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Clinical Pilot Study of Automated Selective Ablation of Dental Composite

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Clinical Pilot Study of Automated Selective Ablation of Dental Composite

by
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Dedication and Acknowledgments

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Clinical Pilot Study of Automated
Selective Ablation of Dental Composite

Judy Jeehye Choi

ABSTRACT

INTRODUCTION: Lasers are now used for several applications in dentistry. They offer many advantages to the dental field over traditional high-speed handpieces. Lasers that are computer controlled in conjunction with optical methods of feedback can conservatively ablate composite from healthy enamel and dentin. Due to composite's similarity in appearance with natural dentition, composite restorations are difficult to remove without damage to healthy tooth structure in practice. This damage to healthy tooth structure can be minimized with spectral guidance and computer controlled lasers. The hypothesis tested in this study is that composite can be safely and selectively removed from tooth surfaces at clinically relevant rates using laser ablation in conjunction with spectral feedback as compared to removal using a high-speed handpiece.

METHODS: A CO_2 laser, a computer-controlled galvanometer based scanning system, and a spectral discrimination system were used for the removal of composite from enamel and dentin surfaces. Subjects (N=8) being treated at the UCSF Orthodontics post-doc clinic were recruited for this study. Subjects were 18+ years old and scheduled for bilateral premolar extractions. Premolars to be extracted were screened to have a significant section of the occlusal portions with healthy, untouched enamel. Patients were seen in two visits: The first visit consisted of occlusal preparations of the two premolars, scanning of the preparations with OCT, and restoring with composite. The second visit consisted of removing the composite with laser technology or the traditional high-speed hand piece and scanning the results. Patients subsequently completed extractions. Data from the scans were analyzed to compare the initial cavity preparation volume with resulting cavity volume after composite removal by laser or high-speed handpiece.

RESULTS: Volumetric data obtained from OCT scans were analyzed via a data visualization software. There was no significant difference ($P<0.05$) in initial preparation size across all patients. Volumetric differences of composite removal revealed no significant differences between handpiece vs CO_2 laser methods.

CONCLUSIONS: There was no significant difference in terms damage to enamel or totality of composite removed, but this study indicates favorably that the CO_2 laser set up with automated feedback for the selective ablation of dental composite can be used clinically.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Composite is a widely used material within the field of dentistry, ranging from restoration after caries removal to the bonding of orthodontic brackets. It is highly favored in restorative dentistry due to the ability of the clinician to color match composite for ideal esthetics.[1] Removal of existing composite may be necessitated when there is secondary dental caries requiring a replacement filling, or when a patient is finished with orthodontic treatment and the orthodontic appliances need to be removed.[2,3] Incomplete resin removal is not acceptable in both scenarios. In the case of secondary dental caries, the old composite must be removed to insure thorough caries excavation. Any remaining composite could also negatively affect the bond strength of the new composite restoration unless extra precautions are taken to increase the bond strength between old and new composite.[4] If composite is not entirely removed at the conclusion of orthodontic treatment, it can to lead increased accumulation of dental plaque around resin remnants as well as unaesthetic discoloration at the composite and enamel interface over time.[5] Currently there is no technique that allows for removal of composite remnants without any damage to healthy tooth structure. This results from a culmination of many factors, some of which include the difficulty in enamel and resin differentiation, the difference 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.[6]

In addition to the difficulty in differentiating between composite and healthy enamel by the human eye, there are multiple techniques and tools within a clinician's arsenal that can quantitatively affect the amount of composite remaining and excessive removal of healthy tooth structure.[7] Among the variety of methods used to remove composite of an existing restoration or remaining after orthodontic appliance removal are pliers, scalers, sandpaper discs, diamond burs, tungsten burs, carbide burs, stones, and ultrasonic instruments.[8] Diamond and tungsten carbide burs were shown to be favored in bulk removal of composite, but they also remove a substantial layer of enamel and roughen its surface. While discs, ultrasonic tools, hand instruments, rubbers,

and composite burs were also effective, they require increased chair time.[6,8] 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. Previous studies indicate that a speed of about 30,000 rpm is optimal for rapid adhesive removal while minimizing enamel damage. Higher speeds would only be satisfactory for bulk removal but would lead to unacceptable damage to the enamel surface when there is only a thin amount of resin remaining.[5]

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. One such system where undergoing research is the use of lasers. Lasers have been used in dentistry for soft tissue alterations, removal of hard dental tissue, caries inhibition, and caries detection[9-11]. Studies investigating CO_2 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-µm wavelengths.[12,13] 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. The laser parameters used was wavelength of 9.3 µm at 25 or 50 Hz and an incident fluence of 20 J/cm^2 .[14]

During tooth and composite surface ablation, 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.[15,16] Dental hard tissues give off a plume that has a distinctive high intensity calcium emission, which allows for differentiation of dentin and enamel from composite. [17-19]

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. 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.[20] This study utilizes this same set up 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

MATERIALS AND METHODS

Participant Recruitment and Screening

Sample size calculations derived a target recruitment of ten test subjects with a minimum of 2 teeth set for extractions. The OCT system used in this study has an axial resolution of 12 µm, and assuming a conservative estimate of a measurement dimensional accuracy of ±50 µm, 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. Volume differences of residual composite and damage to healthy enamel was anticipated to easily exceed 50% for the dental bur as it is unlikely that even a highly skilled clinician can selectively remove composite from tooth surfaces with such high precision.

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-significant 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 untouched enamel. Purpose and procedures of the study were reviewed with the subjects and informed consent was obtained. Patients were compensated for their time with gift debit cards.

Participant Visits

Participants were seen in two visits. Purpose of the study and informed consent forms reviewed and signed by participant and primary investigator prior to start.

During the first visit, a high-speed handpiece and 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 ~ 4 mm^3) on the occlusal surfaces 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™ was then used to restore the preparation. This is a filled composite that is temperature sensitive; when cooled to below physiological temperatures it appears green, thus aiding in identification of any residual composite left on the tooth surface.

The second visit occurred 1 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. The CP-OCT system was utilized again to collect volumetric data. Patients were then taken to have their extractions completed the same day as the second visit. Figure 1 shows clinical images of the preparations in the various stages of the experiment mentioned above.

Clinical Laser Scanning System

The clinical laser scanning system used in this study has the following components: CO_2 laser, articulating arm, lens, fiber optic, galvanometer, handpiece head, photodiodes, and air water spray (Figure 2).[20] The laser was set to operate at a wavelength of 9.3 μm, a pulse duration of between 10-15 μm, and a high pulse repetition rate of 50 Hz. The safety of these parameters was confirmed in a previous study.[14]

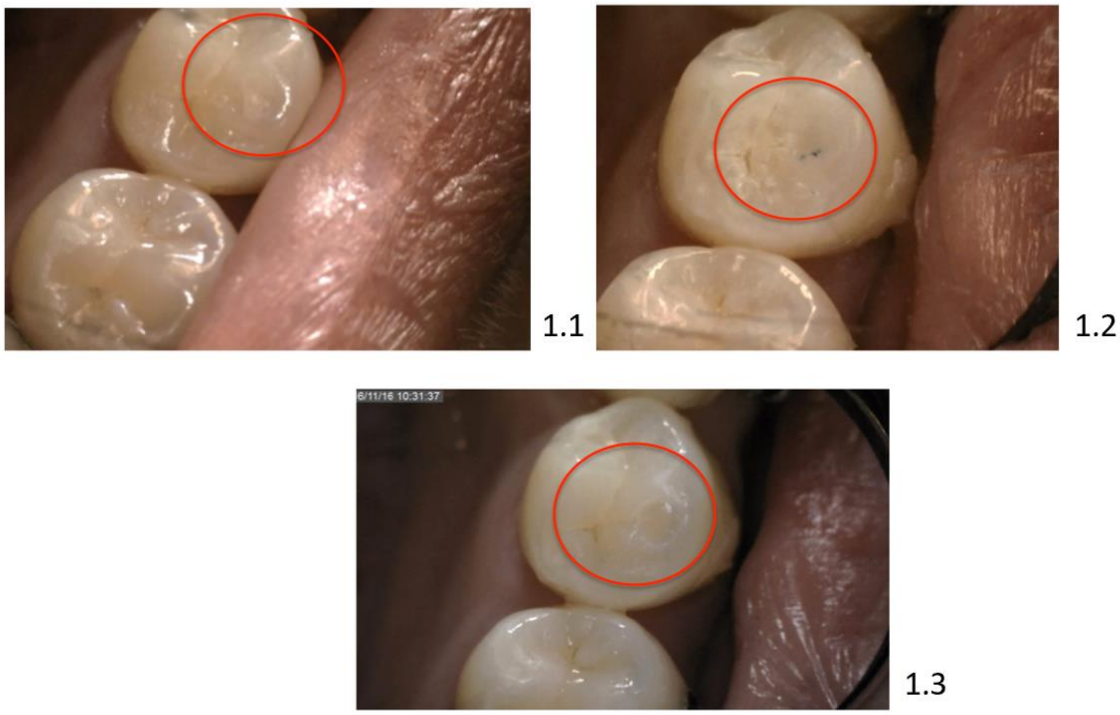

Figure 1: Clinical images of (1.1) initial preparation (1.2) restoration with GreenGlo composite (1.3) composite removed

Figure 2: Image of the clinical handpiece and probe head

The articulating arm allowed for proper positioning of the laser handpiece. The galvanometer was used to scan the laser beam over tooth surfaces. The lens was an f-theta scanning lens to focus the laser beam onto the 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 necessary to collect and feed the plume emission into the two photodiodes (one with and the other without a filter) for spectral feedback. Air water spray was a part of the system in order to improve the spectral feedback loop. Too little water leads to formation of a carbonized layer of composite at the ablation site, but too much water attenuates the laser beam. This in turn would reduce the ablation rate and plume intensity.[20]

The laser scanning system was held into position intraorally during scanning via a mouth prop made of polyoxymethylene, also known as Delrin (an autoclavable material). This was

incorporated to the clinical handpiece. It was further stabilized with PVS bite impressions made for each participant.

Cross Polarization Optical Coherence Tomography

The CP-OCT system used in this study use a swept laser source and operates with a 30 kHz sweep rate. This system has been used previously on clinical imaging studies.[21,22] It yields a 6x6mm area around the area of the preparation before composite placement and after composite removal. The resulting images will have a voxel size of 32.5 µm x 24.7 µm x 8.3 µm. Processing of the obtained images were completed using MATLAB.

Volumetric Analysis

Volumetric Analysis was completed using a data visualization software called Avizo. Each initial preparation scan ($\mathbf{V_I}$) and post composite removal scan ($\mathbf{V_F}$) was segmented and volumetric measurements of the preparations obtained. Volumetric differences calculated between $\mathbf{V_I}$ and $\mathbf{V_F}$ yielded information as to whether there was left over composite (If $\mathbf{V_I}$ - $\mathbf{V_F}$ yielded a positive value), and excess enamel removed (if $\mathbf{V_I}$ -$\mathbf{V_F}$ yielded a negative value). Statistics were obtained using the Prism software, and volumetric differences were analyzed using the unpaired t test.
The raw OCT data were processed using MATLAB which allowed for 3-dimensional visualization of the OCT data in Avizo; these renderings of the preparation OCT scans prior to composite placement and after restoration removal is shown in Figure 3. From the 3D renderings of the OCT scans, volumetric data of the preparation sizes was obtained, as seen in Figure 4.1 and 4.2.

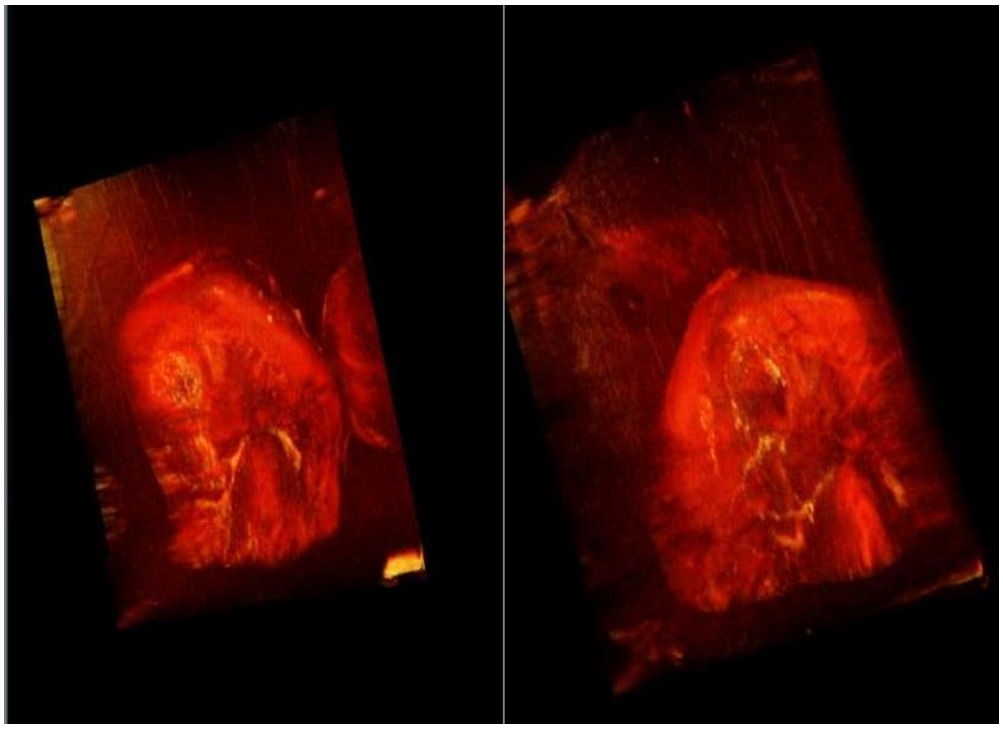

Figure 3: 3D rendering of OCT Scan (a) initial prep (b) post composite removal

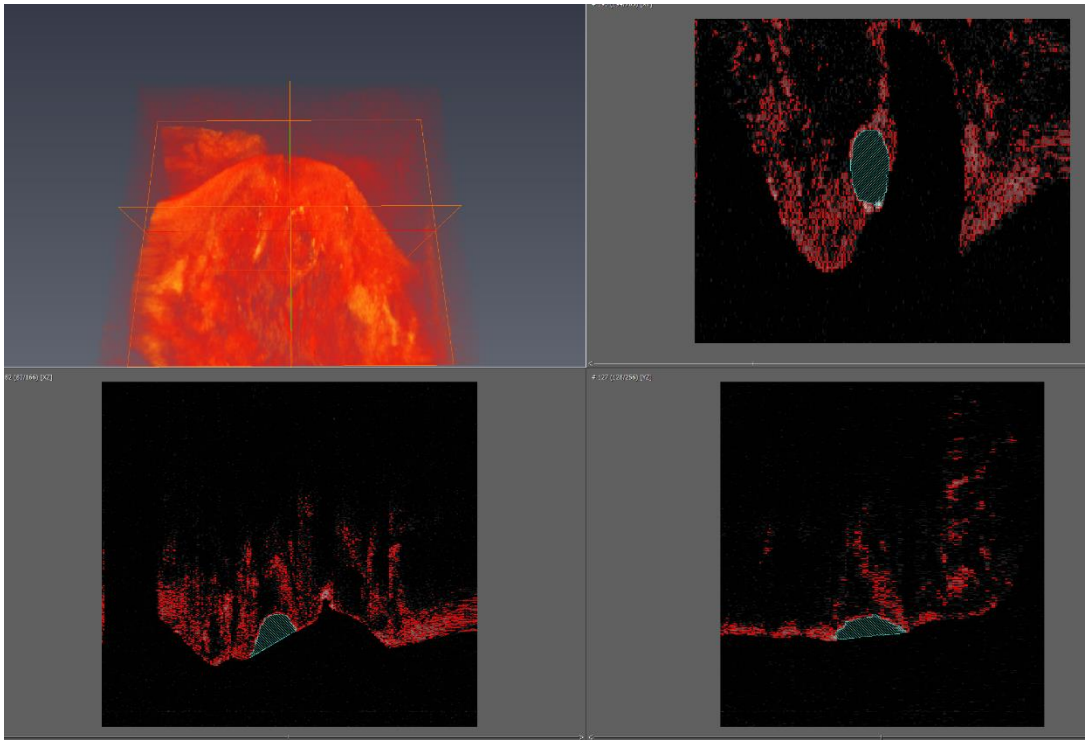

Figure 4.1: Volume rendering of the preparation as seen in all three planes space (b) isolated volume rendering of the preparation

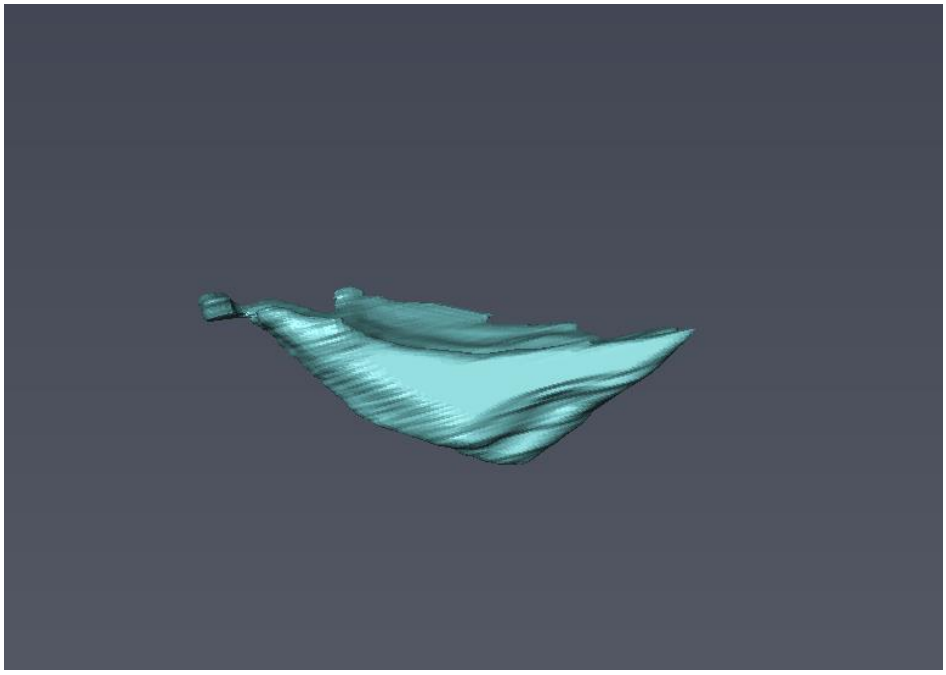

Figure 4.2: An isolated volume rendering of the preparation

RESULTS

Table 1 shows the volumetric data. Two samples were discarded; on patient 6 electrical problems arose leading to arcing and laser malfunction, while on patient 7 the feedback system was not operating.

Table 1: Volumes of preparations prior to and after composite removal along with calculated volumetric differences

Sample	Initial Preparation Volume (mm^3)	Preparation Volume after composite Removal (mm^3)	Difference
1_21	0.39	0.81	-0.42
1_28	0.33	0.33	0
2_20	0.27	0.55	-0.28
2_29	0.72	0.36	0.36
3_21	1.58	2.89	-1.31
3_28	3.1	6.61	-3.51
4_21	1.96	2.16	-0.2
4_28	3.12	6.07	-2.95
5_21	0.86	1.86	-1
5_28	2.99	2.76	0.23
8_21	2.68	0.36	2.32
8_28	6.26	3.79	2.47

The mean initial preparation size ± SEM for the Laser group was 1.548±0.4617, and 2.495± 0.9029 for the High-speed handpiece (HD) group. One-way ANOVA analysis (Figure 5) comparing the volume of initial preparations between laser and handpiece samples yielded a P value of 0.3725, showing a non-significant difference between the two groups (P<0.05).

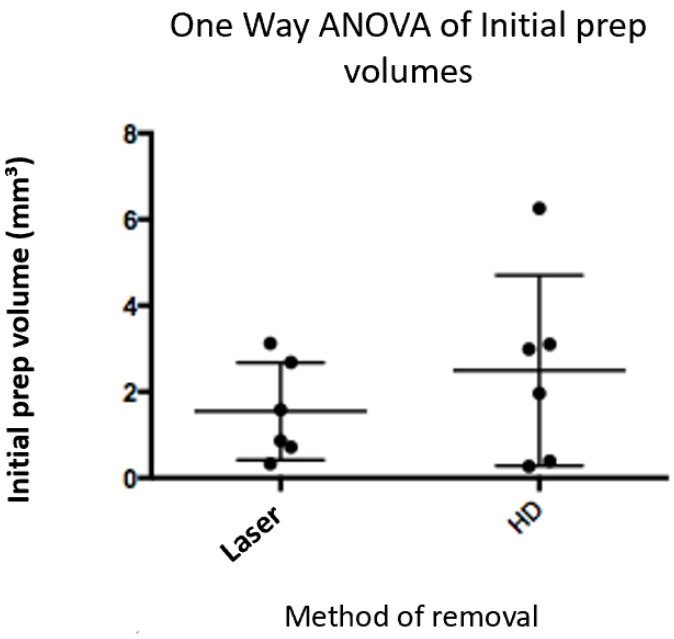

Figure 5: One Way ANOVA comparing Initial preparation volumes

$\mathbf{V_I}$ - $\mathbf{V_F}$ volume values between laser and handpiece were compared using the unpaired t test. On average the CO_2 laser removed an excess of 0.43 ± 0.7262 while the handpiece removed an excess of 0.2850 ± 0.7806. 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 CO_2 laser (Laser) in removing composite (Figure 6).

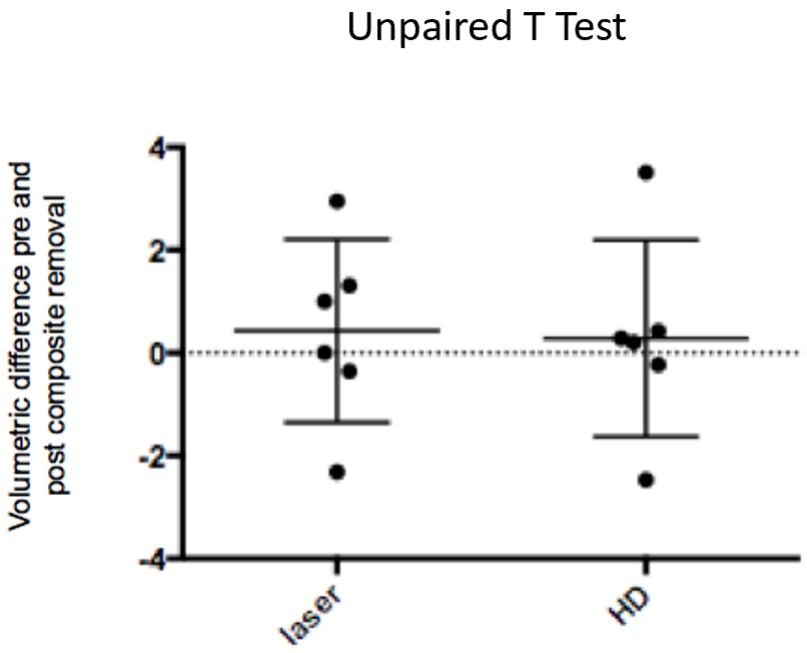

Figure 6: Unpaired T test showing $\mathbf{V_I}$ - $\mathbf{V_F}$ values of the two methods of composite removal

DISCUSSION

The preclinical study previously done in this lab was able to demonstrate the use of a computer-controlled CO_2 laser scanning system with integrated spectral feedback at clinically relevant rates to selectively remove composite from dental hard tissue. The setup that resulted from that study was used in this study: a handpiece that could be used intraorally on a patient that integrated the CO_2 laser to a spectral feedback system utilizing two photodiodes, and a CP-OCT system suitable for clinical use to capture images in order to capture volumetric data.

The position of the handpiece was designed to be stabilized for intraoral use via an articulating arm and galvanometers, which allowed for the laser simultaneously scan over the occlusal surface of the tooth. This led to composite being removed by the CO_2 laser at speeds acceptable in the clinical setting. A fluence of 8.615 J/cm^2 and a pulse repetition rate was set at 50 Hz even though higher repetitions rates of up to 2,000- Hz is possible, due to for pulpal

safety.[14,20] The clinical OCT system was also clinically feasible with it's resolution (32.5 µm x 24.7 µm x 8.3 µm) and short scan time of approximately 4 seconds.

The above specifications were determined to be clinically acceptable after tabletop testing from a previous study[20], so this study utilized those settings and test it in a real clinical setting to test for feasibility. This study was 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. Another barrier to patient recruitment was that participating in this study affected patients' orthodontic treatment as coordinating for two visits and requiring the extractions to be on the same day as the second visit delayed treatment. This deterred many possible adult participants from partaking in the study, despite an NIH grant providing compensation to participants.

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 (Figure 7), 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.

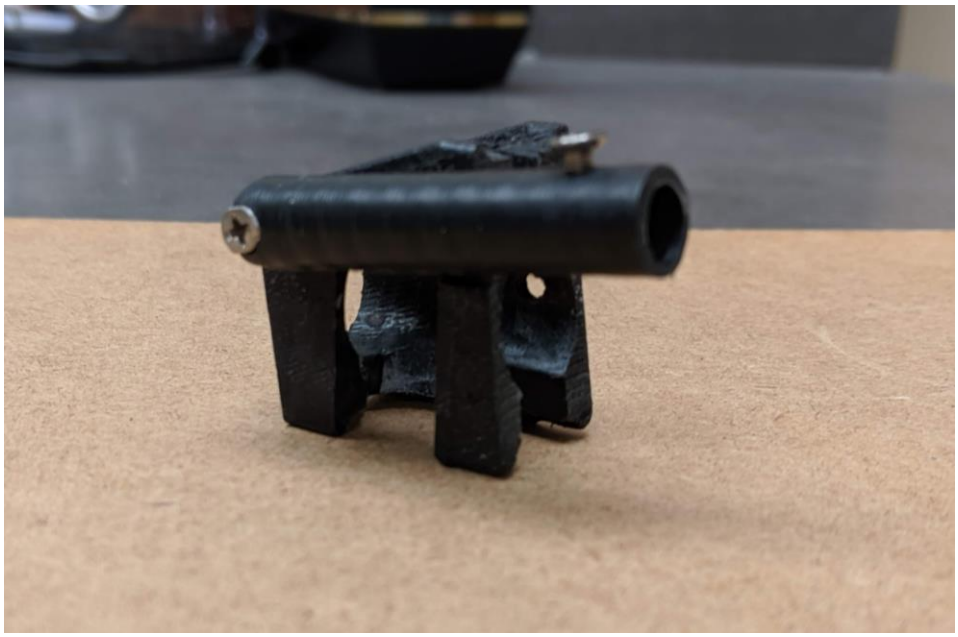

Figure 7: Image of the bite block used to stabilize the patient's bite during laser activation

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 to this it was clinically difficult to align the 2 mmx2 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, GreeGlo 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 ($\mathbf{V_F} - \mathbf{V_I} > 0$) or on whether there was removal of excess enamel ($\mathbf{V_F} - \mathbf{V_I} < 0$). Data analysis revealed that there was no significant difference between the use of the CO_2 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.

While the data derived from this study does not have enough sample size to determine the effectiveness of using one method of composite removal over the other, this study illustrated that the CO_2 clinical laser handpiece can be successfully used in vivo at clinically relevant rates.

CONCLUSION

We have successfully shown the feasibility of using the clinical CO_2 laser in live patients, and showed that composite can be safely and selectively removed from tooth surfaces using laser ablation in conjunction with spectral feedback. There was no conclusive information about whether the use of the clinical CO_2 laser led to more complete removal of composite with less damage to healthy tooth structure when compared to use of a traditional high-speed handpiece. There are newer laser systems in the current market that are more compact and better suited for clinical use, such as the MEMS scanners. Another study looking into adapting newer laser systems and changing the experiment design with better fixation of the laser system could possibly analyze the effectiveness of selective composite ablation.

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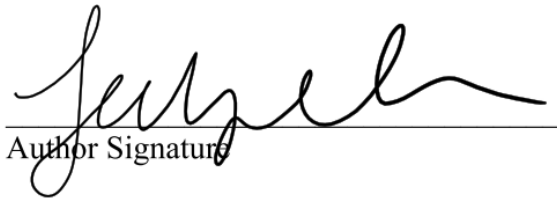

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