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Comparison of sandblasting, laser irradiation, and conventional acid etching for orthodontic bonding of molar tubes

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SUMMARY The purpose of the study was to determine if sandblasted and laser-irradiated enamel may be viable alternatives to acid etching for molar tube bonding. Seventy-seven molar teeth extracted for periodontal reasons were used. Seventy teeth underwent shear bond strength (SBS) testing and the remaining seven were examined under scanning electron microscopy (SEM). Adhesive remnant index (ARI) scores were also considered. An erbium, chromium-doped:yttrium-scandium-gallium-garnet (Er, Cr: YSGG) laser was used for enamel etching. Sandblasted and laser-irradiated enamel surfaces with different power outputs (0.5, 0.75, 1, 1.5, and 2 W) were compared with conventional phosphoric acid etching. Descriptive statistics, including mean, standard deviation, and minimum and maximum values, were calculated for each group. Multiple comparisons of the SBS of different etching types were performed by analysis of variance testing. The chi-square test was used to evaluate differences in ARI scores between groups.

Acid-etched, 1-, 1.5-, and 2-W laser irradiation groups demonstrated a clinically acceptable mean SBS (7.65 ± 1.38, 6.69 ± 1.27, 7.13 ± 1.67, 7.17 ± 1.69 MPa, respectively). Irradiation with an output of 0.5 and 0.75 W and sandblasting of the enamel showed a lower SBS than the other groups (2.94 ± 1.98, 4.16 ± 2.87, 2.01 ± 0.64 MPa, respectively). SEM evaluation of 1, 1.5, and 2 W laser irradiation revealed similar etching patterns to acid etching. Sandblasting and 0.5, and 0.75 W laser etching were not able to etch enamel in preferential patterns. Laser irradiation at 1.5 and 2 W was able to etch enamel. More adhesive was left on the enamel surface with low-power laser irradiation.

Sandblasting and low-power laser irradiation (0.5, 0.75, and 1 W) are not capable of etching enamel suitable for orthodontic molar tube bonding, but 1.5- and 2-W laser irradiation may be an alternative to conventional acid etching.

Introduction

Bonding of molar tubes has many advantages over banding in daily orthodontic practice (Zachrisson, 1977). More plaque accumulation and gingival inflammation, although not statistically significant, have been associated with banding (Boyd and Baumrind, 1992).

The primary effect of enamel etching is to increase the surface area and thereby change the surface from a low-energy hydrophobic surface to high-energy hydrophilic surface (Reynolds, 1975). Various surface properties may be accomplished but the most important point is to modify the surface characteristic of the enamel for adhesive attachment (Silverstone *et al.*, 1975). Various preparation methods including orthophosphoric acid, sandblasting, and laser irradiation have been shown to etch enamel for orthodontic bonding (Büyükyılmaz *et al.*, 1995; Wigdor *et al.*, 1995; Zachrisson *et al.*, 1995; Miller and Zernik, 1996; Millett *et al.*, 1995; Chung and Hwang, 1997; Takeda *et al.*, 1998, 1999; Aoki *et al.*, 2000; Chung *et al.*, 2001; Üşümez *et al.*, 2002).

Acid etching decalcifies the inorganic component of the enamel and the enamel becomes more susceptible to carious attack, which is induced by plaque accumulation around the bonded orthodontic attachments.

Many researchers have investigated the effects of sandblasting (Zachrisson and Büyükyılmaz, 1993; Büyükyılmaz *et al.*, 1995; Zachrisson *et al.*, 1995; Miller and Zernik, 1996; Millett *et al.*, 1996; Chung and Hwang, 1997; Chung *et al.*, 2001). Some (Zachrisson and Büyükyılmaz, 1993; Büyükyılmaz *et al.*, 1995; Zachrisson *et al.*, 1995; Miller and Zernik, 1996; Millett *et al.*, 1996; Chung and Hwang, 1997) preferred the use of sandblasting to increase surface roughness of non-enamel surfaces (metal, gold, amalgam, or porcelain), while Chung *et al.* (2001) suggested that direct sandblasting may be a feasible method for preparing teeth for orthodontic bonding.

Laser irradiation removes the smear layer. After laser etching, some physical changes occur, such as melting and recrystallization. Numerous pores and bubble-like inclusions appear (Takeda *et al.*, 1998, 1999). Thus, irregular surfaces are created which permit penetration of fluid adhesive components. In dentistry, the first-generation lasers were used only for soft tissues. The main disadvantage was the immediate increase in temperature, resulting in an inflammatory pulpal response (Wigdor *et al.*, 1995; Aoki *et al.*, 2000). The development of the erbium, chromium-doped:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser has overcome this problem and it is convenient for both soft and hard tissue treatments in the oral environment because these lasers can ablate enamel and dentine effectively due to their highly efficient absorption of both water and hydroxyapatite (Wigdor *et al.*, 1995). The main advantage of the laser-etched surface is acid resistance. It yields more resistant enamel for caries attack (Vissuri *et al.*, 1996; Klein *et al.*, 2005). In a previous study, Üşümez *et al.* (2002) demonstrated that ablation of tooth surfaces using an Er,Cr:YSGG laser with different power outputs showed differing etching patterns of enamel, resulting in different shear–peel bond strengths.

Chung *et al.* (2001) suggested that sandblasting provided clinically acceptable bond strengths, while Millett *et al.* (1995) showed low bond strengths with sandblasting for orthodontic bonding.

The purpose of the present study was to investigate the shear–peel bond strength and adhesive failure location of laser- and sandblasted-etched enamel compared with conventional acid-etching techniques, and to determine the suitability of these modalities in molar tube bonding.

Materials and methods

Experimental design

Seventy-seven molar teeth, extracted for periodontal reasons, were used in the present investigation. The teeth were stored in distilled water for a maximum of 1 month. To prevent bacterial growth, the water was changed weekly (von Fraunhofer *et al.*, 1993). The teeth were free of caries, macroscopic cracks, abrasions, and staining as assessed by visual examination. Seventy teeth were used for the bond strength experiments and the remaining seven (one specimen for each group) for scanning electron microscopy (SEM) to determine the topography and morphology of the treated enamel surface. This technique lacks a quantitative scale and the information that is provided is subjective. However, SEM was used to visualize enamel with different etching protocols. The order of testing each specimen was randomized.

Before the experiment, the teeth were embedded horizontally in self-cure acrylic resin blocks with the facial surface of the teeth at least 2 mm above the surface of the acrylic resin. Before bonding the molar tubes, the enamel surfaces were prepared with different enamel preparation techniques. Seventy teeth, 10 for each group, were randomly assigned as follows:

Group 1: Enamel irradiated with Er,Cr:YSGG laser with 0.5 W power output.
Group 2: Enamel irradiated with Er,Cr:YSGG laser with 0.75 W power output.
Group 3: Enamel irradiated with Er,Cr:YSGG laser with 1 W power output.
Group 4: Enamel irradiated with Er,Cr:YSGG laser with 1.5 W power output.
Group 5: Enamel irradiated with Er,Cr:YSGG laser with 2 W power output.
Group 6: Enamel etched with 38 per cent orthophosphoric acid.
Group 7: Enamel sandblasted with 50 μm aluminium oxide.

Etching procedure

The Er,Cr:YSGG laser (Waterlase, Biolase Europe GmBH, Floss, the Germany) is a hydrokinetic system (Figure 1). This device allows precise hard tissue treatments by virtue of laser energy interaction with water above and at the tissue interface. It operates at a wavelength of 2.78 μm and a pulse duration of 150 μs at a rate of 20 Hz. The average output can be varied from 0 to 6 W. The laser energy is delivered through a fibre optic system to a sapphire tip and is bathed in an adjustable air/water spray. The air and water level was 90 and 80 per cent, respectively. The laser beam was directed perpendicular to the enamel surface at a distance of 1 mm. To avoid unnecessary irradiation, acrylic resin with a 4 × 6 mm hole was placed on the tooth surface. The first five groups were irradiated with varying power outputs (0.5, 0.75, 1, 1.5, and 2 W). All laser irradiations were performed for 15 seconds.

Group 6, etching for 15 seconds (Surmont *et al.*, 1992) with 38 per cent orthophosphoric acid (Pulpdent, Watertow, Massachusetts, USA), was performed followed by 15 seconds of rinsing with an air/water spray.

For group 7, the buccal surfaces of the teeth were sandblasted at 65–70 psi for 10 seconds with aluminum oxide (GAC International, Inc., Bohemia, New York, USA) with a particle size of 50 μm. The sandblasting apparatus (Microetcher II, Danville Engineering, San Ramon, California, USA) was directed perpendicular to the enamel surface at a distance of 1 mm. To avoid unnecessary sandblasting, acrylic resin with a 4 × 6 mm hole was placed on the tooth surface. The sandblasted specimens were rinsed for 15 seconds using an air/water spray to remove all particles from the surface.

SEM examination

One representative specimen from each group was left unbonded and not subjected to SBS testing. The treated surface of each tooth was marked for SEM.

Bonding procedure

The surface etched by acid, laser, or sandblasting was covered with a small amount of adhesive using a microbrush. After applying the adhesive paste (Transbond XT, 3M Unitek, Monrovia, California, USA), the molar tube was placed on the tooth surface and adjusted for final positioning. Excess adhesive was hand removed and light curing was performed for 40 seconds.

After storing the specimens in water at 37°C for 24 hours, thermocycling for a total of 500 cycles at 5–55°C with a

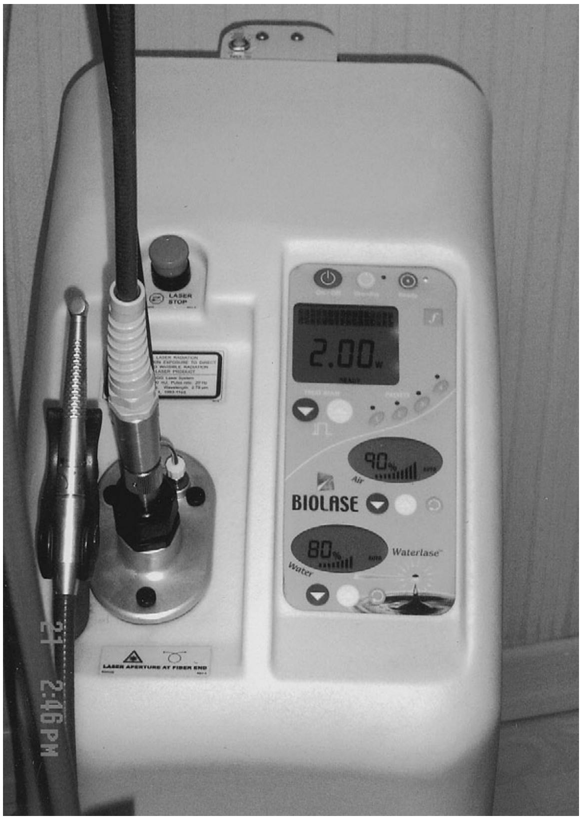

Figure 1 The erbium, chromium-doped:yttrium-scandium-gallium-garnet laser system used in the study.

dwell time of 30 seconds was performed. SBS was accomplished using a chisel edge, mounted on the crosshead of the testing machine (Instron testometric M500-25, Testometric Company Ltd, Rochdale, Lancashire, UK). The edge was aimed at the molar tube and the enamel interface at a crosshead speed of 0.5 mm/seconds. The force decay was recorded for each specimen in Newtons and then converted into megapascals. SBS was calculated by dividing the force decay by the molar tube base area. The base area of the molar tubes was 19.88 mm^2 (GAC International, Inc.).

After debonding, the tubes were examined under ×10 magnification to evaluate the amount of resin remaining on the tooth. The adhesive remnant index (ARI; Årtun and Bergland, 1984) was used to describe the amount of resin remaining on the tooth surfaces. The ARI scores ranged from 0 to 3 as follows: 0, no adhesive remained on the tooth; 1, less than half of the enamel bonding site covered with adhesive; 2, more than half of the enamel bonding site covered with adhesive; and 3, the enamel bonding site covered entirely with adhesive.

Statistical analysis

Descriptive statistics, including mean, standard deviation, and minimum and maximum values, were calculated for each group. Multiple comparisons of the SBS of different etching types were performed by analysis of variance. The chi-square test was used to evaluate differences in ARI scores between groups. All statistical evaluations were calculated using the Statistical Package for Social Sciences Windows, release 10.0.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Descriptive statistics of the laser-irradiated, sandblasted-, and acid-etched enamels are shown in Table 1. The mean shear–peel bond strengths observed in groups 1 and 2 were below clinically acceptable levels. Although the mean strengths were acceptable, some shear–peel bond strengths produced by 1-W laser irradiation were lower than clinically acceptable limits. Laser irradiation with an output of 1.5 and 2 W and acid etching produced higher mean shear–peel bond strengths. Multiple comparisons of the groups revealed statistically significant differences from each other (Table 2). When all groups were compared, 0.5- and 0.75 W laser irradiation and sandblasting produced similar shear–peel bond strengths, which were lower than the other groups. The 1, 1.5 and 2 W laser irradiation groups demonstrated similar shear–peel bond strengths compared with the acid-etched group.

No significant enamel surface etching was obtained when using 0.5-W laser irradiation. Small cavitations only were seen on the enamel (Figure 2a). Laser irradiation with 0.75 W revealed deeper cavitations (Figure 2b) than in the 0.5 W laser irradiation group, but still did not resemble the etching patterns described by Silverstone *et al.* (1975). The 1 W laser produced a more preferential Type I etching pattern (Figure 2c). A honeycomb-like appearance was observed in the 1 W laser-etched group with microcracks on the laser-ablated surfaces, which aid the penetration of resin.

Laser irradiation at 1.5 W resulted in a Type I etching pattern with more microcracks (Figure 2d). Laser irradiation of 2 W produced a Type III acid-etching pattern with microcracks, and the surface destruction was more prominent (Figure 2e). The characteristic Type III acid-etching pattern with regular rough surface and spaces (Silverstone *et al.*, 1975) can be seen with the acid-etching procedure (Figure 2f). Dissolution of hydroxyapatite by phosphoric acid produced tags and rough surfaces that afforded the mechanical lock for resin.

Although sandblasting of the enamel surface did not result in the typical etching pattern described by Silverstone *et al.* (1975), some cavitations occurred (Figure 2g).

The ARI scores are listed in Table 3. Sandblasting and 0.5 and 0.75 W laser irradiation produced adhesive failures, whereas cohesive failures were seen with acid etching and 1, 1.5 and 2 W laser irradiation.

Discussion

Acid etching results in chemical changes that may produce modification of the organic matter and decalcification of

Table 1 Descriptive statistics for acid etching, sandblasting, and laser irradiation with different power outputs.

	n	Mean ± Standard deviation	Standard error	Maximum (MPa)	Minimum (MPa)	F	*P*
0.5 W	10	2.94 ± 1.98	0.711	5.62	2.09		
0.75 W	10	4.16 ± 2.87	0.677	5.18	2.53		
1 W	10	6.69 ± 1.27	0.402	7.39	5.62		
1.5 W	10	7.13 ± 1.67	0.530	8.07	5.33		
2 W	10	7.17 ± 1.69	0.536	8.18	5.87	20.529	<0.001
Acid etching	10	7.65 ± 1.38	0.328	8.19	6.29		
Sandblasting	10	2.01 ± 0.64	0.202	3.51	1.21		
Total	70	5.39 ± 1.64	0.322	8.19	1.21		

Table 2 Multiple comparison testing for acid etching, sandblasting, and laser irradiation with different power outputs.

	0.5 W	0.75 W	1 W	1.5 W	2 W	Acid etching	Sandblasting
0.5 W		0.327 n.s.	***	**	**	***	n.s. (0.668)
0.75 W			0.97 n.s.	0.612 n.s.	0.568 n.s.	***	*
1 W				0.966 n.s.	0.976 n.s.	0.639 n.s.	***
1.5 W					0.998 n.s.	0.107 n.s.	***
2 W						0.125 n.s.	***
Acid etching							***
Sandblasting							

*P < 0.05, **P < 0.01, ***P < 0.001, n.s. not significant.

the inorganic component of enamel (Bertolotti, 1992; Pashley, 1992). Acid etching is a form of microetching, whereas sandblasting can be regarded as a form of macroetching. Chung *et al.* (2001) used sandblasting to remove unfavourable oxides and contaminants and increase surface roughness promoting a convenient surface for bonding. In the present study, sandblasting was applied to the enamel surface to test whether it was capable of producing etching patterns suitable for bonding (Zachrisson and Büyükyılmaz, 1993; Millett *et al.*, 1995). Laser-irradiated enamels result in fractured and uneven dentinal tubules, which are ideal for bonding. The laser-etched enamel surface is acid resistant; thus, it is more resistant to carious attack (Vissuri *et al.*, 1996). Therefore, laser etching might have an advantage for orthodontic bonding.

The laser used in this study was a hydrokinetic system. The main disadvantage of the previous lasers was the immediate increase in temperature, resulting in an inflammatory pulpal response (Wigdor *et al.*, 1995; Aoki *et al.*, 2000) With this system, not only could the temperature be suppressed but also cutting efficiency could be increased (Eversole and Rizoiu, 1995). Laser energy is delivered through a fibre optic system to a sapphire tip terminal. The average output can be varied from 0 to 6 W. For cutting enamel, high irradiation outputs varying from 2.5 to 6 W can be used (Hossain *et al.*, 2003). In this study, in order to etch enamel, lower outputs (0.5, 0.75, 1, 1.5, and 2 W) were used.

The varying power outputs produced different etching patterns. While 0.5 W laser irradiation demonstrated a significantly lower SBS and more even surfaces, higher power outputs showed different characteristics. Laser irradiation at 0.75 W showed no significant difference in SBS, but the mean SBS was below clinically acceptable limits (Reynolds, 1975). Although 1 W laser etching produced a clinically acceptable mean SBS (Reynolds, 1975), some results were below acceptable limits and, in agreement with a previous study (Üşümez *et al.*, 2002), indicating that it is not suitable for enamel etching. Laser etching of 1.5 and 2 W demonstrated comparable mean, maximum, and minimum levels of SBS to that of acid etching.

Reynolds (1975) reported that 6–8 MPa were clinically acceptable bond strengths, whereas Maijer and Smith (1986) found 8 MPa to be adequate. In this study, the acid-etched specimen was the control group which showed a mean bond strength of 7.65 ± 1.36 MPa. Laser irradiation showed varying bond strengths between 2.94 ± 1.98 and 7.17 ± 1.69 MPa. In a previous study (Üşümez *et al.*, 2002), a similar bond strength was reported with acid etching (8.23 ± 2.3 MPa) and laser irradiation (5.64 ± 3.19 and 7.11 ± 4.56 MPa) indicating that the mean bond strengths in this study were reliable.

During orthodontic treatment, attachments are subjected to shear, tensile, and torsion forces. In the present investigation, shear–peel forces were generated. The relatively low bond strengths may be related to the forces

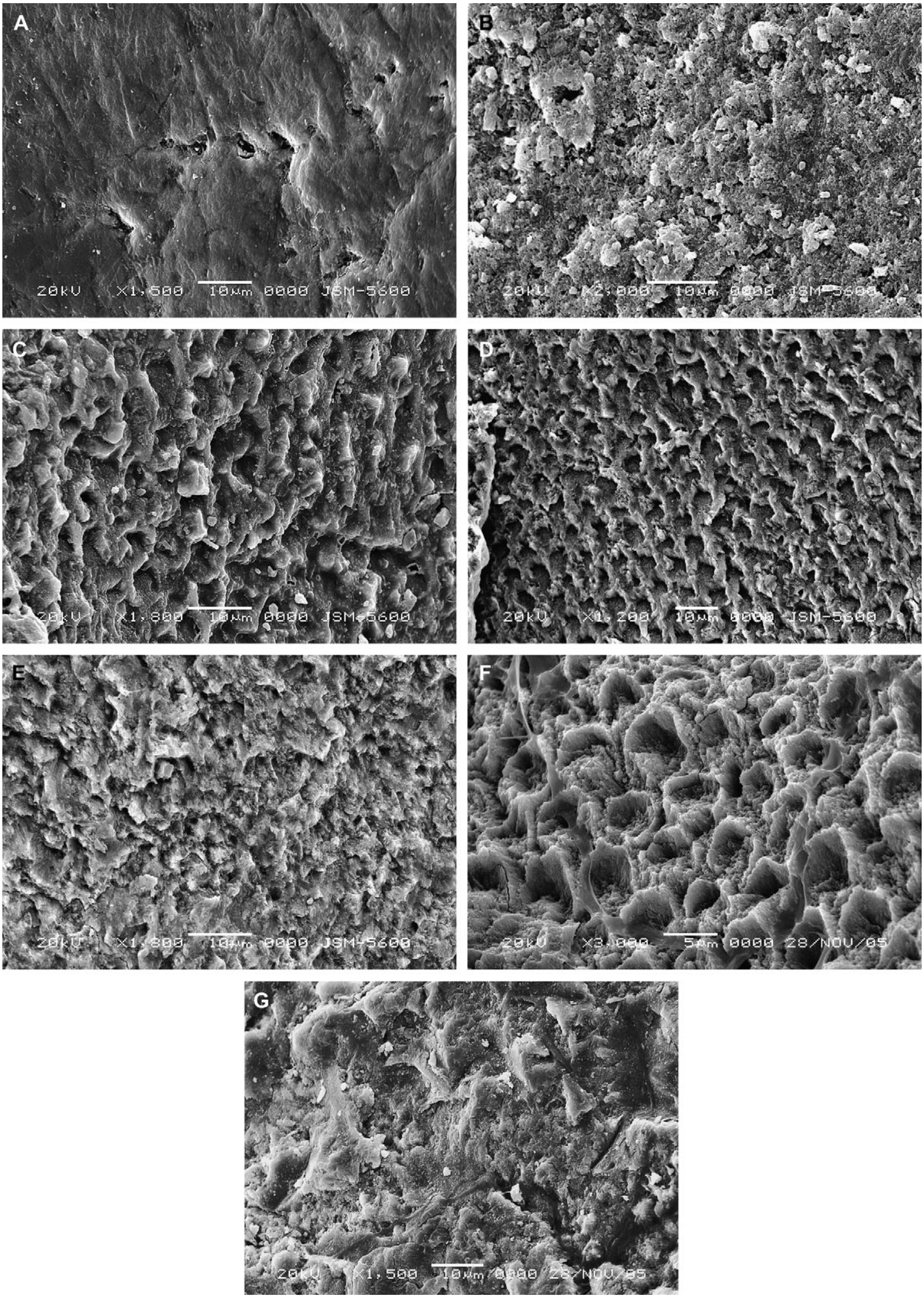

Figure 2 Scanning electron photomicrographs of enamel irradiated with an erbium, chromium-doped:yttrium-scandium-gallium-garnet laser with power output of (A) 0.5 W, (B) 0.75 W, (C) 1 W, (D) 1.5 W, and (E) 2 W, and (F) conventional acid etching and (G) sandblasting.

Table 3 Adhesive remnant index scores for acid etching, sandblasting, and laser irradiation with different power outputs.

	0	1	2	3
0.5 W	9	1		
0.75 W	7	3		
1 W	1	4	5	
1.5 W	1	5	3	1
2 W		4	4	2
Acid etching	1	4	4	1
Sandblasting	8	2		

generated. The technique sensitivity of the experiments is also an important factor. The storage of the specimens and the different configuration of enamel prisms on molars may also have contributed to the low bond strength values.

Sandblasting of the enamel in this study produced a lower shear–peel bond than clinically acceptable limits. It has been shown to be helpful to increase bond strengths on porcelain or amalgam surfaces (Zachrisson and Büyükyılmaz, 1993; Zachrisson *et al.*, 1995; Miller and Zernik, 1996).

There are some contradictory findings concerning the use of lasers for enamel etching. Some researchers (von Fraunhofer *et al.*, 1993; Üşümez *et al.*, 2002) stated that laser irradiation is not capable of etching enamel. However, the present findings are in agreement with Vissuri *et al.* (1996), Hossain *et al.* (2003), and Lee *et al.* (2003) who reported that laser irradiation may be used to etch enamel. These contradictory findings are due to the different outputs and experimental designs of the studies. The importance of using suitable settings is clearly highlighted by the findings of the present research. SEM demonstrated that 0.5 and 0.75 W laser irradiations were not able to etch enamel, but 1, 1.5 and 2 W irradiation produced preferable etching patterns. Fewer microcracks were produced with 1 W irradiation than 1.5 and 2 W. A Type I etching pattern was produced with 1 and 1.5 W, whereas a Type III pattern was produced with 2 W laser irradiation. The cavitations were not uniform with 2 W laser irradiation. Obtuse angularities and sharp irregularities were both seen on 2 W laser-irradiated surfaces, leading to the conclusion that outputs of 1 and 1.5 W are suitable to etch enamel.

The SBS obtained in the present study demonstrated wide variations. The 0.5 and 0.75 W laser-irradiated groups and the sandblasted group showed lower bond strengths than clinically acceptable limits (Reynolds, 1975). The mean SBS obtained with 1, 1.5 and 2 W laser irradiation and phosphoric acid was within acceptable limits. Some results for 1 W laser irradiation were below acceptable limits, so the use of 1 W laser irradiation must be questioned. Laser irradiation with an output of 1.5 and 2 W was more successful in producing acceptable etchings.

Sandblasting the enamel surface was not a good alternative for acid etching because the etched enamel was similar to the 0.5 W laser irradiation group. Although Chung *et al.* (2001) indicated, contrary to present results, that bonding attachments could be used on sandblasted enamel. This finding may be due to the different forces applied to debond. The sandblasted surfaces displayed obtuse angularities instead of the sharp irregularities of etched enamel surfaces which could lead to weak bond strengths. Improved SBS has been reported with sandblasting of the brackets or substances other than natural tooth (amalgam, porcelain) in combination with acid etching (Zachrisson and Büyükyılmaz, 1993; Büyükyılmaz *et al.*, 1995; Millett *et al.*, 1995; Zachrisson *et al.*, 1995; Miller and Zernik, 1996). They also reported unacceptable bond strengths with sandblasted tooth structures, as observed in the present investigation.

In a previous study (Üşümez *et al.*, 2002), the time used for etching enamel with laser irradiation was also 15 seconds. This was sufficient to scan a 4 × 6 mm area which was used in the present investigation to bond molar tubes. Sandblasting the selected area was performed for 10 seconds, which was followed by 15 seconds of air/water spraying. Acid etching was applied for 15 seconds and then 15 seconds of rinsing with air/water spray. Since etching the enamel by laser irradiation required no rinsing, a gain in chairside time of 15 seconds for each tooth was obtained. Although, the exact time required for etching was not determined, it is clear that laser etching takes less time thus reducing chairside time.

The ARI scores revealed differences between etching procedures. Generally, more adhesive was left on the enamel surface with low-power laser irradiation. This demonstrates that shallow etching patterns are unsuitable for bonding.

While less chair time is needed when less adhesive is left on the enamel, it may cause enamel fracture while debonding. Breakage at the bracket adhesive interface is safer, but the time spent to clean the tooth after debonding results in an increase in chair time. The ARI scores obtained in the present research with suitable etching procedures (1, 1.5, and 2 W and phosphoric acid) were generally 1 and 2, which means that adhesive was left both on the bracket and on the tooth.

Since the handpiece of Er,Cr:YSGG laser is light, its manipulation is easy. Unnecessary etching of the enamel is prevented with Er,Cr:YSGG laser. The handling in the posterior segments of the mouth could be problematic because of the cheek muscles.

Conclusions

1. Sandblasting and low-power laser irradiation (0.5, 0.75, and 1 W) are not capable of etching enamel suitable for orthodontic molar tube bonding.
2. Laser irradiation with outputs of 1.5 and 2 W could be a viable alternative to the conventional acid-etch technique.

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