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Laser Conditioning of Enamel with the Erbium YAG and the CO2 Laser. Bond Strength and Surface Structure

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Abstract

Introduction: Acid etching is the standard procedure for enamel conditioning. However it leaves a demineralized surface, which is prone to caries. This is a major disadvantage especially in combination with a fixed orthodontic appliance and reduced oral hygiene. Therefore it was the aim of this study to evaluate the effect of an Erbium:YAG laser as well as a CO_2 laser on bond strength and enamel surface structure.

Material and methods: 90 freshly extracted bovine incisors were used as substitutes for human enamel. One group of 30 samples was bonded following conventional acid conditioning and served as the control group. The two other groups were conditioned with an Erbium:YAG laser or a CO_2 laser. All samples were tested for shear forces with a universal testing machine (Instron 4444). PMMA (polymethylmethacrylate) cylinders were used as shear bodies. SEM (scanning electron microscope) images were taken to compare the effect of the conditioning methods on the enamel surface.

Results: There was a significant difference between the shear forces attained with conventional etching (16.5 MPa), the Erbium:YAG laser (6.2 MPa) andthe CO_2 laser (3.3 MPa). However due to large standard deviations in the groups conditioned with laser, no significant difference was observed between the Erbium:YAG laser and the CO_2 laser. The SEM images revealed a micro-retentive relief for both lasers, but the surface treated with the Erbium:YAG laser showed cracks in the enamel.

Conclusion: Conventional acid etching showed a superior bond strength in comparison with both the laser conditioning methods. Of concern were the fissures observed in the enamel surface treated with the Erbium:YAG laser.

Keywords: Self-ligating brackets; Torque

Introduction

Since the introduction of phosphoric acid etching for enamel conditioning in 1955 [1], the method has changed substantially and new techniques have been introduced. Nowadays a 37% phosphoric acid conditioning for 15 to 60 s is the standard procedure and no significant reduction of bond strength has been observed [1,2]. It results however in an unintentional demineralization of the enamel surface [3], an irreversible loss of the mineralized surface [4,5] of approximately 10µm and a possible irritation of the adjacent soft tissues. Therefore other etchants such as polyacrylic and maleic acids [6,7] or self etching primers have been proposed as alternatives.

Alternative methods of enamel conditioning include air abrasion and laserapplication. Air abrasion has been successfully applied to bands [8], brackets [9], and lingual retainers [10]. However results for enamel conditioning seem to be controversial [11,13].

The use of the laser in dentistry was first described in 1964 [14]. The intention was to alter the enamel surface and increase resistance against caries [15-17]. The therapy was based on the observation that a laser conditioned enamel surface has a modified calcium to phosphorus and carbonate to phosphorus ratio [18,19]. Thepercentage of water and organic substances is reduced [15] which leads to a less acid-soluble and therefore more caries resistant enamel surface [18,19]. Also laser conditioning might promote the formation of microspaces which in turn remineralize by trapping free ions and increase caries resistance [15].

Different surface structures after laser conditioning have been described after conditioning with different lasers and with different energy settings. For the Nd:YAG laser [20] a honeycomb structure has been described at 60mJ and 15 Hz. Apart from the honeycomb structure, granules which were probably blasted out by the laser impact have been observed as well as melted and recrystalized parts of the enamel surface. With lower energy levels these morphological changes have been rarely observed but have been found to be more frequent when energy levels are increased [20]. The CO_2 laser produced more of an indented surface at 5W and 10ms pulse duration [20]. Increased energy levels lead to combustion spots, melted enamel and cracks [20,21] and reducing the level of energy had almost no effect on the enamel surface [20]. The Erbium:YAG laser showed an irregularly roughened pattern with microcracks on the surface at 300mJ/pulse, 10pps and 10 s of irradiation [22]. For the ER,Cr:YSGGlaser at 2W (5.6 J/cm^2) a pattern similar to the type III acid etching pattern [23] was described. In conclusion, surface roughness after laser irradiation is reported to be similar [24] or lower [21] than with conventional etching.

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Bond strength with different laser treatments is not consistent either. Some studies have indicated significantly increased bond strengths with conventional etching [25,26] whereas others found comparable [27,28] or even enhanced bonding [29,30] for laser conditioning.

It was the aim of this study to evaluate the effect of an Erbium:YAG laser as well as a CO_2 laser on bond strength and enamel surface structure with the hypothesis that both treatments would lead to equivalent bond strengths.

Materials and Methods

Three enamel conditioning methods (37% phosphoric acid, CO_2 laser, Erbium:YAG laser) were evaluated for their shear bond forces. 30 freshly extracted bovine incisors were used for each group. All teeth were pumiced and stored in a 25°C Ringer solution.Instead of using brackets, transparent polymer cylinders with surface of 28.3mm^2 were used as shear bodies (Karl HaugKunststoffverarbeitung, Basel, Switzerland). The bonding surface of the polymethacrylate cylinders was conditioned using a Rocatec treatment with 30 µm silica-modified alumina particles (Rocatec, 3M Espe, St Paul, Minnesota, USA). The surface was cleaned with a blast of air.Thereafter the base of the PMMA cylinders was silanized with Monobond-S (IvoclarVivadent, Schaan, Lichtenstein). The PMMA cylinders were bonded to the teeth with Transbond XT primer and Transbond XT adhesive (3M Unitek, Monrovia, USA). Superfluous adhesive was carefully removed and the samples were light cured with a Bluephase C8 curing light (IvoclarVivadent, Schaan, Lichtenstein). Finally all teeth were embedded in a polymer block (TechnoVit 4071 Kaltpolymerisat; Heraeus-Kulzer, Germany) and the frontal border of the polymer blocks was trimmed parallel to the labial surface of the bovine incisors. The teeth were randomly allocated to the different roughening procedures.

The enamel for the conventional conditioning group was etched with a 37% phosphoric acid for 30 s (3M Unitek, Monrovia, USA), rinsed and dried with a blast of air.

For the CO_2 laser conditioning a NovaPulse LX-20SP (Luxar Corporation, Washington, USA) was used with a 0.8mm ceramic tip, a super-pulse (0.1-0.8ms), 5 W and a distance of 10mm to the enamel surface. A surface of 8mm^2 was irradiated for 20 s.

The Erbium:Yag Laser (Key-Laser 3, KaVo, Biberach, Switzerland) was used with the 2060 laser handpiece (KaVo, Biberach, Switzerland). The irradiation was applied to a surface of 8mm^2 from a distance of 10 mm and a duration of 20 s. Pulse energy was set at 300mJ with a frequency of 6 Hz.

For shear testing the probes were inserted into a shear force jig and measured with an Instron 4444 (InstronCorp., Wilmington, Delaware, USA) with a crosshead speed of 0.1mm/s and distance of 1.5 mm of the labial surface of the tooth to the ram of the jig. The teeth were carefully oriented in the jig in order to maintain distance and parallel orientation of the labial surface of the tooth and the shear die. The data was stored on PC using the software Origin 6.1 (Origin Lab, California, USA).

The ARI (adhesive remnant index) score [31] was evaluated under 10x optical magnification.

Descriptive statistics with mean, median, and standard deviation (SD) were calculated using GraphPadInstat (GraphPad Software Inc., San Diego, USA).Statistically the data sets were tested for normality and evaluated with a two factorial ANOVA using a Tuckeypost test at a level of significance of $p \leq 0.05$.

In addition SEM at 1000x magnification were taken from three typical samples conditioned with acid etchant and laser and evaluated visually.

Results

Mean, standard deviation (SD), statistical significance and ARI scores are given in Table 1. There was a highly significant difference in shear forces between the conventionally etched (16.5 MPa, SD 9.9) and the laser conditioned groups (3.3 MPa, SD 2.1 for CO_2, 6.2 MPaSD 2 for Erbium:YAG). However, the difference between the two laser groups was not statistically significant due to large standard deviations.

ARI scores correlated well with the shear forces reached with a high score of 2.67 for the conventional etching and lower scores for the CO_2 laser (2.3) and Erbium:YAG laser (1.69). The surface of the enamel conditioned with conventional acid etching showed a regular etching patternin line with previous documentation [23] (Figure 1). The enamel after CO_2 laser conditioning showed a uniform pattern with small indentations (Figure 2) However carbonized residues on the enamel adjacent to the conditioned enamel could be seen macroscopically. The surface of the Erbium:YAG laser treated samples showed a honeycomb-like microstructure, resembling the type three etching pattern [23] with a regular pattern of roughness and spaces after dissolution of the hydroxyapatite around relatively unaffected prism cores. In addition a network of micro-fissures was observed in all Erbium:YAG samples (Figure 3).

Discussion

According to ISO 11405/TS bovine incisors can be used as a substitute for human enamel. Unlike bovine dentine, which is not recommended as a substitute for human dentine [32], bovine enamel

	Shearforce [MPa], STDEV	ARI (mean)	Significance $p \leq 0.05$
Etching	16.5 +/- 9.9	2.67	CO2, Er:YAG
CO_2laser	3.3+/- 2.1	2.3	etching
Er:YAGlaser	6.2 +/- 2	1.69	etching

Table 1: Bond strength, mean ARI (adhesive remnant index) score and significance. Conventional etching showed superior bond strength to lasing.

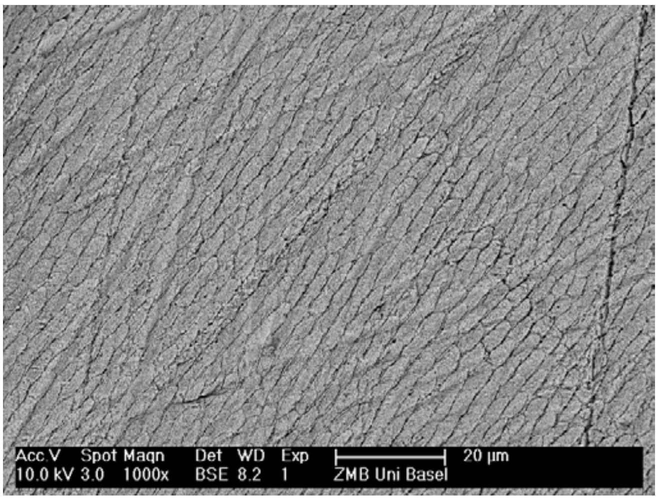

Figure 1: Typical surface after conventional etching with 37% phosphoric acid for 30s.

exhibits very similar bonding characteristics to human teeth [33] and has often been used as a replacement [34,36]. A previous study supports this, as in comparing the bond strength after CO_2 laser etching no significant difference was found among human, porcine and bovine enamel [28].

The use of brackets was intentionally avoided. Brackets have very different bonding surfaces, ranging from mesh bases to undercuts. In addition the extension and curving of the bases vary greatly. These parameters complicate the interpretation of different study results. It has been shown, that modifications of the experimental setup, can lead to variations in shear forces of up to 400% [37,38]. In addition, the bracket wings are not ideal attachments for a shear force die. Depending on the bracket chosen, the lever arm for the shear mechanism will vary according to the distance of the wing from the enamel surface for example in low or high profile brackets and unintentional rotational moments [39] can be applied to the adhesive interface. However, as composites do not adhere well to metal, the major problem with the use of brackets in shear force testing investigating adhesion between enamel and adhesive is the high probability of a detachment at the bracket-adhesive interface [11,12,40-,42] Whereas this feature from a clinical point of view allows safe detachment, it is not suitable for the testing of the adhesive-enamel interface. Therefore bracket analoga made of PMMA cylinders, which were subjected to asilanization with the Rocatec system and Monobond-S Silanewere used. The cylinders also permit a standardized lever arm for the die, which was set at 1.5 mm. In conclusion the described procedure can only be partially recommended. Standardization is certainly enhanced with uniform lever arms and avoidance of torsional moments, but not all failures were found at the adhesive-enamel interface.

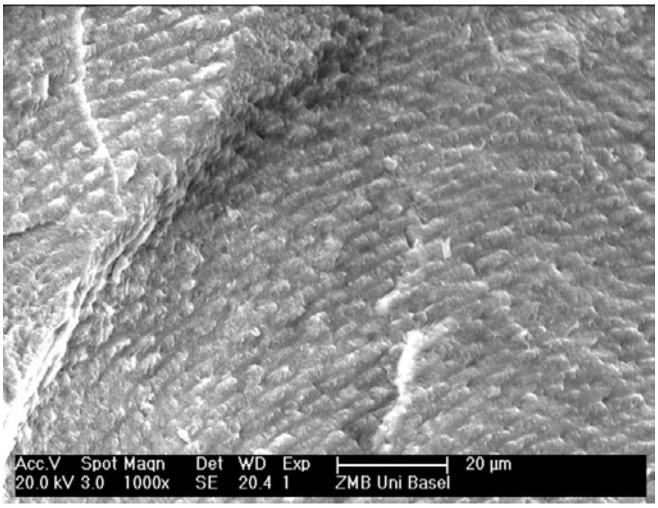

Figure 2: Surface structure after CO2 laser. A microretentive relief can be seen on the enamel.

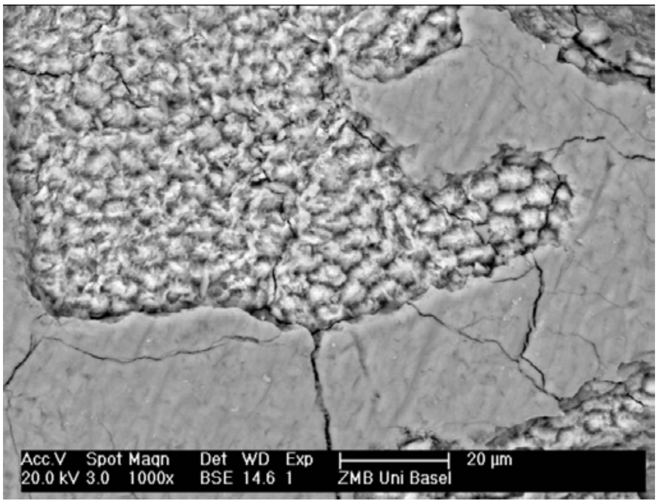

Figure 3: Surface structure after Erbium:YAG laser. Multiple microfissures perpendicular to the enamel surface can be seen. The smooth structure on this SEM is unconditioned enamel. Note that the cracks even disrupt the adjacent areas of unconditioned enamel.

The ARI scores of the present study showed an even distribution of fractures. No clear correlation to absolute bond strengths or conditioning technique could be found, which agrees with earlier literature [11,43]. The results showed that it is the adhesion between a shear body and composite which still remains a crucial factor in testing the enamel-adhesive interface.

The shear forces achieved in the present investigation for traditional etching correlated well with the literature [44] and were in excess of the minimal bonding forces suggested by several authors [45,46]. The strongly significant difference in shear forces between the conventional acid etching and the laser treatment has been confirmed by some authors [44,47,48], whereas others found no significant difference [20,22,49]. The Erbium:YAG laser treatment has been frequently investigated with respect to shear force testing. The mean shear bond strength of 6.2 MPa found in this investigation was less than the values previously reported in the literature [22,44,49] (8,45 MPa, 9.9 MPa, 13 MPa), but within the minimal recommended range [6,46]. For the CO_2 laser however, there are only three studies on adhesive strength [20,28,50]. All three investigations found shear forces comparable to the present study and far below the values for acid etching. Moreover the relatively large standard deviation leads to questions over the reliability for clinical application.

In the SEM, surface conditioning with the CO_2laser lead to a homogenous surface pattern with micro-retentive areas (Figure 2). The microretentions were less extensive than after conventional etching. Reduced roughening might account for the low bond strengths compared to conventional etching. In an earlier investigation [20] surface morphology was found to differ according to the power output of the laser. With an output of 5W and a pulse duration of 10ms the surface resembled enamel etched with phosphoric acid. These settings are comparable to the ones used in the present investigation, although a super-pulse with increasing pulse duration from 0.1-0.8 ms was chosen in the present investigation. The super-pulse has the advantage of a very short heating time, which reduces the risk of pulp damage, especially in freshly erupted teeth with large pulp chambers [51,52]. However it might lead to less surface roughening. Increased power outputs with a pulse duration of 20ms, resulted in melting, blistering of the enamel and the formation of micro-craters, whereas a lower power output of 3W at a pulse duration of 10ms resulted in virtually no alteration of the enamel surface [20].

The use of the Erbium:YAG laser resulted in surface similar to a type III etching pattern [23] with adequate bond strengths. However, considering the large standard deviation, clinically unreliable bond strengths must be expected. Apart from the low bond strength the surface morphology with a network of micro-fissures (Figure 3) raises concerns about the use of this laser configuration. Micro-fissures were also detected in earlier investigations [22,44]. In polished cross section SEM two types of fissures could be identified: deep fissures perpendicular to the surface with a mean depth of nearly 60 µm and a smaller type, which was observed at a depth of 25 µm running between the enamel rods [44]. This damage is more profound than the one induced by conventional enamel etching with cracks no deeper than 12 µm [53,54].

In conclusion, CO_2 or Erbium:YAG laser abrasion with the configurations described in this study seem to be inappropriate for enamel conditioning. Not only are the bond strengths of questionable reliability but with the Erbium:YAG laser, the enamel is morphologically damaged to a greater degree than with conventional etching. It is questionable whether the advantage of higher caries resistancy after laser conditioning can outweigh these disadvantages.

Conclusion

Within the limits of an in-vitro design the study suggests, that low bond strength paired with high standard deviations both laser conditioning techniques are not suitable for clinical use.

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