Published in final edited form as:

Proc SPIE Int Soc Opt Eng. 2020 February ; 11217: . doi:10.1117/12.2550985.

***In vivo* spectral guided removal of composite from tooth surfaces with a CO₂ laser**

Jacob C. Simon, Jee Hye Choi, Andrew Jang, Daniel Fried

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

Abstract

Dental composites are used as restorative materials to replace tooth structure after the removal of caries, shaping, covering teeth for esthetic purposes and as adhesives. Dentists spend more time replacing existing restorations that fail than they do placing new restorations. Tooth colored restorations are difficult to differentiate from the surrounding tooth structure making them challenging to remove completely without incidental removal of healthy tooth structure. Previous studies have demonstrated that CO₂ lasers in conjunction with spectral feedback can be used to selectively remove composite from tooth surfaces. In addition, we assembled a system feasible for clinical use that incorporates a spectral feedback system, scanning system, articulating arm and a clinical handpiece and subsequently evaluated the performance of that system on extracted teeth. The purpose of this study was to test this system *in vivo* to demonstrate its efficacy relative to dental clinicians. Eight test subjects with premolar teeth scheduled for extraction for orthodontic reasons had bilateral premolars prepared with small occlusal cavity preparations and filled with dental composite. The laser scanning system was used to remove the composite from one of the preparations and a dental handpiece was used to remove the composite from the other. Cross polarization optical coherence tomography was used to measure the volume of the preparation before and after composite placement and removal. There was no significant difference in the loss of enamel and residual composite between the laser and the handpiece. This study demonstrated that a computer controlled spectral guided CO₂ laser scanning system can be used *in vivo* to selectively remove composite from tooth surfaces.

Keywords

composite; selective laser ablation; spectral feedback

1. INTRODUCTION

Composite materials are widely used across the field of dentistry with applications ranging from tooth restoration after caries removal to the bonding of orthodontic brackets.

Composites are highly favored in restorative dentistry due to the ability of the clinician to color match composite to tooth for ideal esthetics. Removal of existing composite is necessary when there is secondary dental caries requiring a replacement filling, or when a patient has finished with orthodontic treatment and the orthodontic appliances need to be removed.[1] Incomplete resin removal is not acceptable in both scenarios. In the case of secondary dental caries, the preexisting composite must be removed to ensure thorough caries excavation and any remaining composite could also negatively affect the bond

strength of the new composite restoration unless extra precautions are taken. If the composite is not entirely removed at the conclusion of orthodontic treatment, it can lead to increased accumulation of dental plaque around resin remnants as well as unaesthetic discoloration at the composite and enamel interface over time.

There is no currently available technique that utilizes modern technologies to minimize iatrogenic loss and damage of healthy tooth structure during the removal of composite materials. Direct vision through dental surgical loupes is limited in accuracy by a culmination of many factors, namely the difficulty of enamel and composite differentiation due to advanced color matching and the similarity in hardness between enamel and the tools used to remove resin, the multitude of different techniques to remove resin, and the differences in practitioner experience.

In addition to the difficulty in differentiating between composite and healthy enamel by the human eye, there are multiple techniques and instruments within a clinician's arsenal that can quantitatively affect the amount of composite remaining and excessive removal of healthy tooth structure. Among the variety of methods used to remove composite of an existing restorations or remaining bonding after orthodontic appliance removal are hand instruments such as pliers and scalers or diamond burs, tungsten burs, carbide burs, polishing discs, white stones, and ultrasonic instruments.[2] Diamond and tungsten carbide burs are favored for the bulk removal of composite because of their speed for gross composite removal but high speed removal typically also removes a substantial layer of enamel. While discs, ultrasonic tools, hand instruments, polishing rubbers cones, and composite burs were also effective, they require increased chair time. All of these tools and methods result in different degrees of damage to underlying tooth structure due to differences in hardness of each tool, as well as the speed at which the burs are used.[3]

The difficulty of removing composite, in conjunction with the goal of clinicians to minimize chair time, has led to research seeking a system to remove composite with minimal damage to surrounding healthy tooth structure. Several studies have been published regarding the use of lasers to remove composite from tooth surfaces.[4-15] Studies investigating CO₂ lasers for the uses of removing either composite, enamel and dentin found that it can be accomplished with minimal impact to the pulp if operated at 9.3 and 9.6- μ m wavelengths. A clinical study investigating the pulpal response to the same carbon dioxide laser used in this study demonstrated that the laser can be used safely to ablate enamel without pulpal damage. [16] The laser parameters used was wavelength of 9.3 μ m at 25 or 50 Hz and an incident fluence of 20 J/cm².

During the ablation of materials at CO₂ wavelengths with pulse durations on the order of 10 μ s, the laser pulse energy electronically excites the localized ablated particle and gives rise to a luminous plume. This plume can be used to differentiate materials due to the emission spectra of the ablation site. [7, 11] Dental hard tissues give off a plume that has distinctive high intensity calcium emission lines, that can be used to differentiate between dental hard tissues and dental composites.

An earlier *in vitro* study utilizing a carbon dioxide laser operating at 9.3 μm with high pulse repetition rates was able to successfully remove composite from dental hard tissue surfaces. [11] Composite removal was confirmed with a spectral optical feedback and scanning system that was incorporated into a clinical handpiece via an articulating arm and galvanometer. Analysis of selectivity was achieved using a high-speed optical coherence tomography system. This study utilizes this same instrumentation with the goal of demonstrating feasibility of its use *in vivo*.

This study has the following objectives:

1. Test the feasibility of using this clinical handpiece *in vivo*.
2. Test the hypothesis that composite can be safely and selectively removed from tooth surfaces at clinically relevant rates using laser ablation in conjunction with spectral feedback when used *in vivo* in comparison to a traditional high-speed handpiece.

2. MATERIALS AND METHODS

2.1 Participant Recruitment and Screening

Sample size calculations derived a target recruitment population of ten test subjects with a minimum of 2 teeth set for extractions. The OCT system used in this study has an axial resolution in air of 12 μm , and assuming a conservative estimate of a measurement dimensional accuracy of $\pm 50 \mu\text{m}$, then a sample size of 10 is estimated to have 99% power to detect a 20% difference in volume before and after composite removal corresponds to a 100 μm difference in each dimension.

Ultimately, we were successful in the recruitment of eight subjects through the University of California San Francisco Orthodontics post-doc clinic. Subjects were 18 years or older and scheduled to have bilateral premolar extractions completed for their orthodontic treatment. Subjects were screened to have non-contributory medical histories, and to be in good health. Premolars scheduled to be extracted were screened to have a significant section of the occlusal portion to be healthy and untreated enamel. The study was carried out with approved UCSF IRB 12-10225 and NIH/NIDCR Protocol 10-098-E.

Participants were exposed to two interventions at two visits. The purpose of the study and informed consent forms were reviewed and signed by the participant and primary investigator prior to start.

During the first visit, a high-speed air driven handpiece equipped with a 2 mm round bur were used to create preparations solely within enamel approximately 2 mm in length x 2 mm across by 1 mm in depth (volume $\sim 4 \text{ mm}^3$) on the occlusal incline planes of the matched premolars. A cross-polarization optical coherence tomography system (CP-OCT) was then used to scan the preparations and surrounding occlusal surface for volumetric analysis. GreenGlo™ fromOrmco (Orange, CA) was then used to restore the preparation. GreenGlo is a filled composite with temperature sensitive optical properties such that when cooled to

below physiological temperatures it appears green, aiding in identification of any residual composite left on the tooth surface.

Participants returned for their second visit one week after the first visit to allow for complete curing time of the composite. One composite restoration was removed with the laser scanning system with spectral feedback, while the other was removed using the high-speed handpiece and 330 diamond burs. The CP-OCT system was utilized again to collect volumetric data. Patients were then taken to have their premolars extracted the same day as the second visit. Figure 1 shows clinical images of the preparations in the various stages, A – handpiece prep, B – composite fill, and C – handpiece removal of the experiment mentioned above.

2.2 Clinical Laser Scanning System

The clinical system (Fig. 2) consists of the following components: CO₂ laser (not pictured), articulating arm, galvanometer, lens, handpiece head, fiber optic, photodiodes, and air/water spray. A detailed description of the clinical scanning system is described in reference. [11] The laser used for this study was an industrial marking laser, Impact 2500 from GSI Lumonics (Rugby, United Kingdom) operating at a wavelength of 9.3- μ m. The laser was set to operate at a pulse duration of between 10-15 μ s and a high pulse repetition rate of 50 Hz. The safety of these parameters was confirmed in a previous study. [16]

The articulating arm allowed for proper positioning of the laser handpiece. The galvanometer was used to scan the laser beam over tooth surfaces. The clinical handpiece head was custom designed and machined out of aluminum and contained copper mirrors at the end.

A bifurcated fiber optic was utilized to collect the plume emissions and feed them into the two photodiodes (one with and the other without a filter) for spectral feedback. One photodiode was equipped with an optical filter and the other was not in order to discriminate tooth and composite as reported in our previous publication. Air/water spray was integrated into the system in order to improve the spectral feedback loop and reduce tooth temperature rise. If not enough water is used it leads to formation of a carbonized layer of composite at the ablation site. If there is too much water it attenuates the laser beam and decreases the cutting efficiency and in turn reduces the ablation rate and plume intensity.[17] The laser scanning system was held in position intraorally during scanning via a bite block made from delrin, an autoclavable material, and was incorporated to the clinical handpiece. It was further stabilized with clear polyvinyl siloxane (PVS) bite impressions made for each participant.

2.3 Cross Polarization Optical Coherence Tomography

The cross-polarization OCT system used for this study was purchased from Santec (Komaki, Aichi, Japan). This system acquires only the cross polarization image (CP-OCT). The Model IVS-3000-CP utilizes a swept laser source; Santec Model HSL-200-30 operating with a 30 kHz a-scan sweep rate. The Mac-Zehnder interferometer is integrated into the handpiece which also contains the microelectromechanical (MEMS) scanning mirror and the imaging optics. It is capable of acquiring complete tomographic images of a volume of 6 x 6 x 7 mm

in approximately 3 seconds. The body of the handpiece is 7 x 18 cm with an imaging tip that is 4 cm long and 1.5 cm across. This system operates at a wavelength of 1321-nm with a bandwidth of 111-nm with a measured resolution in air of 11.4 μm (3 dB). The lateral resolution is 80- μm ($1/e^2$) with a transverse imaging window of 6 mm x 6 mm and a measured imaging depth of 7-mm in air. The polarization extinction ratio was measured to be 32 dB. An autoclavable appliance made out of delrin was placed on the distal end of the OCT scanning handpiece and the handpiece was covered with polyethylene film for infection control.

2.4 Volumetric Analysis

Volumetric Analysis was completed using Avizo from Thermo Fisher Scientific (Waltham, MA) which also was used to render 3-dimensional visualization of the OCT data. The raw OCT data were processed using Mathworks MATLAB (Natick, AM). Each initial preparation scan (V_I) and post composite removal scan (V_F) was segmented and volumetric measurements of the preparations obtained. Volumetric differences calculated between V_I and V_F yielded information as to whether there was left over composite (If $V_I - V_F$ yielded a positive value), and excess enamel removed (if $V_I - V_F$ yielded a negative value). Statistics were obtained using Prism from Graphpad software (San Diego, CA), and volumetric differences were analyzed using the unpaired t test.

3D renderings of the preparation OCT scans prior to composite placement and after restoration removal are shown in Fig. 3. From the 3D renderings of the OCT scans, volumetric data of the preparation sizes was obtained before and after removal.

3. RESULTS AND DISCUSSION

Two samples were discarded in the analysis of this study. During intervention on patient six, electrical problems arose leading to arcing and laser malfunction, and on patient seven the spectral feedback system was not operating. The initial preparation volumes $V_I - V_F$ volume values between laser and handpiece were compared using the unpaired t test. The mean initial preparation size $\pm$ SEM for the Laser group was 1.548 ± 0.4617 , and 2.495 ± 0.9029 for the high-speed handpiece (HD) group. The P value was 0.3725, showing a non-significant difference between the two groups ($P < 0.05$).

On average the CO₂ laser removed an excess of 0.43 ± 0.73 while the handpiece removed an excess of 0.29 ± 0.78 . For both laser and hand piece, all composite was removed for four of the six samples. With a P value of 0.8945 ($P < 0.05$), there was no significant difference between the use of a high-speed handpiece (HD) and the CO₂ laser (Laser) in removing composite. The composite was removed by the CO₂ laser at speeds acceptable in a clinical setting. A fluence of 8.6 J/cm² and a pulse repetition rate was set at 50 Hz even though higher repetitions rates of up to 2,000 Hz are possible for CO₂ laser now commercially available. Performance was much higher for the laser in our *in vitro* study on extracted teeth where motion was not a problem.[11]

This study was only approved by the UCSF IRB for recruitment of adults 18 years and older who were undergoing orthodontic therapy requiring premolar extractions. Difficulties were

met due to this restriction in the age group, as most patients consenting to orthodontic treatment requiring premolar extractions were under the age of 18. While composite was successfully removed intraorally, the preclinical laser set up was met with some limitations when used clinically. Premolars selected for testing were limited to mandibular premolars due to the handpiece set up, and this dictated where the PVS could be placed on the bite block. As the laser needed clearance to the occlusal surface of the mandibular premolars and a window had to be cut out of the bite block to allow for visual verification of laser alignment, PVS could only be placed on the top portion of the bite block and the occlusal surfaces of the maxillary dentition. For the bite registration to be taken the laser handpiece had to first be positioned to align the 2 mm x 2 mm area of the laser's field with the area of composite placement. Due to the bulk of the bite block, the handpiece had to be removed from the mouth for PVS placement and repositioned to the verified position to the best of the clinician's ability.

Despite bite registrations with PVS material on bite blocks added to the handpiece to stabilize the patient's bite, there was difficulty in holding the system steady during treatment. This was due to the lack of a stable bite registration between the bite block and both maxillary and mandibular teeth. In addition, it was clinically difficult to align the 2 mm x 2 mm area of the laser's field with the area of composite. Although GreenGlo was used for better visualization of the composite, the narrow window of vision through the bite block and resulting poor visibility deterred ideal alignment of the laser over the composite. In addition, GreenGlo favored the high-speed handpiece group as the visualization was much easier for the clinician.

Pre- and post- composite removal value differences yielded information on whether composite remained ($V_F - V_I > 0$) or on whether there was removal of excess enamel ($V_F - V_I < 0$). Data analysis revealed that there was no significant difference between the use of the CO₂ laser and the traditional high-speed handpiece in terms of composite remaining and removal of excess enamel.

Another limitation is that the total number of subjects (n=8) was a small sample size, and two of the subject data had to be disregarded due to functional error of the experiment pieces. In spite of these issues we feel that we have demonstrated that the CO₂ clinical laser handpiece can be successfully used *in vivo* at clinically relevant rates.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of NIDCR/NIH grants R01-DE019631 and F30-DE026052. The authors would like to thank Nick Chang for his contribution to this work.

5. REFERENCES

- [1]. Mjor I, Moorehead J, and Dahl J, "Reasons for replacement of restorations in permanent teeth in general dental practice," *Int Dent J*, 50, 361–366 (2000). [PubMed: 11197194]
- [2]. Hong YH, and Lew KK, "Quantitative and qualitative assessment of enamel surface following five composite removal methods after bracket debonding," *Eur J Orthod* 17(2), 121–128 (1995). [PubMed: 7781720]

- [3]. Oliver RG, and Griffiths J, "Different techniques of residual composite removal following debonding--time taken and surface enamel appearance," *Br J Orthod*, 19(2), 131–7 (1992). [PubMed: 1627524]
- [4]. Alexander R, and Fried D, "Selective Removal of Orthodontic Composite using 355-nm Q-switched Laser Pulses, *Lasers Surg Med*, 30 240–245 (2002). [PubMed: 11891745]
- [5]. Alexander R, Xie J, and Fried D, "Selective removal of residual composite from dental enamel surfaces using the third harmonic of a Q-switched Nd:YAG laser," *Lasers Surg Med*, 30(3), 240–5 (2002). [PubMed: 11891745]
- [6]. Almeida HC, Vedovello Filho M, Vedovello SAS, Young AAA, and Ramirez-Ya, "ER: YAG laser for composite removal after bracket debonding: a qualitative SEM analysis," *Int J Orthod Milwaukee* 20(1), 9–13 (2009). [PubMed: 19438107]
- [7]. Chan KH, Hirasuna K, and Fried D, "Rapid and Selective Removal of Composite from Tooth Surfaces with a 9.3- μ m CO₂ Laser using Spectral Feedback," *Lasers Surg Med*, 43(8), 824–832 (2011). [PubMed: 21956630]
- [8]. Chan KH, Hirasuna K, and Fried D, "Analysis of enamel surface damage after selective laser ablation of composite from tooth surfaces," *Photonics & Lasers in medicine*, 3(1), 37–45 (2014). [PubMed: 24707453]
- [9]. Dumore T, and Fried D, "Selective Ablation of Orthodontic Composite using Sub-microsecond IR laser pulses with Optical Feedback," *Lasers Surg Med*, 27(2), 103–110 (2000). [PubMed: 10960816]
- [10]. Fried WA, Chan KH, Darling CL, and Fried D, "Selective removal of dental composite with a diode-pumped Er:YAG laser," *Lasers in Dentistry XXII. Proc. SPIE Vol. 96920 S: 1–7* (2016).
- [11]. Jang AT, Chan KH, and Fried D, "Automated ablation of dental composite using an IR pulsed laser coupled to a plume emission spectral feedback system," *Lasers Surg Med*, 49(7), 658–665 (2017). [PubMed: 28467687]
- [12]. Lizarelli R. d. F. Z., Moriyama LT, and Bagnato VS, "Ablation of composite resins using Er:YAG laser—comparison with enamel and dentin," *Lasers Surg Med*, 33(2), 132–139 (2003). [PubMed: 12913886]
- [13]. Louie TM, Jones RS, Le CQ, and Fried D, "Selective removal of composite restorative materials using Q-switched 355-nm laser pulses," *Lasers in Dentistry X. proc. SPIE, Vol. 53135 4–60* (2004).
- [14]. Thomas BW, Hook CR, and Draughn RA, "Laser-aided degradation of composite resin," *Angle Orthod*, 66(4), 281–286 (1996). [PubMed: 8863963]
- [15]. Yassaei S, Aghili H, and Joshan N, "Effects of removing adhesive from tooth surfaces by Er:YAG laser and a composite bur on enamel surface roughness and pulp chamber temperature," *Dent Res J (Isfahan)*, 12(3), 254–9 (2015). [PubMed: 26005466]
- [16]. Staninec M, Darling CL, Goodis HE, Pierre D, Cox DP, Fan K, Larson M, Parisi R, Hsu D, Manesh SK, Ho C, Hosseini M, and Fried D, "Pulpal effects of enamel ablation with a microsecond pulsed $\lambda = 9.3\text{-}\mu\text{m}$ CO₂ laser," *Lasers Surg Med*, 41(4), 256–63 (2009). [PubMed: 19347946]
- [17]. Staninec M, Xie J, Le CQ, and Fried D, "Influence of an optically thick water layer on the bond-strength of composite resin to dental enamel after IR laser ablation," *Lasers Surg Med*, 33(4), 264–9 (2003). [PubMed: 14571452]

Fig. 1.
Clinical images of (A) initial preparation (B) restoration with GreenGlo composite (C)
composite removed with handpiece.

Fig. 2.
Image of the clinical handpiece and probe head.

Figure 3.
3D rendering of OCT scan (A) initial prep (B) post composite removal. The preparation as seen in a single plane (C) and a volume rendering of the preparation (D).