Comparative Study of the Ultrastructure and Adhesive Properties of Enamel Prepared by Er:YAG Laser and Conventional Bur

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Purpose: The objective of the study was firstly to examine the surface morphology of enamel under scanning electron microscopy (SEM), following Er:YAG laser ablation and conventional high-speed bur preparation, with and without acid etching, and secondly to investigate the adhesion of composite resin (CR) to those surfaces by means of a shear bond strength (SBS) test.

Materials and Methods: The buccal surface of 42 human extracted molars were ground flat using 500-grit silica carbide paper under water. The surfaces were subjected to simulated cavity preparation treatment and placed into groups: (1) Er:YAG laser ablation (350 mJ,10 Hz, VSP), (2) Er:YAG ablation plus acid etching (37% phosphoric acid), (3) conventional bur (Diamond Fis Z10), (4) conventional bur plus acid etching. Three teeth from each group (n = 3) were examined under SEM (Philips XL 30) to determine the nature of the treated surface. The remaining teeth in each group (n = 10), except group 3, underwent an SBS test to investigate the bond strength of CR to those surfaces, using a universal testing machine (Hounsfield; Hounsfield, UK) following ISO standard TR 11405.

Results: Er:YAG laser irradiation resulted in roughened, irregular whitish enamel surfaces, resembling a typical Type I or Type II acid-etch pattern. Surfaces prepared by conventional high-speed bur exhibited a diffuse smear layer that was removed following acid etching. Shear bond strength testing revealed that there was no statistically significant difference in values between acid-etched/laser-ablated (15.89 MPa ± 1.90) and conventionally prepared and etched enamel surfaces (16.55 MPa ± 3.88) ($p > 0.05$). However, samples of Er:YAG irradiation without acid etching produced significantly lower ($p < 0.05$) SBS values (10.10 MPa ± 3.57).

Discussion: Er:YAG laser irradiation produced surfaces visually similar to an acid-etch pattern, although without a smear layer. Both the conventional bur- and laser-prepared samples exhibited similar surfaces following acid etching. Enamel bond strength produced by Er:YAG laser ablation is comparable to that obtained by the conventional bur. However, within the limitations of this study, Er:YAG irradiation alone cannot be recommended as a viable alternative to acid etching to increase bond strength to enamel.

Conclusion: It was concluded that the Er:YAG laser compared very favourably with the conventional bur in preparing enamel surfaces for restoration with composite resin. Of clinical significance, however, is that while the surface produced by the Er:YAG laser is similar to the conventionally prepared, etched enamel surface, it still requires acid etching to obtain an equivalent bond strength.

Keywords: laser, enamel, acid etching, SEM, adhesion, shear bond strength.

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Cavity preparation with slow- and high-speed handpieces involves irritating noise, uncomfortable vibration, and often results in stress and pain to patients. These disadvantages have led to a search for potential alternative cavity preparation methods. Since Goldman et al[4] first demonstrated that removal of carious tissue was possible using the ruby laser, the possible application of CO_2 and Nd:YAG lasers have also been evaluated. Unfortunately, these lasers require relatively higher energy levels for hard tissue removal, which produced major thermal side effects such as melting, carbonization, crater formation, and cracks in the surrounding tissues, and an increase in pulpal temperature.[3,14] Effective ablation of dental hard tissues by means of an Er:YAG laser system has now been reported, with claims that it can be used safely and successfully in the removal of carious tissues or in cavity preparation for restorations.[5,10]

Recently, bonding of materials to Er:YAG ablated dental surfaces have also been investigated. It has been reported that treatment with an Er:YAG laser creates surfaces which appear similar to acid-etched surfaces.[9] Other studies have tested the ability of laser irradiation to produce surface modifications which would allow possible elimination of phosphoric acid etching to enhance bonding. Some studies have reported that the Er:YAG laser alone or combined with acid etching produces a surface which allows composite resin to bond to the tooth structure with strengths equal to or better than that produced by acid etching alone.[6,8] However, results from other studies did not support these findings. Therefore, the objectives of this study were twofold: firstly, to compare the surface morphology of enamel under scanning electron microscopy (SEM), following conventional bur preparation and Er:YAG laser, with and without acid etching, and secondly, to investigate the adhesion of composite resin to those surfaces by means of a shear bond strength (SBS) test, and to compare the effect of etching and nonetching prior to bonding.

MATERIALS AND METHODS

Specimen Preparation

Forty-two freshly extracted human third molars (patient ages ranged from 20-25 years) were stored in 0.2% chloramine solution (extractions at dental clinics distant from the University of Adelaide required teeth to be protected from bacterial overgrowth) and refrigerated at 4°C until used (a period of 8 weeks). Teeth with caries, restorations, hypoplastic areas, cracks, or gross irregularities of enamel structure were excluded. The buccal surfaces of each crown were ground with 500-grit abrasive papers under running water to provide uniformly flat surfaces of enamel. The samples were randomly divided into four groups. The groups were subjected to treatment of either using: (1) Er:YAG laser ablation, (2) Er:YAG ablation plus acid etching, (3) conventional bur, (4) conventional bur plus acid etching. A commercially available Er:YAG laser (Fidelis Surgical Laser model 320 A, Fotona; Geislingen, Germany) was used in this study with a very short pulse (VSP) mode; pulse duration of 250 µs was chosen. Laser energy was delivered to the tooth surface at 350 mJ with a frequency of 10 Hz. These parameters were those recommended by the manufacturer, and had been validated in a preliminary study[7] as resulting in an optimal cutting condition for enamel. The energy was delivered through a seven-mirror articulated arm using the Ro4 handpiece with a spot size of approximately 1 mm in diameter. The handpiece was held at a 90-degree angle approximately 7 mm away from the target tissue. The beam was used in a noncontact mode and moved in a sweeping fashion for 15 s, with the handpiece bathed in an adjustable air-water spray during cutting. Bur cutting was performed with a standard high-speed dental handpiece (Sirona/Siemens; Charlotte, NC, USA) using a fine-grit diamond bur (Fis Z10, Komet; Gebr. Brasseler, Lemgo, Germany). Both of these procedures removed tooth structure to a depth of approximately 0.5 mm over a surface area of approximately 5 mm^2. The objective was to prepare the enamel surface so as to simulate the base of a cavity prepared in enamel, while producing a flat enamel surface for testing composite resin bonding.

Preparation of Specimens for SEM Analysis

Three teeth from each group underwent preparation for SEM analysis, which involved sample fixation, buffer wash, and dehydration using ascending concentrations of ethanol. The samples were mounted on a metal stub and coated with carbon before observation with an SEM (Philips XL 30, FEI; Eindhoven, The Netherlands) at 10.0 kV. Each of the samples was analyzed at 1000X and 5000X and the images were recorded digitally.

Shear Bond Strength Testing

The remaining teeth from each group (n = 10), except group 3 (bur prepared enamel), underwent a shear bond strength (SBS) test to investigate the adhesive potential of composite resin (CR) to those surfaces (the bur plus acid-etch group was the control). Both the bur and laser prepared surfaces were cleaned with water

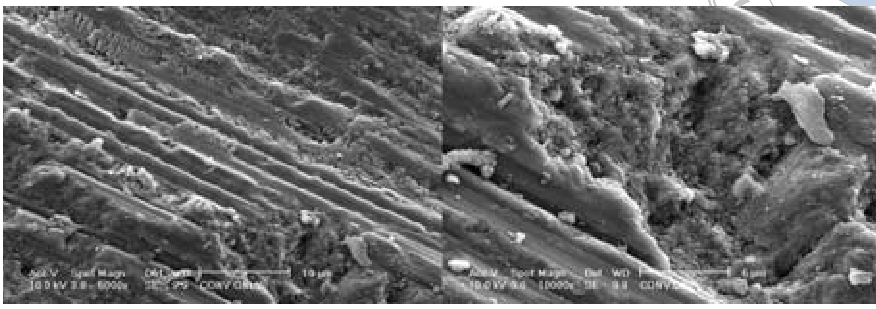

Fig 1a (left) SEM of tooth structure following the use of a fine-grit diamond bur.

Fig 1b (right) At higher magnification, white deposits and surface cratering are visible on the enamel surface.

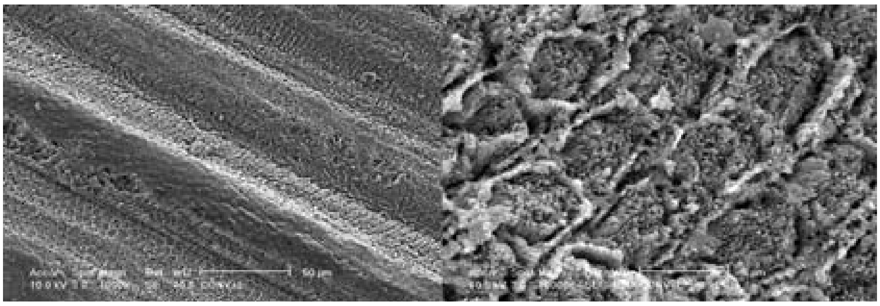

Fig 2a (left) Low magnification SEM following acid etching of the bur prepared enamel. Note the bur striations are still visible.

Fig 2b (right) High magnification, the enamel prism structure and its "keyhole" appearance are clearly demonstrated.

followed by air drying. Prior to CR bonding, the teeth in groups 2 and 4 were treated with a 37% phosphoric acid gel and light-curing resin adhesive (Scotchbond Multi purpose, 3M ESPE, St Paul, MN, USA). These procedures were carried out following the manufacturer's recommendations (etch 15 s, wash 40 s, air spray for 5 s, and light curing of the adhesive for 10 s). A plastic cylinder (4.8 mm inner diameter x 3 mm length) was attached to the surface of the bur- and laser-prepared enamel using sticky wax, and composite resin restorative material Z100 (3M ESPE, St Paul, MN, USA, batch no.1 ET 2004-09 and 1 ER 2004-09, shade A3) was then placed in the plastic cylinder in two increments. Each increment was light cured using a Sirona Light Curing Unit (Siemens, Charlotte, NC, USA) for 40 s following the manufacturer's recommendations. All the tooth roots were then embedded in a polymethyl methacrylate (PMMA) resin block (Dentsply, Weybridge, UK), leaving the composite cylinder exposed and parallel to the base of the resin block. The shear bond strength was measured with a universal testing machine (Hounsfield, UK) following the ISO 11405 requirements. The teeth were oriented in a holding device so that a knife-edge loading head was held as close as possible to the tooth surface and perpendicular to the composite cylinder. The tests were performed at a crosshead speed of 1 mm/min until the composite cylinder was dislodged from the tooth. The maximum load at which the composite cylinders became dislodged were recorded in Newtons and then converted into megapascals (MPa).

The type of fracture, ie, adhesive or cohesive, was determined for each specimen via stereomicroscopic analysis of the bond site surfaces in both enamel and composite resin cylinders (40X magnification, using an Olympus Wild Photo automat MPS 55; Olympus, Tokyo, Japan). This was followed by SEM examination of the residual enamel surface samples after they were cross sectioned using a slow-speed sectioning machine with water cooling (Isomet Low Speed Saw, Buehler; Lake Bluff, IL, USA). This is to facilitate identifying the location of the debonding area and to determine whether the failure was an adhesive, cohesive, or mixed adhesive-cohesive failure.

RESULTS

The SEM views of the buccal enamel surface of the tooth treated with a fine diamond bur not only showed numerous bur striations but also cutting debris (Fig 1a). Under higher magnification, the surface showed numerous white deposits ranging in size from 2 µm to 5 µm in diameter, presumably grinding debris, present between the striations (Fig 1b).

Following conventional acid etching, the striations were less obvious and the smear layer was almost completely removed (Fig 2a). Typical type II acid etching ef-

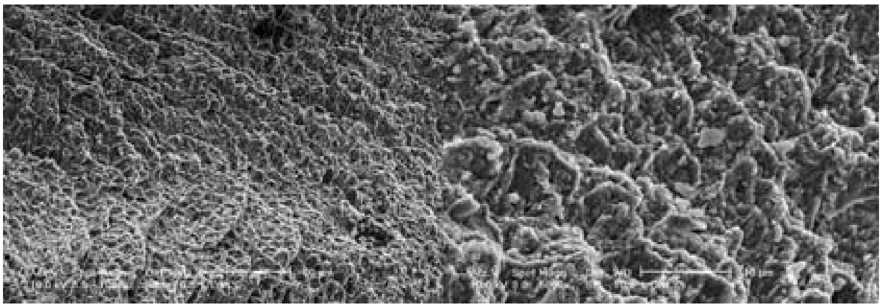

Fig 3a (left) Low magnification SEM of laser-ablated enamel demonstrating the absence of a smear layer.

Fig 3b (right) At higher magnification, the laser ablated surface resembles an acid-etch pattern. Note the crack in the enamel (highlighted area).

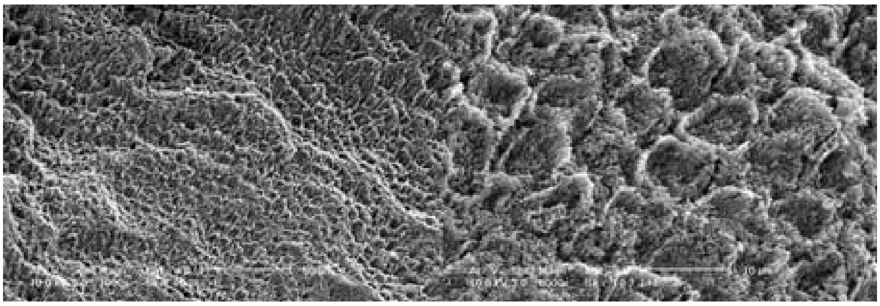

Fig 4a (left) Low magnification SEM of laser ablated enamel which was subsequently acid etched.

Fig 4b (right) At higher magnification, the laser-ablated, acid-etched surface displays the typical diamond shape of the enamel prisms.

fects were seen at higher magnification, where the structure of enamel prisms with their keyhole shape appearance was visible (Fig 2b).

In contrast, Er:YAG laser ablation produced a rough, irregular, whitish surface that showed effects resembling those of an acid-etch pattern (Fig 3a). No smear layer was evident, athough at higher magnification, some white deposits were randomly distributed across the surface (Fig 3b).

Even though the trajectory of HA crystals was difficult to determine exactly, the general outline of the prisms' shapes was roughly visible. The oval shaped area in Fig 3b shows a microcrack line present on the treated tooth surface. Teeth treated with an Er:YAG laser followed by acid etching also show a rough, irregular whitish surface. The enamel prisms were clearly evident throughout the surface, showing the keyhole or diamond shape appearances (Fig 4a and 4b).

No statistically significant difference ($p > 0.05$) in mean value was observed between etched, laser-ablated (15.89 MPa ± 1.90) and bur-prepared, acid-etched enamel surfaces (16.55 MPa ± 3.88).

The Er:YAG laser group without acid etching produced the lowest mean values in the shear bond strength test (10.10 MPa ± 3.57) (Table 1). Student's t-tests revealed that shear bond strength was affected by surface treatment (etched or nonetched), but not affected by the treatment methods used (conventional bur or Er:YAG laser). In these instances, the Student's t-test revealed that there was a statistically significant difference in the shear bond strength between samples receiving acid etching compared to the samples that received laser treatment alone ($p < 0.05$).

The types of fracture experienced in SBS testing were divided between adhesive and cohesive, as seen in Table 2.

DISCUSSION

Current understanding of the adhesion of dental restorative materials to tooth structure is based on either chemical adhesion or micromechanical retention. Swift et al[12] reported that the foundation of adhesive dentistry was laid in 1955 when Buonocore proposed that exposure of the enamel surface to acid aided resin bonding. Further, Buonocore found that acid etching of enamel appears to improve retention by selectively exposing hydroxyapatite formations, thereby facilitating resin penetration to a depth of 6 to 12 µm. This penetration of resin is attributed to the production of micromechanical bonds that are believed to contribute to long-term bond strength. Despite the acid etching technique being simple and clinically expedient, clinicians continue to explore alternative methods, such as air abrasion, and, more recently, lasers to treat enamel for

Table 1 Shear bond strength test values in the three treatment groups

	Bond strength of enamel bonded to composite resin (MPa)		
	Bur +acid etch	Laser	Etch + laser
	10.38	15.19	15.46
	16.48	13.39	13.68
	17.66	5.08	18.41
	12.58	10.73	13.55
	21.24	15.08	17.63
	16.42	6.64	18.66
	23.55	8.28	15.70
	17.02	7.96	16.18
	13.47	7.50	13.68
	16.67	11.18	15.94
Mean	16.55	10.10	15.89
SD	3.88	3.57	1.90

Table 2 Results of the stereomicroscope analysis of the fracture pattern of each sample in the three treatment groups

No.	Bur + etch	Laser + etch	Laser
1	Adhesive + cohesive	Adhesive + cohesive	Adhesive + cohesive
2	Adhesive + cohesive	Adhesive + cohesive	Adhesive + cohesive
3	Cohesive (CR)	Cohesive (CR)	Adhesive
4	Cohesive (CR)	Adhesive + cohesive	Adhesive
5	Cohesive (CR)	Cohesive (CR)	Adhesive
6	Cohesive (CR)	Adhesive + cohesive	Adhesive
7	Cohesive (CR)	Cohesive (CR)	Adhesive
8	Cohesive (E+D)	Cohesive (CR)	Cohesive (CR)
9	Cohesive (CR)	Cohesive (CR)	Cohesive (CR)
10	Cohesive (C)	Cohesive (CR)	Adhesive + cohesive

resin bonding. Walsh et al[13] reported that conditioning of human enamel with pulsed CO_2 laser radiation resulted in comparable or weaker bond strengths than that obtained with acid etching. Similarly, Ariyaratnam et al,[1] using Nd:YAG, reported bond strengths that were weaker than with acid etching.

In support of those authors, the present study found that the Er:YAG laser group without acid etching produced the weakest bonding or adhesion between the composite resin materials and the tooth surface (10.10 MPa ± 3.57). In general, an adhesive failure between enamel and resin was observed (Table 2). It is unknown whether this pattern of failure was related to the presence of the surface debris on the enamel resin interface, as observed in Fig 3b.

The highest SBS or adhesion of the composite resin to the tooth surface was achieved in the conventional bur plus acid-etch group (16.55 MPa ± 3.88) and the Er:YAG laser plus acid-etch group (15.89 MPa ± 1.90). These results indicate that there is no significant difference in shear bond strength values recorded between conventional bur-plus-etch and laser-plus-etch groups (p

> 0.05). However, samples treated by Er:YAG laser ablation alone (without acid etching) yielded a significantly lower SBS value ($p < 0.05$).

The difference in bond strength between the present work and that of other authors[6,8] can be possibly explained by different tooth preparation methods (including cavity shape), laser parameters, adhesive test methodology, resin factors (including air entrapment in resin, inadequate curing of composite resin, type of composite resin) and operator variables, all of which can influence the adhesion of resin to enamel. Therefore, differences in experimental design make direct comparison of bond strengths difficult.

It is interesting to note (Table 2) that more adhesive failures were observed with the laser-ablated enamel, while cohesive fractures tended to be a feature of both the bur and laser-plus-acid-etched surfaces. This result would suggest that the penetration of resin tags into the ablated enamel was not as great as in acid-etched enamel.

As a consequence of this observation, the question of whether microleakage can occur is raised. Robles et al[11] compared Class V cavities prepared by conventional high-speed bur and Er:YAG laser with and without acid etching, and observed a higher degree of marginal leakage when the cavities were not acid etched. Ceballos et al[2] found that laser ablation of enamel was not sufficient to prevent microleakage in occlusal enamel surfaces compared to cavities that were acid etched.

In the present study, the influence of laser ablation with or without acid etching and its relationship to microleakage was not tested. Further, the translation of bond strength values to the clinical situation is very challenging. However, it can be inferred that although the surfaces produced by Er:YAG laser ablation are similar to an acid-etch pattern when viewed under SEM, it still cannot be recommended as a viable alternative to acid etching to increase the bond strength of composite resin to enamel.

CONCLUSION

It was concluded that the Er:YAG laser compared very favourably with the conventional bur in preparing enamel surfaces for composite resin adhesion. Although the surfaces produced by Er:YAG laser are similar to the conventionally prepared and etched enamel surfaces, the results of this study indicate acid etching is still necessary to obtain an equivalent bond strength.

REFERENCES

1. Ariyaratnam MT, Wilson MA, Mackie IC, Blinkhoro AS. A comparison of surface roughness and composite/enamel bond strength of human enamel following the application of the Nd:YAG laser and etching with phosphoric acid. Dent Mater 1997;13:51-55.
2. Ceballos L, Osorio R, Toledano M, Marshall G.W. Microleakage of composite restorations after acid or Er:YAG laser cavity treatment. Dent Mater 2001;17:340-346.
3. Frentzen M, Koort HJ. Laser in dentistry: New possibilities with advancing laser technology. Int Dent J 1990;40:323-332.
4. Goldman L, Gray JA, Goldman J, et al. Effects of laser impacts on teeth. J Am Dent Assoc 1965;70:601-606.
5. Hibst R, Keller V. Experimental studies of the application of the Er:YAG laser on dental hard substances: II. Light Microscopic and SEM investigations. Laser Surg Med 1989;9:338-344.
6. Keller U, Hibst R. Effects of Er:YAG laser on enamel bonding of composite materials. Proc SPIE 1993;1680:163-168.
7. Luddin N. Comparative study of ultrastructure and adhesive properties of enamel prepared by Er:YAG laser and conventional bur. Doctorate Thesis 2004; The University of Adelaide.
8. Moritz A, Gutknecht N, Schoop U et al. Alternatives in enamel conditioning: a comparison of conventional and innovative methods. J Clin Laser Med Surg 1996;14:133-136.
9. Niu W, Eto JN, Kimura Y, et al. A study on micro leakage after resin filling of Class V cavities prepared by Er: YAG laser. J Clin Laser Med Surg 1998;16:227-231.
10. Paghdiwala AF. Does laser work on hard dental tissue? J Am Dent Assoc 1991;122:79-80.
11. Robles F, Ramos A, Zezell D, Eduardo CE. SEM and EDX evaluation of the microleakage in cavities prepared with Er:YAG laser. [abstract 239]. J Dent Res 2000;75:1098.
12. Swift Jr. EJ, Perdigao J, Heymann HO. Bonding to enamel and dentin: A brief history and the state of the art. Quintessence Int 1995;26:95-110.
13. Walsh LJ, Abood D, Brockhurst PJ. Bonding of resin composite to carbon dioxide laser modified human enamel. Dent Mater 1994;10:162-166.
14. Wigdor H, Abt E, Ashrafi S, et al. The effects of laser on dental hard tissues. J Am Dent Assoc 1993;124:65-70.

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