

Marginal quality in enamel and dentin after preparation and finishing with an Er:YAG laser

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ABSTRACT: ***Purpose:*** To find the most appropriate Er:YAG laser parameters for an optimal marginal adaptation of Class V restorations in enamel and dentin. ***Methods:*** Six saucer-shaped mixed Class V cavities were prepared in each of the eight experimental groups with an Erbium:YAG hard laser (Opus Duo) on extracted human molars in near contact mode with a conical 800 μm sapphire tip under continuous water spray by using different pulse energy and pps (pulse per second) parameters. The cavities were restored under the simulation of dentin fluid with Clearfil SE Bond and Clearfil APX PLT composite applied in two layers and light-cured. Marginal adaptation in enamel and dentin was quantified before and after simultaneous thermal (5-50-5°C, 2 minutes each) and mechanical (max. 49N; 1,200,000 cycles) stresses by using the replica technique in a SEM under x200 magnification. ***Results:*** With the exception of dentin margins before loading, significant differences for percentages of “continuous margin” and “enamel fractures” were detected before and after loading ($P < 0.05$, ANOVA, Student’s *t*-test). A pulse energy of 100 mJ both on dentin and enamel was found optimal for finishing and smoothing the preparation margins after cavity preparation with 500 mJ or more. (*Am J Dent* 2006;19:337-342).

CLINICAL SIGNIFICANCE: After efficient cavity preparation with 500 mJ per pulse by using an Er:YAG laser the finishing with 100 mJ/pulse optimized marginal adaptation in mixed Class V cavities restored with a self-etching adhesive system and composite.

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Introduction

Er:YAG laser was given FDA-approval for cavity preparation in 1997,¹ and since then, it has been established as one of the most efficient laser types for hard tissue ablation. Under water spray cooling, this laser type can be used for almost painless cavity preparation without the danger of thermal damage.² To gain maximum efficiency, relatively high energies of over 300 mJ per pulse are usually used for the ablation of hard tissues.³⁻¹⁰ It has been shown that these energies leave the tooth surface disintegrated with micro-cracks and loosely bound particles,^{11,12} potentially compromising adhesion and thus increasing microleakage of restorations.

Different measures have been proposed to remove the damaged surface layer, such as phosphoric acid etching, ultrasound or air-abrasion,¹³⁻¹⁹ to obtain an improved substrate quality for adhesion. However, these methods complicate the clinical procedure, are time consuming, require an additional tool and may be painful to the patient. From the clinical point of view, finishing of the tooth surface by means of the Er:YAG laser after preparation would represent the most suitable solution. Different studies^{20,21} have shown that laser cavity preparation showed similar results to bur-treated cavities or may decrease microleakage; however, comprehensive studies on the exact parameters are lacking, as it is not specified whether laser finishing occurred or not. This *in vitro* evaluation defined the best parameters for cavity preparation and for finishing with an Er:YAG laser, leading to an optimal marginal adaptation of subsequently placed adhesive composite restorations. A rapid preparation of the cavities by the Er:YAG laser was targeted, followed by finishing of enamel and dentin with the same device.

Table 1. Description of the eight experimental groups.

Groups	A	B	C	D	E	F	G	H
<i>Cavity preparation</i>								
Energy (mJ)	500	500	500	500	500	500	500	800
Frequency (Hz)	12	12	12	12	12	12	20	12
<i>Enamel finishing (margins)</i>								
Energy (mJ)	200	250	150	100	-	-	200	-
Frequency (Hz)	15	15	15	20	-	-	20	-
<i>Enamel Bevel (1.5 mm large)</i>								
Energy (mJ)	-	-	-	-	-	200	-	-
Frequency (Hz)	-	-	-	-	-	15	-	-
<i>Dentin finishing (cavity walls and margins)</i>								
Energy (mJ)	100	100	150	100	-	200	100	-
Frequency (Hz)	20	20	15	20	-	20	20	-

Materials and Methods

Twenty-four intact, caries-free human molars with complete root formation were stored immediately after extraction in 0.1% thymol solution. At the beginning of the study they were cleaned and randomly assigned to eight experimental groups (Table 1) with three teeth each. After sealing of their apices, the roots were fixed in the centre of custom made specimen holders using a cold polymerizing resin (Technovit 4071 Resin cold curing^a). A metal tube 1.2 mm in diameter^b was inserted into a cylindrical hole, drilled at the middle third of the root and glued with an adhesive system (OptiBond FL^c). Connected through a flexible silicone hose to a bottle placed vertically 34 cm above the sample, this setup permitted the simulation of dentin fluid with 1:3 PBS-diluted horse serum under a hydrostatic pressure of 25 mm Hg.^{22,23}

Two saucer-shaped Class V cavities were prepared in all teeth, one buccal and one lingual. The preparation occurred under a stereoscopic microscope at x12 magnification with an

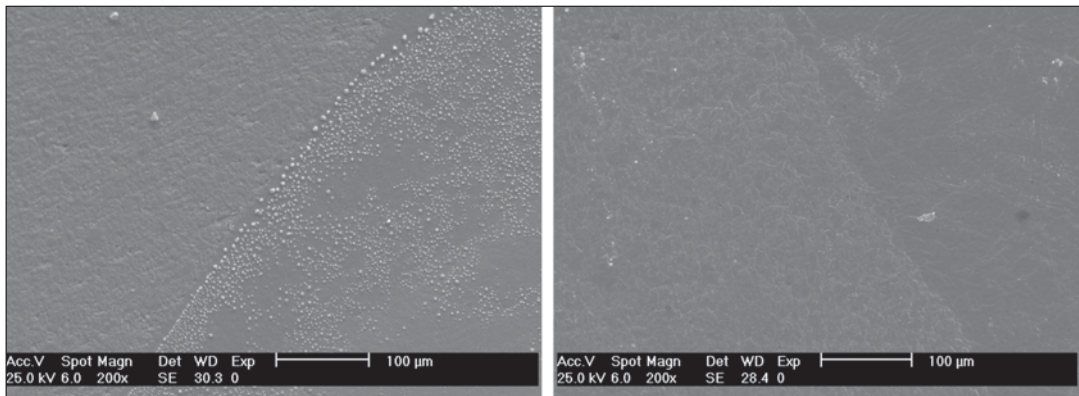


Fig. 1. Group D margins after loading in dentin (left) and in enamel (right): Preparation 500mJ 12 Hz / Finishing E 100 mJ 20 Hz / D 100 mJ 20 Hz (SEM micrographs, original magnifications left & right: x200).

Er:YAG laser (Opus Duo Model SA 5601000^d) in near contact mode under continuous water spray cooling, set at 0.2 bar for both air and water, with a conical 800 µm sapphire tip at a distance of less than 1 mm between the tooth surface and the tip. This preparation method allows for an accurate and precise sight taking and vision, compared to a non contact method. The cavities extended vertically 50% into dentin and 50% into enamel with a diameter of 3.0 mm and a maximum depth of 1.5 mm.²⁴ For each experimental group, specific preparation parameters were applied (Table 1), reflecting most of the parameters used in available studies on Er:YAG-treated cavities. Even though a real bevelling of enamel margins was not perfectly possible with the Er:YAG laser, a group with quasi-bevelled margins was included (Group F). Two groups did not receive any finishing of dentin and enamel margins (Groups E, H) and served as controls. In all the other groups the entire cavity surface and the cavity margins (enamel and dentin) were finished with specific laser parameters.

After laser application, all preparations were checked for imperfections under a stereo microscope at x12 magnification and corrected if necessary.

Following the manufacturer's instructions, bonding procedure with a self-etching adhesive system was performed (Clearfil SE Bond^e). The Primer was applied and brushed into the surface for 20 s, followed by air drying with oil-free compressed air. The Bond was then applied, very gently blown out with a soft air blast, and light cured for 10 seconds (Optilux 501^c).

The cavities were then filled with a fine hybrid composite (Clearfil APX,^e Shade A3) in two layers. The first layer, about 1.5 mm thick, was placed into the cervical half of the cavity, followed by the application of the second incisal layer. Each layer was light-cured for 40 seconds (Optilux 501). After curing, the restorations were finished and polished under x12 stereo microscope magnification using flexible discs (Soft-Lex^f). After brush-cleaning with toothpaste (Elmex^g), an impression with a vinyl polysiloxane impression material (President light body^h) was made.

After at least 7 days of storage at 37°C in the dark, the restored teeth were loaded with repeated thermal and mechanical stresses in a chewing machine, under constant simulation of dentin fluid flow.²⁵ Thermal cycling was carried out in closed chambers where water circulated with water temperatures changing 3'000 times from 5° to 50° and a dwell

Table 2. ANOVA & Student's *t*-test for the percentage of "Continuous margin" for the total marginal length before and after loading (Means with the same letter are not significantly different in Student's *t*-test comparison; $P < 0.05$).

Group	Before loading	Mean Group	After loading	Mean
A	A	96.2 D	A	90.6
G	A B	95.4 G	A B	88.8
C	A B C	94.3 B	A B	88.2
B	A B C	94.2 A	A B	88.1
D	A B C	92.9 C	A B	87.1
H	B C	91.4 F	A B C	84.8
E	C	90.2 H	B C	82.0
F	C	89.6 E	C	78.3

time of 2 minutes each. Simultaneously, the center of the occlusal surfaces of the restored teeth was mechanically stressed with 1,200,000 chewing cycles at a frequency of 1.7 Hz by an antagonistic natural molar cuspid with a maximum load of 49 N.

After loading, replicas were taken again. The replicas before and after loading were poured out with epoxy resin, gold sputtered and subjected to a quantitative marginal analysis in a scanning electron microscope (XL20ⁱ) under x200 magnification.²⁶ The following marginal criteria were evaluated in percent of the marginal length analyzed: continuous margin, marginal gap, marginal enamel fracture, marginal dentin fracture, marginal restoration fracture, overhang and underfilled margin. The results of "continuous margin" and "marginal enamel fractures" were analyzed by ANOVA and Student's *t* post hoc test for the inter-group comparisons and with the paired *t*-test for the comparisons of the results before and after loading of each single group.

Results

Less than 3% of marginal dentin fractures, marginal restoration fractures, overhangs and underfilled margins were identified. This is why these results are not reported in detail.

Significant differences (ANOVA, $P < 0.05$) between groups were detected before loading for the total marginal length and with the exception of Group D, all groups underwent a significant decrease of the percentages of "continuous margin" due to loading, resulting in significant differences in the percentages of "continuous margin" after loading (Table 2). Group D showed the best values of "continuous margin" for the total marginal length after loading (Fig. 1).

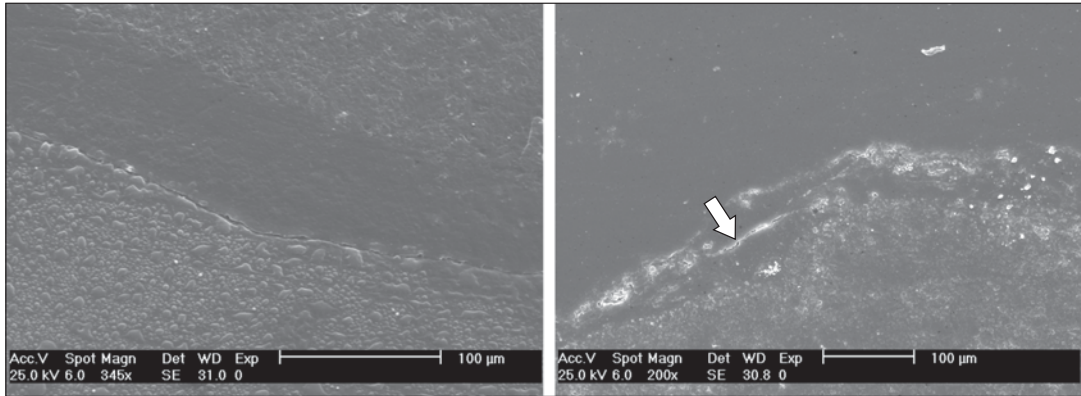


Fig. 2. Left: Group E - Margins after loading in dentin. Prep 500 mJ 12 Hz without finishing of margins, gaps between dentin and composite, open margins. Right: Group H - Margins after loading in enamel. Preparation 800 mJ 12 Hz without finishing of margins, cracks on enamel side and open margins (see arrow) (SEM micrographs, original magnification left: 345x, right: x200).

Table 3. ANOVA and Student's *t*-test for the percentage of "Continuous margin" in dentin before and after loading (Means with the same letter are not significantly different in Student's *t*-test comparison; *P* < 0.05).

Group	Before loading	Mean	Group	After loading	Mean
A	A	100.0	D	A	100.0
F	A	100.0	H	A B	99.5
C	A	100.0	A	A B	99.2
D	A	100.0	C	A B	99.0
E	A	100.0	B	A B C	96.8
H	A	100.0	G	B C	90.5
G	A	99.7	F	C	89.1
B	A	99.6	E	C	88.0

Table 4. ANOVA & Student's *t*-test for the percentage of "Continuous margin" in enamel before and after loading (Means with the same letter are not significantly different in Student's *t*-test comparison; *P* < 0.05).

Group	Before loading	Mean	Group	After loading	Mean
A	A	91.8	G	A	86.9
G	A	91.3	D	A B	83.6
C	A B	89.4	F	A B C	81.1
B	A B C	87.6	B	A B C	78.6
D	A B C	87.4	C	B C	75.0
E	B C	83.4	A	B C	73.6
H	B C	81.9	E	C D	70.9
F	C	81.3	H	D	62.5

By separately evaluating the enamel and dentin portions of the margins (Tables 3, 4), a general trend towards higher percentages of "continuous margin" in dentin could be observed. No significant differences were detected between groups before loading in dentin, but significant differences were present in enamel. Loading significantly decreased the percentage of "continuous margin" in dentin in Groups F and G only. In enamel, groups A, B, C, E and G were significantly affected by loading. After loading, the percentages of "continuous margin" both in enamel and dentin were significantly different.

All groups showed marginal enamel fractures with a significant increase in Groups A, B, C and H due to loading (Table 5). The differences between the groups were significant, both before and after loading. Group H exhibited the most important increase from 12.2% before to 30.0% after loading, meaning that the lower percentage of continuous margins in this group were almost fully caused by enamel fractures (Fig. 2).

Discussion

Bond strength tests are commonly performed to test adhesion and they give controversial results on adhesion to laser-treated enamel and dentin surfaces.^{14,27-30} Bond strength tests have the advantage of being quite rapid, facilitating screening of large number of samples. However, their correlation to cavity sealing appears limited³¹ and they use quasi-static load until fracture. In the clinical situation, failure due to quasi-static catastrophic load is rare and restorations often fail due to fatigue caused by repeated sub-catastrophic stress.³² This is why clinical tests remain the gold standard in

Table 5. ANOVA & Student's *t*-test for the percentage of "Marginal enamel fracture" in enamel before and after loading (Means with the same letter are not significantly different in Student's *t*-test comparison; *P* < 0.05).

Group	Before loading	Mean	Group	After loading	Mean
F	A	14.7	H	A	30.0
E	A B	13.2	C	A B	24.6
H	A B	12.2	A	A B C	19.9
B	A B	11.4	E	A B C D	19.4
D	A B	11.3	B	B C D	18.6
C	A B	10.6	F	B C D	15.3
A	A B	8.2	D	C D	13.3
G	B	6.1	G	D	9.1

evaluating dental materials and techniques. Their major drawback is the fact that they are very time consuming and difficult to standardize. Thermo-mechanical loading *in vitro* is therefore increasingly used for simulation of fatigue stresses occurring in the oral environment,^{24,33-35} within all limitations that may apply, it may help to predict clinical performance of new restorative materials and techniques in an acceptable time under standardized conditions.³⁶ This is why thermo-mechanical loading was used in this investigation, where the marginal adaptation of restorations after cavity preparation with different laser parameters was evaluated.

None of the groups tested showed a 100% perfect marginal adaptation. This is in agreement with studies on sealing of Class V restorations after Er:YAG laser preparation.³⁷⁻⁴¹ However, the percentages of "continuous margin" in this study were generally high for both enamel and dentin margins. This shows that under specific conditions the combination of a self-etching adhesive system and Er:YAG

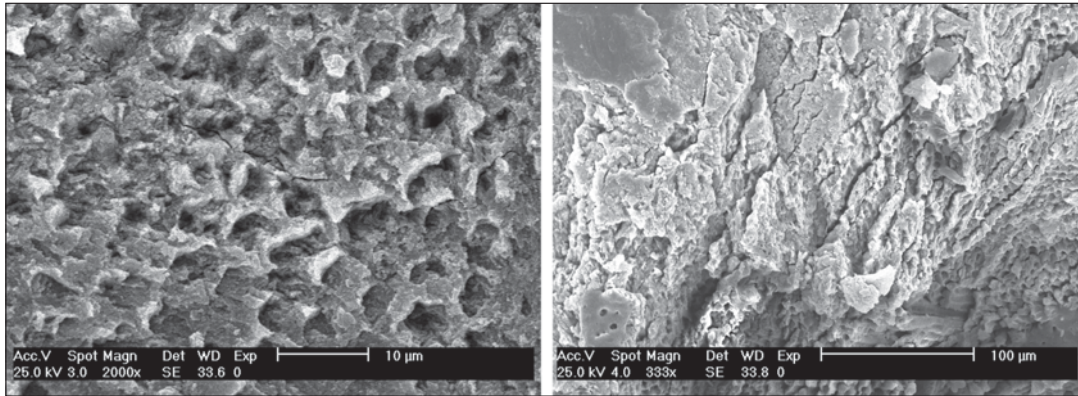


Fig. 3. Enamel structure after preparation 500 mJ and finishing with 100 mJ (left), and after preparation with 800 mJ, without finishing (right) (SEM micrographs, original magnification left: x2000, right: x333).

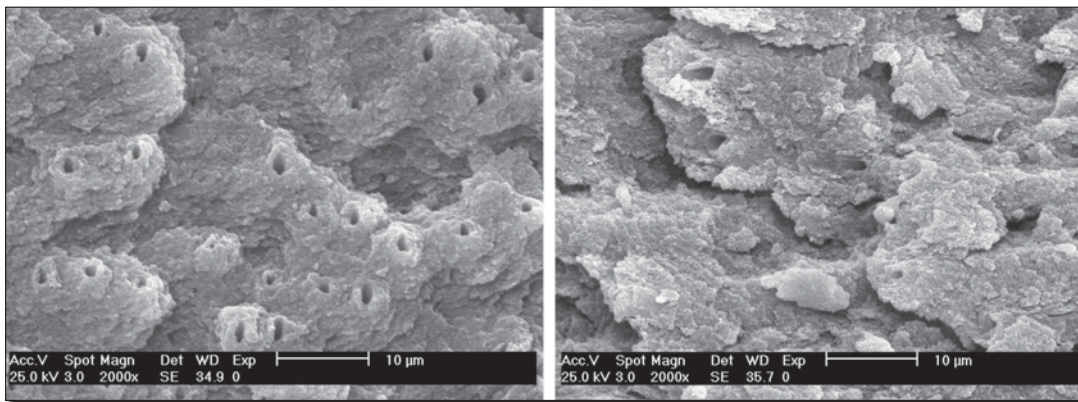


Fig. 4. Dentin structure after preparation with 500 mJ and finishing with 100 mJ (left) and preparation without finishing with 500 mJ (right) (SEM micrographs, original magnifications left & right: x2000).

laser preparation is able to seal cavities in enamel and dentin to a high extent. Especially the combination of efficient cavity preparation with 500 mJ/pulse and 100 mJ/pulse for finishing (Group D) allowed for well sealed and load stable margins both in enamel and dentin.

In all groups, the marginal imperfections in enamel were mainly caused by enamel fractures. This is not surprising because the removal of hard tissue by Er:YAG laser occurs by micro-explosions of water vapor and of hydroxyapatite, initiated by laser light energy pulses.² In the stiff, brittle, prismatic enamel,⁴²⁻⁴⁴ these explosions cause micro-cracks that compromise adhesion.⁴⁵ The severity of these micro-cracks seems to grow with increased energy of the micro-explosions (Fig. 3). This would explain why Group H, prepared with 800 mJ and Group E, prepared with 500 mJ, showed an increased number of enamel fractures. Working on such “destroyed” enamel surface with reduced pulse energy of 100 mJ acted as “surface finishing”, most probably similar to the use of ultrasound or air abrasion.^{13,46} This is similar to mechanical cavity preparation where coarse diamond burs are used for efficient cavity preparation but leave cracks in the tooth surface which may be removed by finishing procedures.⁴⁷ The comparison between Groups A and G suggests that higher repetition rate of the laser pulses may allow for a more complete surface finish. This might be explained by the fact that by applying a slow sweeping motion for working on the enamel surface, as was the case in this investigation, more complete coverage is possible by

higher repetition rates because more laser “shots” hit the surface per given time period. The influence of this parameter should be evaluated in more depth in future studies.

Bevelling enamel did not significantly improve marginal adaptation (Group F vs Group A), which might be related to the fact that the saucer-shaped cavities prepared in this investigation already had a cavo-surface angle of about 45° in their original configuration. Thus, the additional bevelling only increased the restoration’s surface without having a beneficial effect on marginal adaptation.

The SEM inspection of the dentin surface after Er:YAG preparation within a pilot investigation (Fig. 4) confirmed earlier studies reporting absence of smear layer with wide open dentin tubuli and the intertubular dentin selectively more ablated than the peritubular dentin.^{48,49} The simulated dentin fluid was thus able to penetrate the cavity surface, but apparently without interfering with dentin adhesion of the self-etching adhesive system, as in most of the groups very good marginal adaptation in dentin was obtained even after loading. Dentin represents a more hydrated, softer and more elastic tissue if compared to enamel. It was removed very efficiently by the Er:YAG laser microexplosions. When applying higher pulse energies, the surface became rough and a contamination with ripped off dentin parts of different diameters was obvious (Fig. 4). It is likely that such loose material interfered with adhesion when no additional finishing of dentin occurred, thus explaining the somewhat lower quality of marginal adaptation in Group E. Group H did not

receive dentin finishing as well, but as cavity sealing is also related to composite stress development,⁵⁰ the poor marginal adaptation in enamel probably reduced composite shrinkage stress at the dentin adhesive interface to a certain extent by making an additional free surface available and consequently reducing the C-factor.⁵¹

With the Duo Er:YAG laser, a vast choice of sapphire near contact tips and energy settings are possible. The choice of 800 µm sapphire tips and 500 mJ energy per pulse seems to provide an excellent cavity preparation according to authors' clinical experience, as under these conditions efficient preparation is possible without pain sensation in most cases even in deep cavities. The subsequent finishing with 100 mJ/pulse at a frequency of 20 Hz allows in combination with a self-etching adhesive system for good marginal adaptation in enamel and dentin. The quality of this adaptation seems to be even slightly better than the one after preparation with the help of conventional rotary instruments with the same adhesive system and under the same experimental conditions as used in this study.⁵² It is likely that these parameters are not applicable in an universal way to other Er:YAG lasers as every device uses among others different pulse lengths, light conducting systems, water spray technology and optics.⁵³ Further studies are needed to improve the understanding of different Er:YAG laser parameters, to extend the research to different cavity classes and finally to confirm the findings within the framework of a clinical study.

- a. Heraeus Kulzer GmbH, Wehrheim, Germany.
- b. Terumo Europe N.V., Leuven, Belgium.
- c. Kerr Sybron, Danbury, CT, USA.
- d. Lumenis Company, Yokneam, Israel.
- e. Kuraray, Kurashiki, Japan.
- f. 3M ESPE Dental Products Co., St. Paul, MN, USA.
- g. GABA, Therwil, Switzerland.
- h. Coltène AG, Altstätten, Switzerland.
- i. Philips, Eindhoven, The Netherlands.

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