# Influence of Different Er:YAG Laser Energies and Frequencies on the Surface Morphology of Dentin and Enamel

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**Purpose:** This study evaluated the micromorphology of Er:YAG-lased enamel and dentin surfaces at different energy outputs (EO) and repetition rates (RPR), and determined the depth of tooth substance ablation with these different parameters.

**Materials and Methods:** A total of 35 central incisors and 35 molars were collected for determination of the ablation depth. The laser parameters were: EO: 100 mJ, 150 mJ, 200 mJ, 250 mJ, 300 mJ, 350 mJ, and 400 mJ; RPR: 5 Hz and 10 Hz, 5 and 10 MVS over enamel (incisor) and dentin (molar) surfaces. This resulted in 56 experimental groups, each with 5 surfaces to be investigated. Depths of the tracks were measured after perpendicular sectioning. Micromorphological effects were evaluated on enamel surfaces of 28 central incisors and on dentin surfaces of 28 molars by SEM (2 x 7 groups of 4 teeth, separate groups per EO and per substrate).

**Results:** Three comparisons were made: (1) enamel vs dentin with identical EO, RPR and number of MVS; (2) difference in RPR with identical EO within the enamel and within the dentin groups; (3) difference in number of MVS with identical RPR and EO within the enamel and dentin groups. Statistically significant differences were found for all groups in (2) and (3) ($p < 0.01$), and for comparisons of enamel vs dentin (a) at 10 Hz and 10 MVS, (b) at 10 Hz and 5 MVS for 100 mJ, 300 mJ, 350 mJ, 400 mJ, (c) at 5 Hz and 5 MVS at 100 mJ, 150 mJ, 200 mJ, 250 mJ, 300 mJ, 350 mJ. SEM evaluation showed the typical characteristics of Er:YAG-lased enamel and dentin surfaces. Vitrification was seen at 300 mJ for dentin and 200 mJ for enamel.

**Conclusion:** Er:YAG cavity preparation without vitrification is recommended at energy outputs of 200 mJ for enamel and 300 mJ for dentin. At these energies, a 10 Hz RPR is more effective, and will not result in earlier and/or more signs of vitrification.

**Keywords:** ablation, dentin, enamel, energy output, Er:YAG laser, morphology, SEM.

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With the introduction of the Er:YAG laser, in contrast to other available lasers, it became possible to remove dentin and enamel more effectively and efficiently.[1-3] Thermal damage was reduced, especially in conjunction with water spray.[4,5] Moreover, cavity pretreatment with Er:YAG laser (laser etching) was proposed by some as an alternative to acid etching of enamel and dentin: laser irradiation of enamel and dentin has been reported to yield a fractured and uneven surface and open tubules, both apparently ideal for adhesion.[6] Roughened dentin surfaces with open dentinal tubules without smear layer production were reported by others.[7-12] Next to cavity preparation, the ablative effect of Er:YAG laser light in healthy enamel and dentin could also be used for modifying dental surfaces and eliminating the need for acid etching. Some researchers have explored the use of lasers to modify surfaces of teeth intentionally and to improve bonding of restorations.[13-18]

In a review of the literature on Er:YAG lasers and adhesion to tooth structure, it also became clear that different terminologies for the effect of a laser on tooth substance were used (eg, laser ablation, laser cavity preparation, laser etching, laser conditioning, laser modifying) and that confusion existed on what was exactly meant by laser etching, laser conditioning, and laser modifying.[18] Furthermore, it was not always clear from these studies and those evaluating tensile bond strength and microleakage which laser parameters were used, and the information on parameters employed was regularly incomplete, ie, on the amount of energy per pulse, the repetition rate, the pulse duration, distance from the laser to the experimental surfaces, the time of irradiation (exposure of the surface to the laser), contact mode or noncontact mode. In addition, there was also a large heterogeneity in the amounts of energy used as well as in the repetition rates. As a consequence, comparison of the findings of these different investigations is not possible. The latter also explains the contradictions in results. Therefore, the necessity of golden standards has been emphasized.[18]

However, irrespective of this sometimes confusing information, there is nowadays the opinion (scientifically based) that the decision to use the Er:YAG laser as an alternative to conventional techniques of acid etching is questionable, and that given the available adhesive systems requiring acid conditioning, it would not be advisable to skip this operative step.[19]

A common disadvantage of excessive laser energy output is the phenomenon of vitrification. This structural alteration, which modifies the qualities of dentin and enamel surfaces, can prevent the restorative materials from successfully bonding to tooth structure. Moreover, hard tissue cohesive microfractures can be found in the areas below the irradiation target.[20]

The purpose of this study was then to evaluate the micromorphology of Er:YAG-lased enamel and dentin surfaces (ie, cavity preparation) at different energy outputs and repetition rates, and also to evaluate the amount of tooth substance ablation with these different parameters. In order to be able to compare the effects of the laser irradiation, ablation was performed in a standardized way by means of an apparatus which allowed the use of the laser beam over a previously determined distance between tooth and head of the handpiece.

## MATERIALS AND METHODS

### Tooth Selection

One hundred twenty-six teeth (63 noncarious central incisors and 63 noncarious molars) were scaled with a scalpel and/or scaling instruments to remove residual tissues and calculus, polished with Zircate Prophy Paste (Denstply/Caulk, Milford, DE, USA), and rinsed thoroughly with tap water. After being examined macroscopically for defects in enamel and dentin, these teeth were stored in distilled water at 4°C for up to one month.

### Sample Preparation

For the enamel study, the buccal surfaces of 63 central incisors were flattened with a 1000-grit paper. Dentin specimens were prepared by horizontal sectioning of 63 molars at the middle third of the molars' crowns. The surfaces were finished with a 1000-grit paper.

### Er:YAG Laser Ablation

A short-pulsed Er:YAG laser system (Fidelis Plus, High Tech Dental, Herzele, Belgium) emitting a wavelength of 2.940 µm was used. The laser beam was delivered by a series of mirrors in an articulated arm. The noncontact delivery tip (source: RO2-F-125) was used under abundant water spray coolant. The laser treatment was carried out by moving the handpiece continuously and perpendicularly above the marked tooth surface at a distance of 7 mm (in focus) in order to obtain a pattern of rows and columns that overlapped. The laser handpiece was fixed in a custom-designed apparatus (Figs 1a and 1b) which allowed for a standardized movement of the laser beam with fixed distance of the head of the handpiece from the tooth surface at a previously determined speed (4 mm/s). The lengths of the rows were 6 mm.

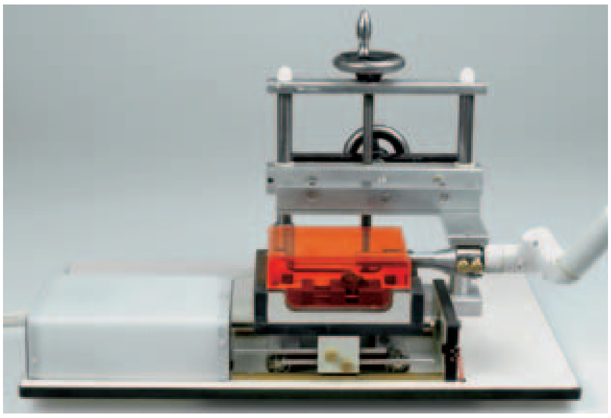

**Fig 1a** Apparatus used in this study for standardized laser preparation with a power driven x-y moving table.

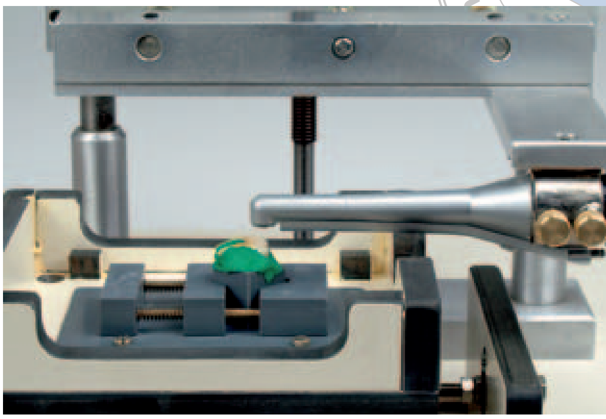

**Fig 1b** Preparation unit showing the fixation of the tooth and the laser handpiece.

**Study of the Er:YAG Ablation Rate**

Before irradiation, 70 teeth (35 incisors (I) for the enamel study, and 35 molars (M) for the dentin study) were randomly assigned into 56 groups each consisting of 5 teeth. Each tooth surface was divided in halves, a left-hand side (LHS) and a right-hand side (RHS), which resulted in 28 enamel groups (2 x 14 groups of 5 tooth halves) and in 28 dentin groups (2 x 14 groups of 5 tooth halves) as follows:

- Groups 1 to 7: irradiation of 5 enamel surfaces (I-LHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 10 Hz and 10 movements of the laser beam;
- Groups 8 to 14: irradiation of 5 enamel surfaces (I-LHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 10 Hz and 5 movements of the laser beam;
- Groups 15 to 21: irradiation of 5 enamel surfaces (I-RHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 5 Hz and 10 movements of the laser beam;
- Groups 22 to 28: irradiation of 5 enamel surfaces (I-RHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 5 Hz and 5 movements of the laser beam;
- Groups 29 to 35: irradiation of 5 dentin surfaces (M-LHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 10 Hz and 10 movements of the laser beam;
- Groups 36 to 42: irradiation of 5 dentin surfaces (M-LHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 10 Hz and 5 movements of the laser beam;
- Groups 43 to 49: irradiation of 5 dentin surfaces (M-RHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 5 Hz and 10 movements of the laser beam;
- Groups 50 to 56: irradiation of 5 dentin surfaces (M-RHS) with a different energy level per group of 100, 150, 200, 250, 300, 350 or 400 mJ/pulse at 5 Hz and 5 movements of the laser beam.

The pulse duration was 100 µs (very short pulse). The result of this classification means that each entire tooth surface represents a part of a group with a specific energy output. The left-hand half of the surface receives in each case a laser beam with a pulse rate of 10 Hz; the first track is the result of 10 movements of the laser beam and the second track is the result of 5 movements of the laser beam. The right-hand half of the surface represents the pulse rate of 5 Hz; one track is the result of 10 movements and the second track as a result of 5 movements with the handpiece.

To evaluate the depth of each track, the samples were cross sectioned twice, perpendicular to the direction of the tracks. The depths were measured using a stereomicroscope with a reticle scale (0.1 mm), and an average of the two depths per track was calculated.

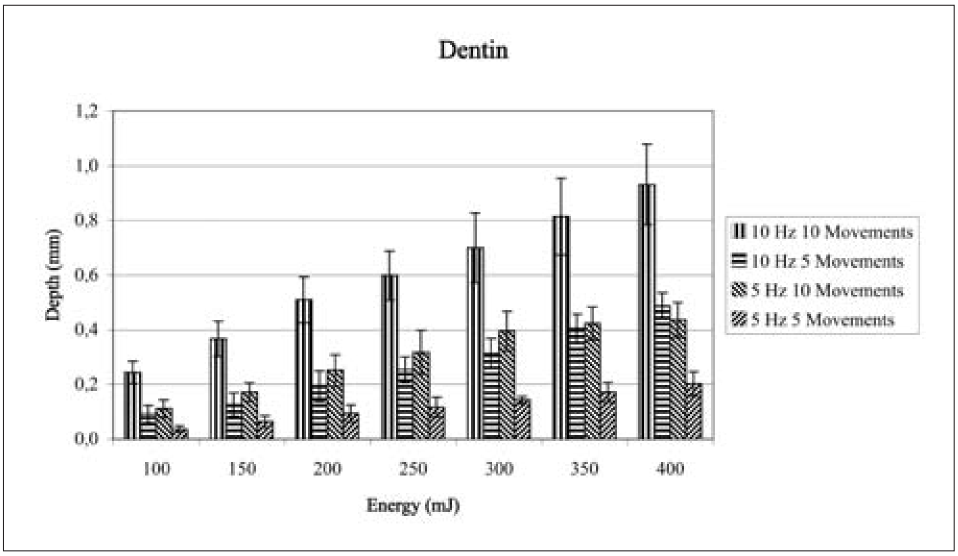


**Fig 2** Mean preparation depths (and standard deviation) in dentin as a function of energy (mJ), repetition rate and number of movements over the enamel surface.

### SEM Analysis of the Surface Morphology of Er:YAG Irradiated Dentin and Enamel Samples

The enamel of the remaining 28 central incisors and the dentin of 28 remaining molars were irradiated following the previously described protocol in a standardized way using a power driven x-y moving table (Figs 1a and 1b). These teeth were divided into 7 groups of 4 teeth. Each group of 4 teeth received a different energy (100, 150, 200, 250, 300, 350 and 400 mJ/pulse). Two different pulse frequencies (5 Hz and 10 Hz) were also evaluated (5 Hz for the left-hand side and 10 Hz for the right-hand side of each surface). The pulse duration was 100 µs. A distinction was also made between 5 and 10 movements over the experimental surfaces. This resulted in 4 tracks per tooth, as previously described. Morphological changes in enamel and dentin were evaluated by scanning electron microscopy (SEM). All teeth were subjected to the SEM procedure as described by Delmé et al.[11,22] Photographs were taken at 300X, 3000X, and 8000X magnification. Each laser-irradiated enamel surface was checked to see whether ablation was restricted to enamel before SEM analysis.

### Statistical Analysis

All data were gathered using SPSS 11.0.1 for Windows statistical package (SPSS, Chicago, IL, USA). The data were submitted to statistical analysis using the Kruskal-Wallis and Mann-Whitney U-test.

## RESULTS

### Determination of the Preparation Depths

Figures 2 and 3 show the preparation depths in dentin (Fig 2) and enamel (Fig 3) as a result of the energy output at 5 and 10 Hz, and 5 and 10 movements over the tooth surface.

There were statistically significant differences ($p < 0.05$) between groups 1 to 7 and groups 29 to 35; groups 8, 12 to 14 and groups 36, 40 to 42; groups 15 to 20 and groups 43 to 48. There were thus statistically significant differences at 10 movements between enamel and dentin ablation depths at 10 Hz for all energies, and at 5 Hz except for the 400 mJ energy per pulse. At 5 Hz and 5 movements there were no statistical differences in the depth of laser irradiation between dentin and enamel.

When comparing groups 1 to 7 to groups 8 to 14, groups 29 to 35 to groups 36 to 42, groups 15 to 21 to groups 22 to 28, and groups 43 to 49 to groups 50 to 56, statistically significant differences ($p < 0.01$) were found for each comparison within the respective energy group. Statistically significant differences in the depth of laser irradiation were thus found for each en-

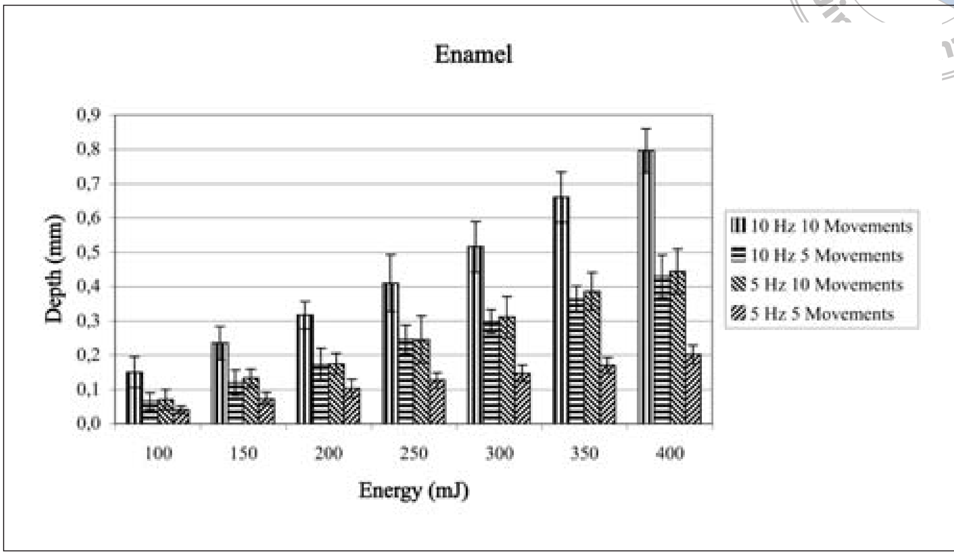


**Fig 3** Mean preparation depths (and standard deviation) in enamel as a function of energy (mJ), repetition rate and number of movements over the enamel surface.

ergy when enamel and dentin where irradiated twice as much (10 movements vs 5 movements).

When comparing groups 1 to 7 to groups 15 to 21, groups 8 to 14 to groups 22 to 28, groups 29 to 35 to groups 43 to 49, and groups 36 to 42 to groups 50 to 56, statistically significant differences ($p < 0.01$) were found for each comparison within the respective energy group. Statistically significant differences in the depth of laser irradiation were thus found for the different energies when the pulse rate of 5 Hz was doubled.

### SEM Surface Analysis

Representative images of the different morphological aspects as a result of laser irradiation using different energy output levels are shown in Fig 4 for enamel and in Fig 5 for dentin. Laser treatment of the enamel surfaces revealed an irregular surface with the typical keyhole shaped enamel prisms and rods. In enamel surfaces, the first signs of vitrification or glazing were found at an energy output of 200 mJ. More pronounced and more areas of glazing were seen starting at an energy output of 300 mJ. Laser ablation of dentin resulted in irregular surfaces and, generally at the lower energy outputs, surfaces without smear layer, exposing the orifices of the dentinal tubules. Intertubular dentin was selectively ablated more than the peritubular dentin, yielding a cuff-like appearance. On dentin surfaces, the first signs of vitrification were seen at an energy output of 300 mJ. At higher energy output, smear plugs could be observed as well as regular signs of vitrification. Vitrification in both enamel and dentin was seen at the described energy outputs irrespective of the repetition rates.

## DISCUSSION

Keller and Hibst reported the first SEM observations of the Er:YAG laser effects on dentin and enamel.[2] The micromorphological findings were similar to those of the present study. Among different authors, there is agreement that Er:YAG laser treatment preserved anatomical features of enamel and dentin substrates.[5,9,11,12,18,22-24] As a fundamental advantage, the absence of smear layer after laser treatment was put forward, where the opposite occurs on bur-treated teeth. The absence of smear layer, the irregular dentin surfaces, and the microretentive surface of Er:YAG-lased enamel result in surfaces upon which retentive adhesion with present day adhesive materials should be possible. When acid etching was not applied prior to the bonding resins, bond strength appeared to be acceptable in different earlier studies.[18]

To date, however, most studies advise acid etching in any case prior to adhesive bonding. Pretreatment with acids always resulted in higher bond strength values than when resin composite was bonded to Er:YAG-

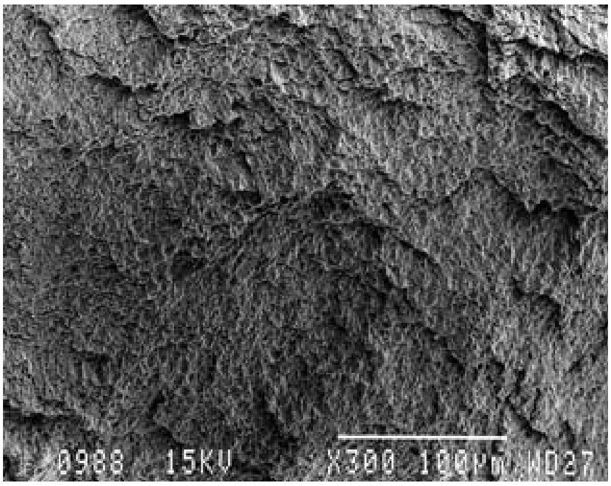


**Fig 4a** Representative enamel surface of the 100 mJ/pulse samples.

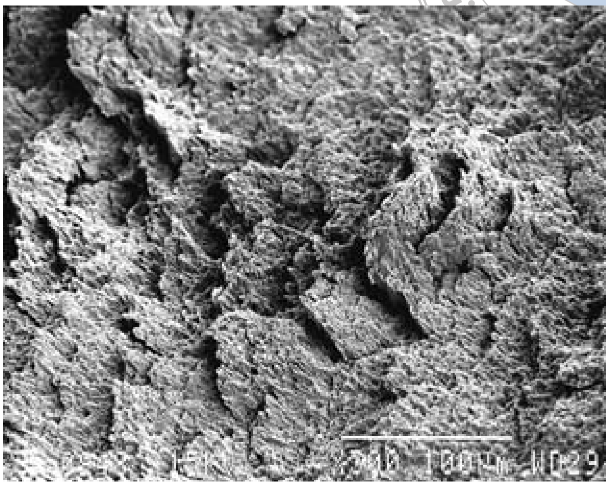

**Fig 4b** Representative enamel surface of the 150 mJ/pulse samples.

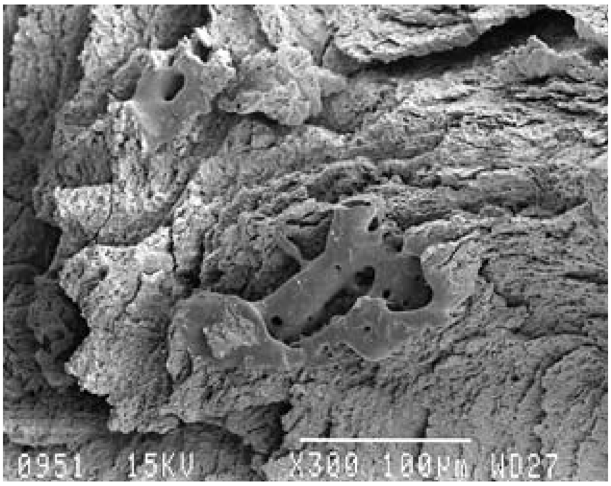


**Fig 4c** Representative enamel surface of the 200 mJ/pulse samples. Next to the irregular and ablated surface two areas of vitrification can be seen.

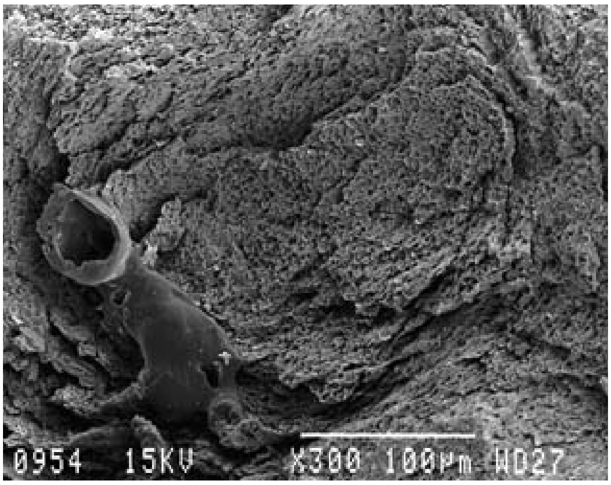


**Fig 4d** Representative enamel surface of the 250 mJ/pulse samples. Next to the irregular and ablated surface an area of vitrification can be seen.

**Fig 4e** Representative enamel surface of the 300 mJ/pulse samples. Next to the irregular and ablated surface an area of vitrification can be seen.

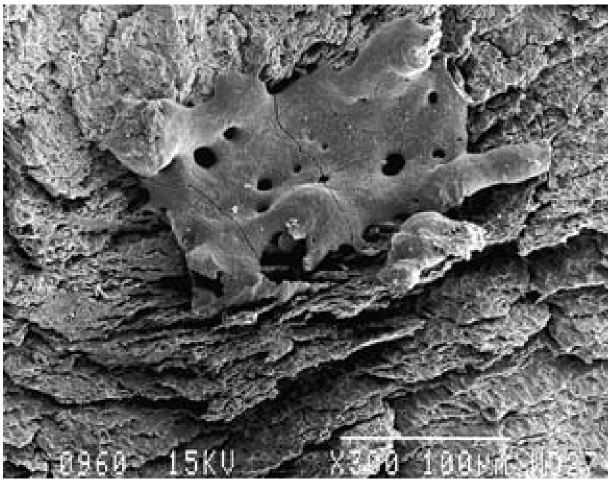

**Fig 4f** Enamel surface representative of 350-mJ/pulse samples with a cleaved surface. Next to the irregular and ablated surface an area of vitrification can be seen.

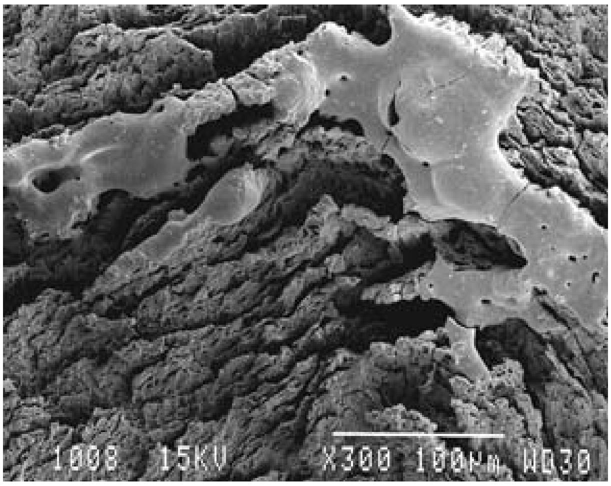


**Fig 4g** Representative enamel sample with cleaved surface of the 400 mJ/pulse samples. Next to the irregular and ablated surface an area of vitrification can be seen.

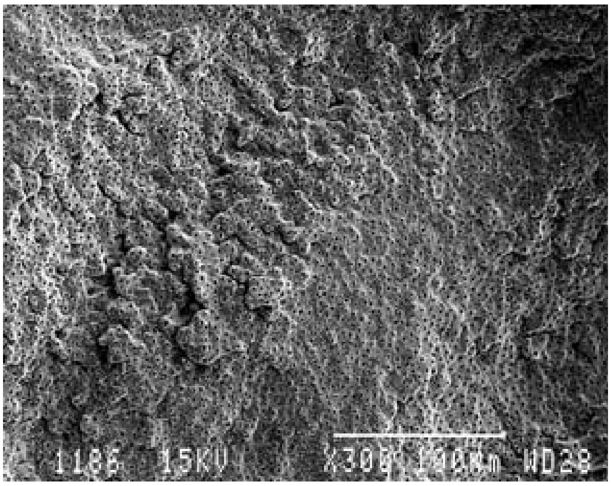


**Fig 5a** Representative dentin surface of the 100 mJ/pulse samples. The ablated dentin surface shows open tubules but remains rather flat.

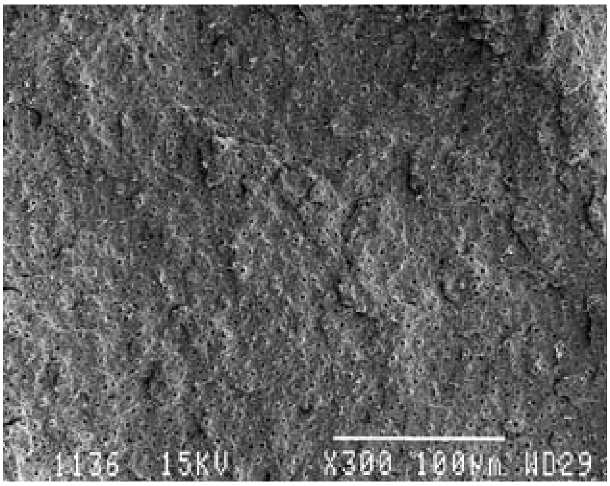


**Fig 5b** Representative dentin surface of the 150 mJ/pulse samples. The ablated dentin surface shows open tubules but remains rather flat.

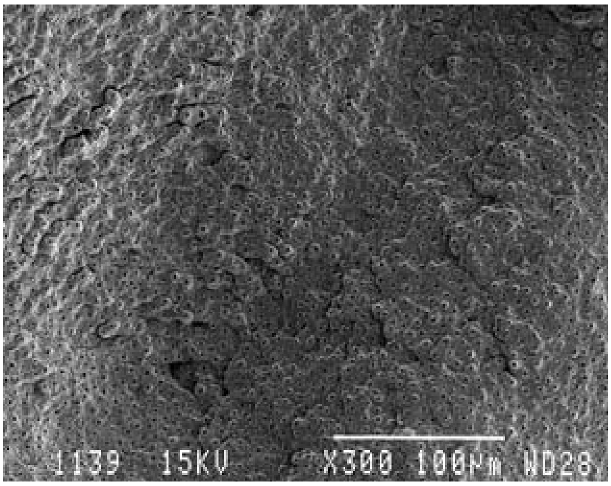


**Fig 5c** Representative dentin surface of the 200 mJ/pulse samples. The ablated surface shows more irregularities at this energy output.

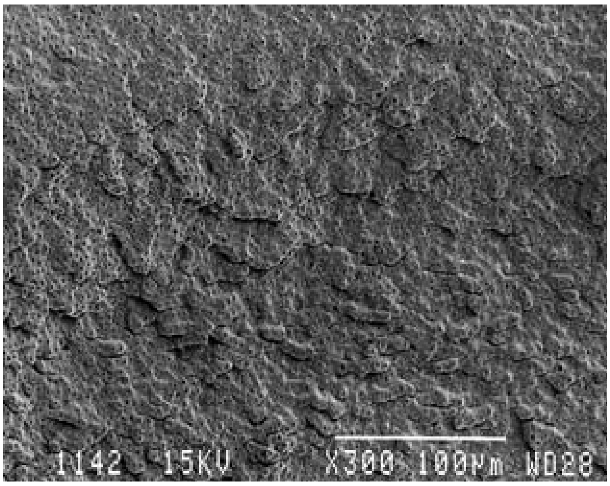


**Fig 5d** Representative dentin surface of the 250 mJ/pulse samples.

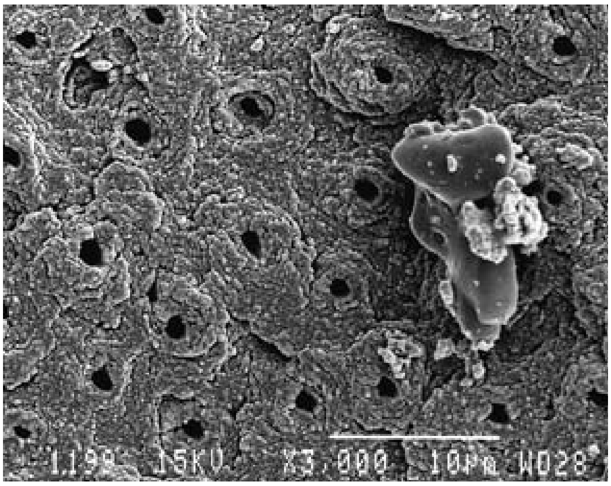


**Fig 5e** Representative dentin surface of the 300 mJ/pulse samples. First signs of glazing of vitrification can be seen.

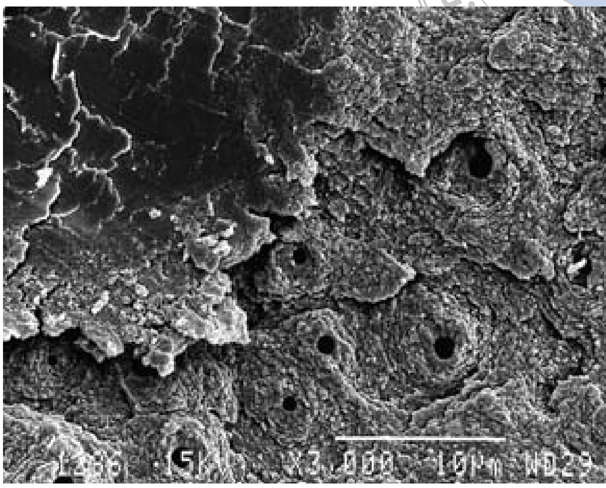


**Fig 5f** Representative dentin surface of the 350 mJ/pulse samples. The present image showns remnants of smear layer and vitrification.

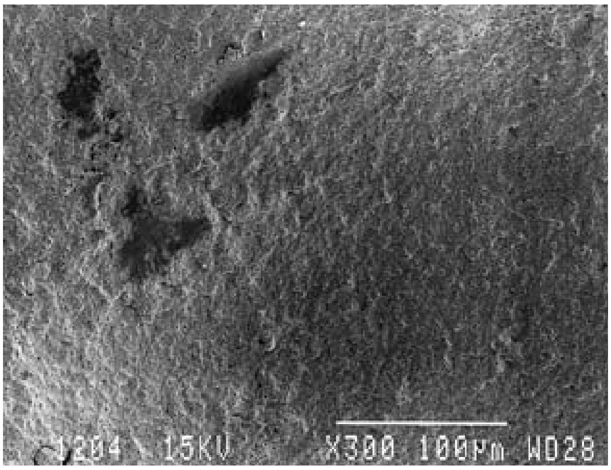


**Fig 5g** Representative dentin surface of the 400 mJ/pulse samples. Areas of vitrification can be observed.

lased tooth surfaces without adhesive pretreatment procedures. An explanation for the lower bond strengths was found in the thermal effect of Er:YAG irradiation on tooth surfaces. In this respect, it has been stated that Er:YAG laser ablates dental hard tissues more effectively with less thermal damage to the tooth and surrounding tissues than other hard lasers.[22,25,26] Thermal side-effects have been an important subject studied in the past, because such side-effects include carbonization, melting and cracking of dental hard tissues as well as inflammation and pulp necrosis.[27,28]

Due to the number of studies showing that adhesion to Er:YAG-lased enamel and dentin surfaces is compromised as compared to the bur-prepared surfaces, more fundamental research of the lased surfaces was undertaken. A common finding in present-day studies dealing with the tooth/adhesive material interface was the recommendation of using lower energy outputs for cavity preparation than in the past. In order to obtain a more retentive surface without cohesive microfractures, it would be advisable to apply an energy output inferior to or around 200 mJ for dentin and enamel using the Er:YAG laser.[18,22] The findings of this study were in line with these statements. It was also interesting to find out that there were significant differences in preparation depths when making 10 tracks as compared to 5 tracks at the same energy level (mJ) and the same repetition rate, but without a higher risk of vitrification. This also confirms findings of other authors that energy output per pulse is important.[18,29]

Although there were no striking differences in the laser-treated dentin pattern within the groups with the same irradiation mode, there seemed to be a tendency towards more extensive ablation of the intertubular dentin when using the higher energies of this study up to 300 mJ. This increase in energy output led to a more irregular surface with microholes. These findings were in agreement with those of Carvalho et al.[30] With higher energy output, more risk of smear layer and/or vitrification was observed. A rough surface can possibly contribute to the adhesion of resin to dentin, but the presence of fragments and microfractures was reported to contribute to an adverse effect on the adhesion of resin, decreasing the bonding quality.[19]

## CONCLUSION

Under the conditions of the present study, it was seen that vitrification occurred on dentin surfaces at an energy output of 300 mJ and on enamel surfaces at an energy output of 200 mJ. These surface alterations were observed irrespective of the pulse frequencies (5 Hz and 10 Hz), and irrespective of the predefined numbers of laser tracks over the lased surfaces (5 vs 10 movements). The recommendations of cavity preparation with the Er:YAG laser at lower energy outputs (200 mJ for enamel and 300 mJ for dentin) are substantiated.

Under the conditions of the present study, these energy outputs at a higher repetition rate (10 Hz vs 5 Hz) were more effective for statistically significant tooth substance removal. Furthermore, it was shown that this higher repetition rate did not result in earlier and/or more signs of vitrification.

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