a new matrix was generated defining the area of composite to be removed in the following scan. This process was repeated until all the composite was removed. A final “clean up” scan was carried out along the margin of composite determined from analysis of the plume emission acquired from the initial scan to remove residual composite at the perimeter.

2.5 OCT System (OCT)

An autocorrelator-based Optical Coherence Domain Reflectometry (OCDR) system with an integrated fiber probe, high efficiency piezoelectric fiber-stretchers and two balanced InGaAs receivers that was designed and fabricated by Optiphase, Inc. (Van Nuys, CA) was integrated with a broadband high power superluminescent diode (SLD) with an output power of 19-mW and a bandwidth of 83 nm, Model DL-CS313159A Denselight (Jessup, MD) and a high-speed XY-scanning system, ESP 300 controller & 850-HS stages, Newport (Irvine, CA) and used for *in vitro* optical tomography. The fiber probe was configured to provide an axial resolution at 9-μm in air and 6-μm in enamel and a lateral resolution of approximately 50-μm over the depth of focus of 10 mm.

The all-fiber OCDR system has been previously described in greater detail. [7] The OCT system is completely controlled using Labview™ software from National Instruments (Austin, TX). Acquired scans are compiled into *b-scan* files. Image processing was carried out using Igor Pro™, data analysis software from Wavemetrics Inc. (Lake Oswego, OR).

2.6 Surface Roughness Measurements

Enamel surfaces were scanned using a mechanical surface profilometer, the SJ-210 from Mitutoyo USA (Aurora, IL) to determine the surface roughness before and after composite removal. The surface profilometer was set with a cut-off of 0.25 mm and was used to measure each tooth three times for a mean value. The following three surface roughness parameters were recorded: Ra (arithmetic mean value, μm), Rq (root mean square roughness, μm), and Rz (mean roughness depth, μm).

3. RESULTS AND DISCUSSION

Images of two of the samples during the different stages of preparation and removal are shown in Figs. 3 & 4 for laser and handpiece removal, respectively. The 1st row shows optical images of the diastema closure before applying composite, after applying composite and after removal. The 2nd row shows depth convolution digital images of the enamel surfaces at 100× magnification and the 3rd row shows OCT images of the diastema closure. The composite was only removed from the area of the red box, and residual composite remains below the box. The high-resolution digital microscopy images of the enamel surface show the perykamata or periodic growth lines and those growth lines are still visible after the composite removal. The OCT images show the size of the gap before and after removal. In addition, the composite has a higher reflectivity/higher scattering than the enamel so it is visible in the central OCT images. The gap is similar in dimension before composite placement and after removal in the area of the box. Figure 4 shows the different stages of composite placement and removal using the conventional dental handpiece. Although the removal appears smooth and uniform, the gap is smaller than the original gap before placement of the composite. Examination of the enamel surfaces before and after removal indicates that although the surface appears smooth, the growth lines are no longer visible on the enamel surface. The OCT images show that there is still some of the composite remaining in between the teeth. The composite is still quite thick near the crown of the tooth.

The mean time for composite removal was 4.2 min for the dental handpiece and 2.1 min for the laser. The area scanned by the laser was 5 × 5 mm while the area encompassing the entire diastema closure is more rectangular approximately 6 × 4 mm as can be seen in Fig. 3. Not all the composite was removed, there is still some extending a mm below the box but removal was obviously faster with the laser and the repetition rate and scanning speed for the laser can easily be increased by more than a factor of ten.

In order to compare the selectivity of removal for the laser versus the drill, the mean separation of the diastema closure was compared before composite placement and after composite removal from the OCT images. For the laser, the mean separation in microns was 1182 ± 418 before and 1160 mm ± 250 after with a mean difference of only 22 μm, while for the handpiece group the gap was 1445 ± 311 before and 503 ± 243 after removal for a mean difference of 942 μm. ANOVA indicated that the diastema distance was significantly lower ($P<0.05$) after removal using the handpiece while the other three groups including the group after laser removal were statistically similar ($P>0.05$). Clearly the clinician had difficulty differentiating between the enamel and composite and left large amounts of composite remaining.

The surface roughness was also measured before composite placement and after composite removal using a surface profilometer. For the laser the mean surface roughness in microns was 0.49 ± 0.26 before and 1.78 ± 0.41 after and for the handpiece group it was 0.58 μm ± 0.26 before and 0.56 μm ± 0.41 after composite removal. ANOVA indicated that the roughness was significantly higher ($P<0.05$) after laser removal while the other three groups including after handpiece removal were statistically similar ($P>0.05$). The laser irradiated enamel surfaces were significantly rougher than those exposed to the dental handpiece, however the mean roughness was less than 2-μm and is unlikely to be a problem.

This pilot study clearly demonstrates the advantages of using the laser to selectively remove composite from tooth surfaces. There are challenges in developing a clinical system. Methods for preventing patient movement during treatment will be needed. It was necessary to scan both the buccal and lingual sides of the diastema closure to completely remove the composite and this will be challenging to do clinically.

In summary, anterior teeth diastema closure can be removed by a CO_2 laser guided by spectral feedback faster and with higher selectivity than by a clinician using a high-speed handpiece, with minimal damage to underlying healthy enamel.

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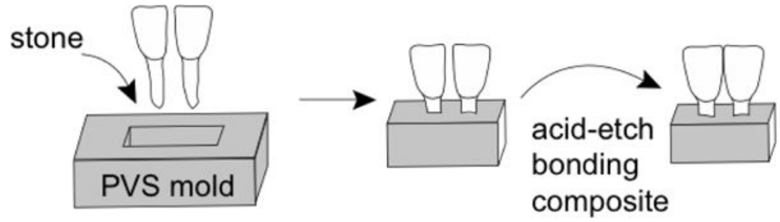

Fig.1.

Diagram of sample preparation, teeth are embedded in dental stone and the appropriate surfaces are etched and the bonding agent and composite are applied.

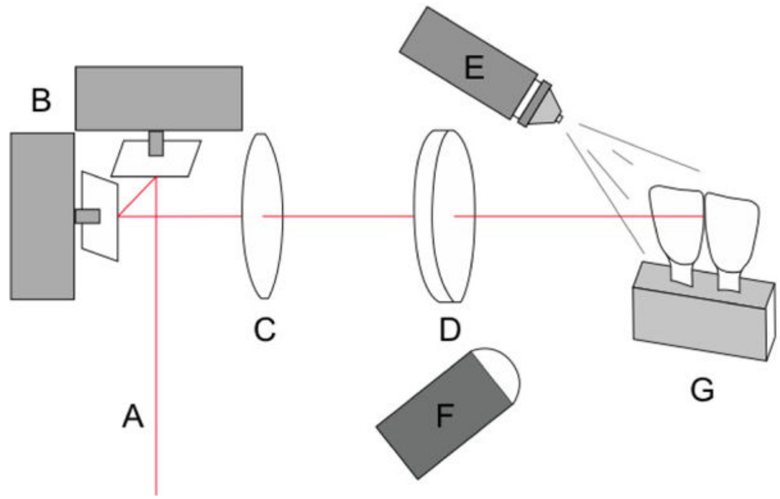

Fig. 2.

Laser set-up for selective ablation: (A) CO2 laser beam, (B) XY galvanometers, (C) CaF_2 attenuator lens, (D) Zn-Se f-theta scanning lens, (E) water spray, (F) spectrometer, (G) composite diastema closure.

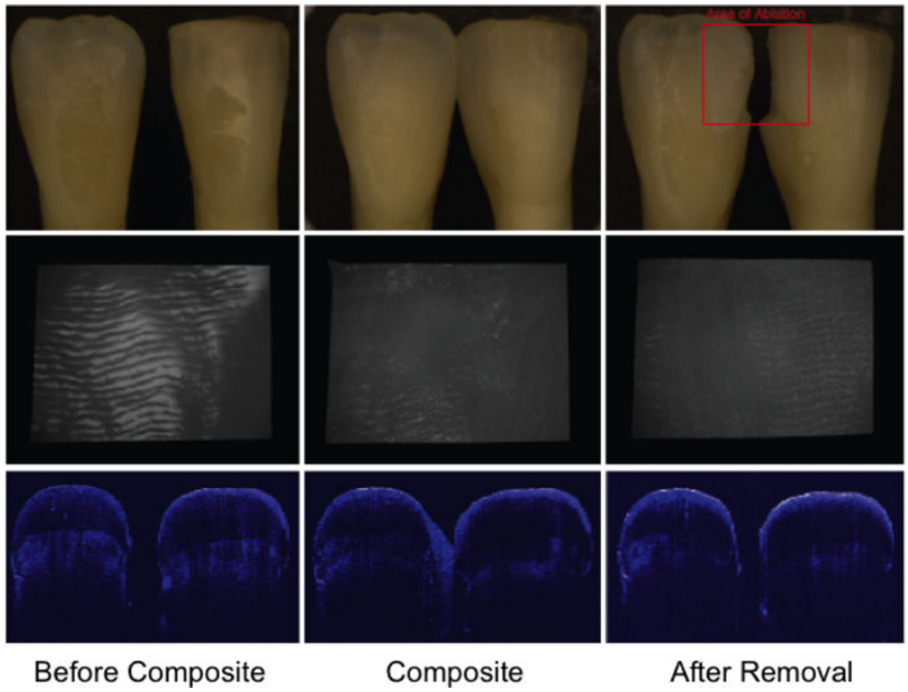

Fig. 3.

Images for LASER removal. The area of removal is shown in the area of the red box. The 1st row shows optical images of the diastema closure before applying composite, after applying composite and after removal. The 2nd row shows digital microscopy depth convolution images of the enamel surfaces at 100× magnification and the 3rd row shows OCT images of the diastema closure.

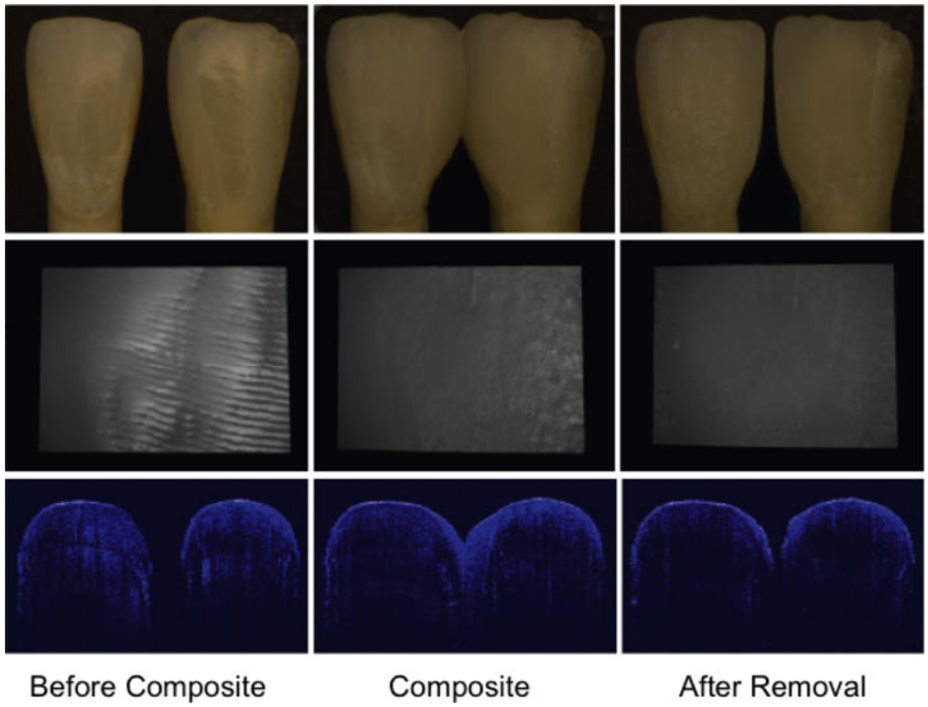

Fig. 4.

Images for HANDPIECE removal. The 1st row shows optical images of the diastema closure before applying composite, after applying composite and after removal. The 2nd row shows digital microscopy depth convolution images of the enamel surfaces at 100× magnification and the 3rd row shows OCT images of the diastema closure.