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Cite This:Journal abbrevation. yyyy, vol, page

International Journal of Dentistry and Oral Medicine

Journal homepage: www.sciforce.org

An in-vitro analysis for using an Er,Cr:YSGG laser for Class II cavity preparation while modulating multiple parameters

Christopher J. Walinski[1*], Layne C. Levy[2], Antheunis Versluis[3], James D. Ritter[4], and Keng Liang Ou[5,6,7,8]

[1]Associate Professor of Dental Medicine, Touro College of Dental Medicine, Hawthorne, NY, 10532, USA

[2] Assistant Professor, University of Tennessee College of Dentistry, Memphis, TN, 38103, USA

[3] Professor of Bioscience Research, University of Tennessee College of Dentistry, Memphis, TN, 38103, USA

[4] General Dentist, Cordova, TN, 38018, USA

[5] Department of Dentistry, Taipei Medical University Hospital, Taipei 110, Taiwan

[6] Department of Dentistry, Taipei Medical University, Shuang Ho Hospital, New Taipei City 235, Taiwan

[7] Department of Dentistry, Cathay General Hospital, Taipei 106, Taiwan

[8] 3D Global Biotech, Inc., New Taipei City 221, Taiwan

ARTICLE INFO

Article history:
Received: 04-28-2021
Received in revised form
Accepted : 05-16-2021
Available online: 15-06-2021

Keywords:
Cavity Preparation;
Er,Cr:YSGG;
Erbium Laser;
Laser Ablation

ABSTRACT

The purpose of this study was to test various laser parameters while creating Class II cavity preparations and comparing treatment time and intrapulpal temperature to high-speed rotary hand piece. Class II cavity preparations were made in 70 extracted maxillary human premolars. Ten preparations were created using a high-speed hand piece and diamond bur, with copious water spray. Each preparation included a proximal box which was 3 mm mesiodistally by 4 mm buccolingually, and 4 mm deep. Six Laser Groups of ten teeth each were completed with an Er,Cr:YSGG laser to a size equal to the control. Treatment time and intrapulpal temperature were recorded and compared. Teeth in the Control Group took an average of 33.4 seconds ± 3.0 seconds to complete. Pulpal temperature in the Control was raised in ten out of ten samples, an average of 3.00ºC ± 2.49ºC, with the highest rise (outlier) being 9.6ºC above baseline. Laser test groups demonstrated an average increase of 0.37°C ± 0.36°C. Additionally, the average preparation time of 36.7 ± 3.3 seconds was 3.3 seconds longer and just under 10% slower than the Control. This study presented three sets of laser parameters using an Er,Cr:YSGG laser to prepare Class II cavities. Based on the results of this study, maintaining the energy per pulse and increasing the number of pulses per second is the most favorable adjustment, as treatment time is reduced, while maintaining a modest increase in pulpal temperature. Results improve further as the volume of water in the spray increases up to a setting of 100%.

*Corresponding author. Tel.: +1-858-208-9100; e-mail: christopher.walinski@touro.edu

Introduction

Since the development of erbium dental lasers, clinicians and researchers have pursued methods to improve the efficiency, comfort, and speed of laser cavity preparation to be comparable to high-speed rotary hand piece. To this end, device improvements have included increased peak power, innovative terminal fiber design and the development of non-traditional lenses, tips and waveguides.

With these improvements in mind, laser cavity preparation has become a viable treatment option. The next logical steps should involve maximizing function and confirming safe use. The purpose of this research was to compare various laser parameters to a high-speed rotary hand piece with a diamond bur while preparing Class II cavity preparations in human maxillary premolars. All adjustments were completed while monitoring intrapulpal temperature so as not to exceed a net rise of more than 5.5°C as described by Zach and Cohen.[1]

Erbium lasers ablate tooth enamel using a combination of photothermal, photomechanical and photo acoustic phenomena.[2] Dental enamel is comprised by as much as 96% of hydroxyapatite, a crystalline form of calcium phosphate. Water and organic material make up the remainder.[3]Erbium lasers have the ability to ablate enamel because of the high absorption coefficient by both water and to a lesser degree, hydroxyapatite.

When an erbium laser irradiates enamel, the energy is absorbed initially by the water molecules suspended within the enamel matrix. As water absorbs laser energy the temperature rapidly increases, causing a sudden significant increase in volume. This expansion by micro-explosions causes enamel cracking. Tooth ablation is complete when the photo acoustic and photomechanical effects from the erbium laser cause the weakened portions of enamel to be expelled from the tooth surface, leaving in its place an ablation crater.[2,4-6] Most of the irradiated energy is consumed during the ablation process, leaving only small amounts of energy in the tooth structure, therefore minimizing thermal effects.[7]

The benefits of using a strong aerosolized water spray during tooth ablation has been established; the rationale being that the water spray keeps target tissues cooler and subsequently, the patient more comfortable. However, it has also been shown that water plays a significant role in the ablation of tooth structure, in fact, initiating the ablative process.[8] Without water spray the heat generated by erbium lasers may cause melting, cracking and other thermal effects.[9] The addition of an aerosolized water spray, along with ultra short, microsecond pulses minimizes increase in pulpal temperature during cavity preparation.[10,11]

The presence of additional water could theoretically slow tooth ablation because of the higher absorption coefficient, since water absorbs much of the laser energy, interfering with target tissue ablation. Then again, some studies suggest that water enhances the ablation process, therefore, this is one of the parameters which is included in this study.[12-15]

The null hypothesis is that there will be no difference in the results observed when comparing data such as treatment time and intrapulpal temperature rise while preparing Class II cavity preparations using either high-speed handpiece or erbium laser.

Material and methods

70 extracted human maxillary premolars were obtained from a tissue bank and used for this study. Each tooth was prepared by amputating the root(s), leaving 5 mm of root intact from the cement enamel junction. A 0.060 inch (1.524 mm) diameter cylindrical post prep bur (Para Post X, Size 6, Coltene/Whale dent, Cuyuhoga Falls, OH, USA) was then used with a low-speed rotary hand piece to enlarge a single root canal into the pulp chamber of every tooth, allowing adequate space for the thermocouple probe to passively extend to the roof of the pulp chamber. All specimens were stored in distilled water containing 0.4% thymol until ready for use.

Each pulp chamber was filled with a conductive silicone paste (Omega herm 201, Omega Engineering, Inc., Stamford, Connecticut, USA). A 1.5 mm diameter Type-J sheathed and grounded thermocouple (IC-SS-116-G-6, Omega Engineering Inc, Stamford, Connecticut, USA) was placed into each tooth and sealed with clear rope wax. A latex dental dam was then placed around the tooth to prevent water spray from reaching the tooth root or thermocouple probe directly. An additional latex dental dam was used to cover and protect the base of the probe, once again, to prevent temperature alterations. All study components were held steady using a series of lab clamps on a ring stand.

A curing light (DemiUltra, Kerr Co., Orange, California, USA) was used to confirm the accuracy and sensitivity of the thermocouple setup. The curing light test was confirmed, as temperature increased 2°C after 30 seconds of light activation at an irradiance of 1135 mW/cm^2.

The first ten Class II cavity preparations were created using a new diamond bur for every specimen (331D FG Pear Diamond, Peter Brasseler Holdings, LLC, Savannah, GA USA) in a high-speed rotary hand piece using copious water spray, by a single operator (KLO). Each preparation included a proximal box which was 3 mm mesiodistally x 4 mm buccolingually, with a depth at least into dentin (4 mm deep). A 5 mm occlusal extension was also prepared with the overall cavity dimensions made slightly larger, but based upon traditional amalgam preparation principles for standardization. 16 After establishing the control using the high-speed rotary hand piece, six Laser

Groups were completed by creating ten Class II cavity preparations in each group (total n = 70) by another experienced operator (CW). All laser preparations were completed to a size equal to the control. The same thermocouple setup was utilized and data was collected for temperature changes and total time for each laser cavity preparation.

An Er,Cr:YSGG dental laser (Waterlase iPlus, Biolase, Inc., Foothill Ranch, CA, USA) was fitted with a hand piece and MZ-6 laser fiber (600µm diameter cylindrical fiber, 6 mm in length). The same operator prepared a Class II cavity preparation into ten premolars. The parameters for Group 2 were 250 mJ/pulse, 15 Hz, 50% water, 100% air, 140 msec pulse, 3.75 Watts. Although air and water ranges are normally closer in value, it was decided that values of 50% and 100% would be utilized for air and water spray in order to more clearly demonstrate changes in temperature. Additionally, Olivi et al. have suggested that more water flow will clear the ablation zone of debris and provide a more uniform prismatic tooth structure.[17] This result was observed following cavity preparation.

Five additional Groups were completed with ten Class II cavity preparations in each group. The same setup was utilized and the same data was collected for temperature fluctuation and total time for each cavity preparation. Before initiating each preparation, the thermocouple was inserted into the pulp chamber and thermal data was collected for 30 seconds, to establish a baseline. A single operator (LL) kept time from the start of each preparation until the end, and a second operator (JR) managed the thermocouple setup and data collection. Group 3 was similar to Group 2 with the exception of the ratio of air and water: 250 mJ/pulse, 15 Hz, 100% water, 50% air, 140 msec pulse, 3.75 Watts. The main difference in Group 4 was the increase in the pulses per second: 250 mJ/pulse, 25 Hz, 50% water, 100% air, 140 msec pulse, 6.25 Watts. Similar to the difference between Groups 2 and 3, the parameters in Group 5 were identical to Group 4 except for the air and water: were 250 mJ/pulse, 25 Hz, 100% water, 50% air, 140 msec pulse, 6.25 Watts. Groups 6 and 7 increased the energy per pulse as comparison, to demonstrate the differences caused by changing this parameter. Group 6: 400 mJ/pulse, 15 Hz, 50% water, 100% air, 140 msec pulse, 6.00 Watts. Group 7: 400 mJ/pulse, 15 Hz, 100% water, 50% air, 140 msec pulse, 6.00 Watts. The energy/pulse and repetition rate in Groups 6 and 7 are the most common as reported by the laser manufacturer.

Table 1

GROUP	1 = CONTROL	2	3	4	5	6	7
AVG PREP TIME (sec)	33.4	52.2	59.2	36.7	38	37.8	44
HIGHEST TEMP (°C)	2.959	0.02	0.059	0.4535	0.322	1.009	0.381
LOWEST TEMP (°C)	N/A	-1.114	-1.592	-0.563	-0.825	-0.549	-0.883

1. Control: High speed handpiece
2. 250mJ/pulse, 15Hz, 50% Water, 100% Air
3. 250mJ/pulse, 15Hz, 100% Water, 50%Air
4. 250mJ/pulse, 25Hz, 50% Water, 100% Air
5. 250mJ/pulse, 25Hz, 100% Water, 50% Air
6. 400mJ/pulse, 15Hz, 50% Water, 100% Air
7. 400mJ/pulse, 15Hz, 100% Water, 50% Air

Results

In Group 1 (Control), ten samples were prepared using a high-speed rotary handpiece with new diamond burs, with copious water spray. Preparations in this group took an average of 33.4 seconds ± 3.0 seconds to complete. Intrapulpal temperature in this Group was raised in ten out of ten samples, an average of 3.00°C ± 2.49°C, the highest temperature rise (outlier) being 9.6°C; significantly above the target of 5.5°C. All test samples in Groups 2 through 7 were prepared with water spray.

Laser parameters for Group 2 were 250 mJ/pulse and 15 Hz (3.75 W), at 50% water and 100% air. With slight adjustments to the air and water settings, these laser parameters are identical to the presets on the laser device. At these settings, a Class II cavity preparation made in human premolar teeth took an average of 52.2 ± 2.8 seconds to prepare ($p<0.0001$), and resulted in a decrease in intrapulpal temperature of -1.11°C ± 0.93°C. When all parameters remained constant except for the percentage of air (100% down to 50%) and water (50% up to 100%) in the water spray (Group 2), preparation time increased to 59.2 ± 4.5 seconds ($p<0.0001$), however, the intrapulpal temperature decreased further, to -1.59°C ± 0.77°C.

In Group 4, the energy per pulse was kept constant at 250 mJ/pulse, but the number of pulses per second increased from 15 Hz to 25 Hz (6.25 W). As might be expected, this resulted in an overall increase in intrapulpal temperature at 50% water and 100% air. It should be noted that this increase in temperature could be offset by increasing the amount of water in the spray from 50% to 100% (Group 5). At a maximum increase of 0.45°C ± 0.61°C ($p<0.0001$), these parameters could be deemed safe to the pulp, and the average preparation time of 36.7 ± 3.3 seconds (Not Significant), creating a maximum increase in temperature of and maximum decrease of -0.56°C ± 0.34°C. Group 5, prepared with more water, took slightly longer at 38.0 ± 3.1 seconds (Not Significant) was 3.3 seconds longer and just under 10% slower than the Control.

As comparison, the last two groups used higher pulse energy, consistent with more commonly used laser settings. In Group 6, the laser was set at 400 mJ/pulse at 15 Hz (6.0 W) at 50% water and 100% air. The highest temperature rise at these settings was 1.01°C ± 1.33°C ($p=0.001$). When the water spray was increased from 50% to 100% and air was decreased to 50% (Group 7), intrapulpal temperature increased a more manageable 0.38°C ± 0.45°C ($p<0.0001$). Total cavity preparation time was 44.0 ± 4.0 seconds.

Discussion

As the dental laser industry moves forward, several areas of dentistry have been positively affected. Soft tissue surgery, endodontics, periodontics and oral implantology have all seen consistent developments with adjunctive laser therapies. An area of dentistry which has not seen as rapid an acceptance is in basic cavity preparation using lasers.

Although studies exist regarding laser cavity preparation, the number of scientific papers presenting safe and effective ablation parameters is relatively limited in comparison. The primary reasons for the increased use of erbium laser cavity preparation are the growing base of studies demonstrating the comfort (less noise and vibration) and effectiveness, along with requiring potentially less local anesthetic, and decreasing damage to the dental pulp.[18-26] In fact, Hadley et al and others have found no significant difference between high-speed rotary hand piece and erbium laser for both cavity preparation and caries removal.[27-30]

Every trial in the high-speed hand piece Control Group demonstrated a sudden, rapid increase in pulpal temperature during preparation. In addition, in none of the Control Group trials did the pulpal temperature drop below the baseline marked at the beginning of each trial. Conversely, in every trial in the erbium laser preparation groups, there was a point when the pulpal temperature dropped below the baseline. In some of the laser trials where the irradiance was higher, the pulpal temperature did rise, however, this increase in pulpal temperature in all six laser groups was significantly less than the Control. (Groups 2, 3, 4, 5, 7 $p<0.0001$, and Group 6 $p<0.001$).

It may be interesting to note that previous studies of dental hard tissue preparation using erbium lasers have resulted in two distinct outcomes. While most researchers have reported open dentinal tubules and an absence of smear layer, resulting in an increase in bond strength, others have found a fusion of collagen fibers, which resulted in a reduction in interfibrillar spaces and lower bond strength.[31-36] Indeed, common ground has not yet been achieved. An increase in dentinal permeability and elimination of smear layer and smear plugs is generally considered positive in light of the finding that as much as 86% of dentinal permeability resistance is caused by smear debris due to its low surface energy.[37-41]

Maintaining a constant energy per pulse at 250 mJ/pulse, but increasing the number of pulses per second from 15 Hz to 25 Hz (Group 4), resulted in an overall increase in intrapulpal temperature at 50% water and 100% air. This thermal increase could be offset by increasing the amount of water in the spray to 100% as noted in Group 4. At a maximum increase of 0.45°C ± 0.61°C, none of these parameters was found to be detrimental to the pulpal vitality, and the average preparation time of 36.7 ± 3.3 seconds took just 3.3 seconds longer than the hand piece control preparation.

Despite the potential for a cleaner and more porous cavity preparation surface, consensus would indicate that etching with phosphoric acid continues to be necessary following either rotary hand piece or laser preparation, and results in a measurable increase in tensile strength.[40,42] Cavities prepared with an erbium laser have been shown to have higher micro hardness values than those prepared with high-speed handpiece.[43-45] It is thought that the measurable improvements are related more to morphologic changes than surface topography. The resultant change in calcium/phosphorus ratio results in caries resistance.[46,47]

The purpose of this paper was to compare three of the most common settings for dentin and enamel ablation using an Er,Cr:YSGG laser, while simultaneously demonstrating the profound effect of modulating the volume of water in the aerosolized spray. While some studies have reported significantly longer preparation times during laser irradiation as compared to high-speed rotary hand piece, [48] the current study suggests that erbium laser cavity preparations of the same size, shape and depth can be completed in 44.6 seconds across all samples compared to 33.4 ± 3.0 seconds with a high-speed rotary hand piece. These results are consistent with research completed by Den Beston et al.[49] There also seems to be an advantage to using an erbium laser with respect to pulpal health. While the average of all laser test groups increased pulpal temperature by 0.74°C ± 1.0°C, the high-speed rotary hand piece group increased pulpal temperature by 3.00°C ± 2.49°C. In addition, all laser test groups produced a decrease in pulpal temperature at some point during cavity preparation (-0.92°C ± 0.39°C). This would seem to be a significant benefit, improving the thermal safety of cavity preparation.

Conclusion

One of the topics most often debated regarding hard tissue laser ablation is whether the *energy per pulse* or the number of *pulses per second* is more important in regards to the speed, efficiency and safety. The average power may be determined by multiplying these two variables (mJ/pulse x pulses/second). The same average power may be achieved with a higher energy per pulse and fewer pulses per second, or by reducing the energy per pulse and increasing the number of pulses per second proportionately. This study presented three sets of laser parameters using an Er,Cr:YSGG laser while cutting Class II cavity preparations, modulating the energy per pulse, the number of pulses per second and the amount of water in the spray. Based on the results of this study, it would appear that maintaining the energy per pulse and increasing the number of pulses per second is most favorable, as preparation speed improves significantly while maintaining a modest increase in pulpal temperature. Results improve further as the volume of water in the spray increases up to 100%.

Within the limitations of this study (in vitro, single laser wavelength, settings tested and only maxillary premolars), it can be concluded that using an Er,Cr:YSGG dental laser is a thermally safe and time efficient method to prepare cavity preparations in human premolars. At the highest pulse energy tested (400 mJ), preparation time averaged 37.8 ± 4.2 seconds, and caused a maximum increase in intrapulpal temperature of 1.01°C ± 1.33°C. The null hypothesis has been disproved, as lower pulse energies resulted in slightly longer preparation times, and as much as -1.6°C ± 0.8°C decrease in pulpal temperature. Increasing the water spray resulted in decreasing pulpal temperature by 50% across all samples, while increasing preparation time by approximately 11%. Increasing water spray significantly during cavity preparation is a practice that should be employed often. It is reasonable to expect that in-vitro thermal increases would be minimized in-vivo because the presence of pulp tissue would likely buffer any thermal changes.

Conflicts of interest

Dr. Christopher J. Walinski is a consultant for Biolase, Inc., the manufacturer of the laser device used in this study. No compensation or support of any kind was received from the manufacturer.

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Christopher J. Walinski, DDS; Layne C. Levy, DDS; Antheunis Versluis, PhD; James D. Ritter, DDS; Keng-Liang Ou, MS, PhD