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Super pulse CO_2 laser for bracket bonding and debonding

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SUMMARY A super pulse and a normal pulse CO_2 laser were used to carry out enamel etching and bracket debonding *in vitro* and *in vivo*. The shear bond strength of the orthodontic brackets attached to laser-etched and conventional chemically-etched extracted premolars was measured. The pulp cavity temperature was also measured using the same laser irradiation conditions as the shear test.

Both super pulse and normal pulse CO_2 laser etching resulted in a lower shear bond strength (super pulse: 6.9 ± 3.4 kg, normal pulse: 9.7 ± 5.2 kg) than that of chemical etching (15.3 ± 2.8 kg). Furthermore, the super pulse CO_2 laser was able to create debonding at 2 watts within a period of less than 4 seconds (2.9 ± 0.9 seconds). The super pulse, when irradiating the ceramic brackets from above, during debonding showed a 1.4°C temperature increase in the dental pulp at 2 watts and an increase of 2.1°C at 3 watts. While etching, directly irradiating the enamel surface at 3 watts, the dental pulp showed a temperature increase of 3.5°C. These temperature increases were within the physiologically acceptable limits of the pulp.

These results indicate that, in orthodontic treatments, super pulse CO_2 laser debonding is more useful than laser etching.

Introduction

There are several reports regarding the application of CO_2 lasers to tooth surfaces for etching (Cooper *et al.*, 1988; Walsh, 1991, 1996; Neiburger, 1992; Walsh *et al.*, 1994), Nd:YAG laser etching (Fraunhofer *et al.*, 1992; Roberts-Harry, 1992) and laser debonding (Strobl *et al.*, 1992; Mimura *et al.*, 1995; Obata, 1995). Previously, Mimura *et al.* (1995) and Obata (1995) have reported on the effects of ceramic bracket debonding using normal pulse CO_2 lasers. 4-META MMA resin bonded brackets were found to be easier to remove than those of Bis-GMA resin when using the normal pulse CO_2 laser associated with small quantities of illuminated energy. There was a slight increase in pulpal temperature, but pathological damage to the tooth pulp was not observed (Obata, 1995).

Nd:YAG laser etching, for the bonding of orthodontic brackets, cannot be recommended because of the numerous bracket failures (Roberts-Harry, 1992). Moreover, Fraunhofer *et al.* (1992) using the same equipment, found that the shear bond strength of brackets was the same as etching only when the maximum output of the laser was utilized. Very little research has been carried out on the application of normal (Mimura *et al.*, 1995; Obata, 1995) and super pulse CO_2 lasers to tooth surfaces for orthodontic treatment. Notably, super pulse CO_2 lasers provide short duration pulses (microseconds) separated by sufficient time to allow the tissue to cool between the pulses and, as a result, limit thermal damage (Ben-Baruch *et al.*, 1988; Christopher *et al.*, 1995). The aim of this study was therefore to compare super pulse CO_2 lasers with normal pulse CO_2 lasers to determine the shear force effect achieved after laser etching and laser debonding. In addition, the increase in temperature in the pulp cavity was measured to compare pulp temperature results with the previously published critical values for pulp survival.

Materials and methods

Laser

The lasers used in this study were a super and a continuous wave normal pulse CO_2 laser with a wavelength of 10.6 μm diameter. Both lasers' modes were generated by one apparatus (LX-20SP, LUXAR, Bothell, WA, USA). Super pulse CO_2 lasers provide short duration pulses (gated pulse width: 1–500 milliseconds, pulse width: 200–800 microseconds) separated by sufficient time to allow the tissues to cool between pulses, thus limiting thermal damage and causing minimal carbonization. Normal pulse CO_2 lasers (gated pulse width: 5–500 milliseconds) on the other hand, have a tendency towards charring and thermal necrosis.

Brackets

Stainless steel brackets (Rocky Mountain, Denver, USA) were selected for laser etching, and ceramic (polycrystalline alumina) brackets (Transcend series 6000, 3M/UNITEK, Monrovia, USA) for laser debonding. The ceramic brackets were the same as those used in previous studies (Mimura *et al.*, 1995; Obata, 1995). These brackets have approximately the same shape and adhesion area (height 2.0 mm, base area 3.5 × 2.0 mm) as those used for maxillary premolar.

Tooth preparation

Two-hundred-and-thirty extracted, non-carious, permanent maxillary premolars, stored in 70 per cent ethanol, were used. The teeth were cleaned with water, polished, rinsed, and dried. The roots were cut away and the crowns were embedded in resin blocks (Figure 1).

Laser etching

Four etching methods were used: laser only; laser etching followed by chemical etching; chemical etching followed by laser etching; and chemical etching as a control. The normal and super pulse laser output level was 3 watts. The size of the etched area corresponded to the bracket base area. The laser etching time was 3 seconds and for chemical etching, using 37 per cent orthophosphoric acid, 45 seconds. Stainless steel brackets were then attached to the tooth surfaces with 4-META MMA resin (Superbond, Sunmedical, Kyoto, Japan; n = 10).

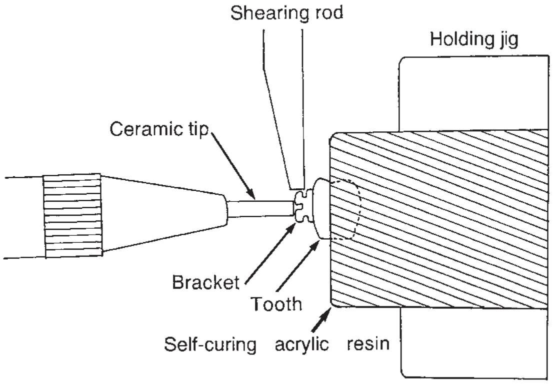

Figure 1 Experimental set-up for shear bond strength and tooth embedding procedure in resin.

Shear bond strength measurement

The teeth with the bonded brackets were stored in 37°C water for 24 hours and then set in a universal testing machine (Autograph AG-5000D, Shimadzu, Kyoto, Japan). This machine was used so that the shear force could be applied to the bracket-enamel interface up to the point of the fracture (Figure 1). In laser debonding, the laser tip was placed just separate from the bracket. Laser irradiation was started at the moment the compression cell touched the bracket at which time 3 kg of force was fully applied. The cross-head speed was 1 mm/min.

Laser debonding

The ceramic brackets were attached to the chemically etched tooth surfaces with 4-META MMA resin. A clinical study (*in vivo*) was performed by one operator, initially carrying out laser debonding, followed by applying a rotational force with tweezers to disengage the bracket. The time required to remove the brackets was

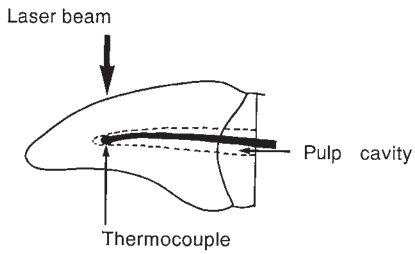

Figure 2 Position of the thermocouple on the tooth and the direction of laser beam.

considered to reflect the degree of loosening after the pulsed CO_2 laser irradiation (n = 10). Bracket debonding times after normal and super pulse irradiation were compared at 2, 3, and 4 watts irradiation. The shear force was then measured *in vitro* using 2 and 3 watts generated by the super pulse laser (n = 20). These output levels were determined from the *in vivo* study.

Temperature measurements

Temperature measurements of laser irradiated teeth were performed at a constant temperature of 23°C and humidity of 60 per cent. The teeth used for pulp temperature measurements had space for the thermocouple prepared under the laser beam level (Figure 2). A–K type thermocouples (Omega Engineering Inc., Stanford, USA) were inserted into the previously excavated pulp cavity and then placed within the internal dentinal surface under the laser beam level. The position of the thermocouples was verified radiographically. The thermocouples were then connected to an X–Y chart recorder (TOA, Tokyo, Japan). The apparatus was checked against a calibrated water bath. The temperature measurement experiment was divided into two groups, (1) the bracket adhesion group (as predicted for debonding) where the laser tip was in contact with the bracket, and (2) the bracket non-adhesion (without bracket) group (as predicted for the bonding), where the thickness of a bracket separated it from the tooth surface. Power settings for the adhesion group were 2 and 3 watts, and for the bracket non-adhesion group, 3 watts (n = 20).

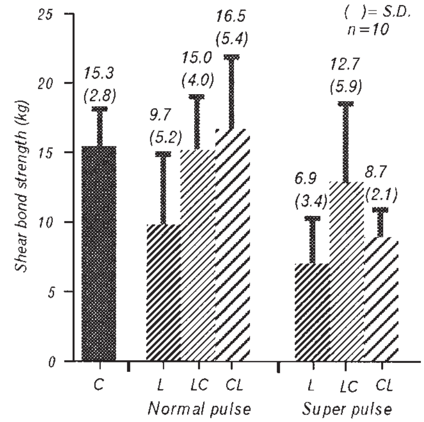

Figure 3 Effects of various laser etching methods on shear bond strength. C: chemical etching (control); L: laser etching; LC: chemical etching followed by laser etching, CL: laser etching followed by chemical etching.

For statistical analysis of the experimental data the Student's t-test was used.

Results

Laser etching

Laser etching followed by chemical etching in the normal pulse group resulted in the highest shear bond strength of the various laser etching methods. However, chemical etching followed by laser etching and the laser etching followed by chemical etching in the normal pulse groups, as well as chemical etching followed by laser etching in the super pulse groups showed no significant difference from the chemical etching (control) group. Generally, it was found that the laser etching groups had a lower bond strength than the chemical etching (control) group (Figure 3 and Table 1).

Laser debonding

The time needed for removal of the bracket by tweezers was shorter for the super pulse than for the normal pulse group. Statistically, the normal pulse and super pulse 2-watt group differed at the 1 per cent level of significance, but for the 3- and 4-watt groups no significant differences could be demonstrated. Bracket removal in the

Table 1 Comparison of bond strength values between different laser etching methods.

			Normal pulse			Super pulse		
		C	L	LC	CL	L	LC	CL
	C	–	$P < 0.01$	NS	NS	$P < 0.01$	NS	$P < 0.01$
Normal pulse	L		–	$P < 0.01$	$P < 0.01$	NS	NS	NS
	LC			–	NS	$P < 0.01$	NS	$P < 0.01$
	CL				–	$P < 0.01$	NS	$P < 0.01$
Super pulse	L					–	$P < 0.01$	NS
	LC						–	$P < 0.05$
	CL							–

NS, non-significant.

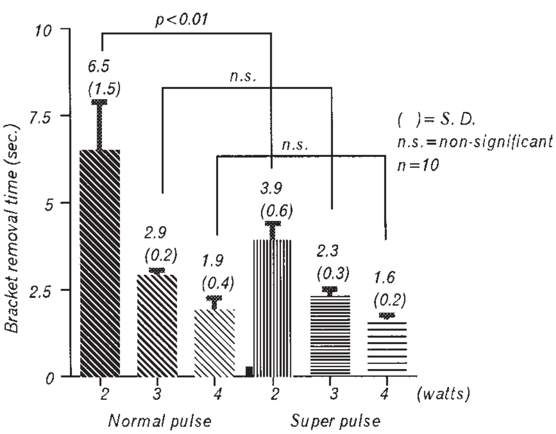

Figure 4 Bracket removal time using tweezers.

super pulse 2-watt group could be carried out in less than 4 seconds (Figure 4). There was no significant difference in the shear bond strength after super pulse 2- and 3-watt laser debonding (Table 2).

Pulp cavity temperature

Figure 5 shows the mean pulp cavity temperatures. The bracket adhesion group resulted in lower temperatures than the bracket non-adhesion group. Moreover, the temperature in the 2-watt group was lower than the 3-watt group. The bracket adhesion group at 2 watts resulted in a pulp cavity increase of only 1.4°C.

Discussion

The properties of a CO_2 laser cause tissue to become absorbent. When comparing the same energy levels of both normal and super pulses, normal pulses were chiefly of a continuous wave, at millisecond duration pulses and heat accumulated. On the other hand, the super pulse CO_2 laser limits thermal damage (Ben-Baruch *et al.*, 1988; Christopher *et al.*, 1995). Accordingly, a comparison of super pulse and normal pulse, using debonding and etching specifically, was made in this study.

Table 2 Shear bond strength and bracket removal time for super pulse CO_2 laser-aided debonding.

	Shear bond strength (kgf)		Bracket removing time (seconds)	
2 watts	4.7 ± 0.9	NS	2.9 ± 0.9	NS
3 watts	4.2 ± 0.7		2.5 ± 0.5	

± = SD; NS, non-significant; $n = 20$.

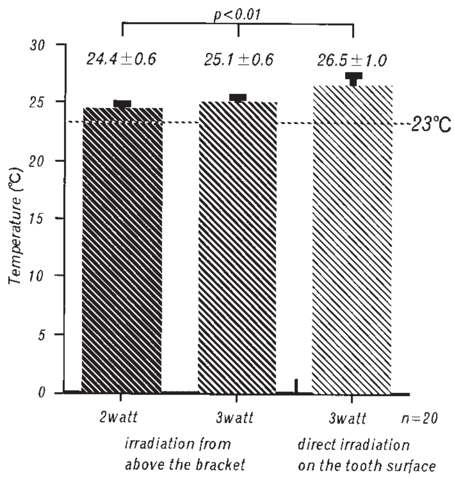

Figure 5 Super pulse CO_2 laser irradiated pulp cavity temperature (°C); baseline temperature is 23°C.

Laser etching

The main reason for the change in order of procedure, either chemical and then laser, or *vice versa* is that laser irradiated tooth surfaces have a grazed effect and chemically etched tooth surfaces a roughened effect. Consequently, it was expected that these variant morphological patterns on tooth surfaces would result in various bond strengths.

Chemical etching is commonly used for comparison when discussing the bond strength of laser etching (Cooper *et al.*, 1988; Anic *et al.*, 1991; Fraunhofer *et al.*, 1992; Walsh *et al.*, 1994; Stratmann *et al.*, 1995; Visuri *et al.*, 1996). The results of this investigation indicate that laser etching produces a lower bond strength when compared with chemical etching. In other words, only the combination of laser etching and chemical etching is capable of equalling the bond strength produced by that of the chemical etching group. An increase in laser power levels or irradiation time may cause higher adhesive properties, but it also may create irreversible, detrimental effects to the tooth pulp.

It has been shown (Walsh *et al.*, 1994) that laser etching, under almost all conditions, has a lower bond strength than acid etching. This current experiment provides corresponding results.

Laser debonding

It has previously been reported that normal pulse irradiation at 3 watts for 3 seconds is the ideal condition for CO_2 laser debonding, and it has been postulated that the 4-META MMA resin contraction from the brackets, combined with the thermal softening of the resin, formed the basis of the normal pulse CO_2 laser-aided debonding mechanism (Mimura *et al.*, 1995; Obata, 1995). This study has confirmed that it is possible to utilize the super pulse CO_2 laser at 2 watts for 3 seconds for debonding. Hence, this lower total irradiation energy is expected to minimize the pulp damage.

A characteristic of the super pulse CO_2 laser is the generation of high energy pulses over a short time interval (Ben-Baruch *et al.*, 1988; Christopher *et al.*, 1995). This physical property may cause vibrations in the adhesion material's molecular structure, and possibly induce a lower power output setting and lower thermal effect.

Temperature change

Super pulse CO_2 laser irradiation at 3 watts when used for etching caused a temperature increase of 3.5°C, which is 50 per cent lower than after normal pulse irradiation (6.6°C). Furthermore, when irradiation for debonding (bracket adhesion group) was carried out, irradiation at 3 watts caused temperatures between the super pulse (increasing temperature: 2.1°C) and normal pulse (increasing temperature: 2.7°C) which were not significantly different. However, debonding could be achieved at 2 watts when using the super pulse CO_2 laser. Therefore, the pulp cavity temperature increase, when using the super pulse 2-watt laser debonding technique, was only 1.4°C. This temperature is lower than the temperature threshold for the occurrence of pulpal damage according to several studies (Pohto and Sheinin, 1957; Zach and Cohen, 1965; Serebro *et al.*, 1987; Goodis *et al.*, 1988; Rickoff *et al.*, 1988).

No temperature-related pulp damage was measured in a previous experiment (Obata, 1995). The super pulse CO_2 laser used for debonding in this study produced temperatures in the pulp cavity that were even lower than those found by Obata (1995). Therefore, the present findings suggest that using a super pulse CO_2 laser for debonding does not result in a risk of pulp damage.

Conclusions

Experimental conditions were consistent with protocols for the safety of tooth pulp. Therefore, laser power levels and irradiation times were set as low as possible. The super pulse CO_2 laser has short duration pulses and other properties limiting thermal damage. Consequently, with respect to the present experimental conditions for the super pulse CO_2 laser, it was possible to minimize power levels (2 watts) and obtain a smaller increase in temperatures compared with normal pulse irradiation for laser debonding. Furthermore, the shearing bond strength of laser etching was less than that of the chemical etching group. In this case, the shear bond strength for laser and chemical joint application, and chemical etching were approximately the same. It is concluded that laser debonding is clinically useful when the super pulse CO_2 laser is applied for orthodontic treatment. Further research is necessary for the selection of suitable laser parameters for improving etching procedures.

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References

Anic I, Pavelic B, Vidovic D, Tudja M 1991 Composite retention area produced by CO_2 laser beam. Acta Stomatologica Croatica 25: 157–160

Ben-Baruch G, Fidler J P, Wessler T, Bendick P, Schellhas F 1988 Comparison of wound healing between chopped mode super pulse mode CO_2 laser and steel knife incision. Lasers in Surgery and Medicine 8: 596–599

Christopher H Q *et al*. 1995 Laser resurfacing in pigmented skin. Dermatologic Surgery 21: 1035–1037

Cooper L F, Myers M L, Nelson D G A, Mowery A S 1988 Shear strength of composite bonded to laser-pretreated dentin. Journal of Prosthetic Dentistry 60: 45–49

Fraunhofer J A, Allen D J, Orbell G M 1992 Laser etching of direct bonding. Angle Orthodontist 63: 73–76

Goodis H E, Schein B, Stauffer P 1988 Temperature changes measured *in vivo* at the dentinoenamel junction during cavity preparation in the *Macaca fascicularis* monkey. Journal of Endodontics 14: 336–339

Mimura H, Deguchi T, Obata A, Yamagishi T, Ito M 1995 Comparison of different bonding materials for laser debonding. American Journal of Orthodontics and Dentofacial Orthopedics 108: 267–273

Neiburger E J 1992 Evaluation of the CO_2 laser for endodontic root apex welding. Journal of the Massachusetts Dental Society 41: 77–79

Obata A 1995 Effectiveness of CO_2 laser irradiation on ceramic bracket debonding. Journal of Japan Orthodontic Society 54: 285–295

Pohto M, Sheinin A 1957 Microscopic observations on living dental pulp, Part 2. Acta Odontologica Scandinavica 24: 303–314

Rickoff B, Trowbridge H, Baker J, Fuss Z, Bender I B 1988 Effects of thermal vitality tests on human dental pulp. Journal of Endodontics 14: 482–485

Roberts-Harry D 1992 Laser etching of teeth for orthodontic bracket placement: a preliminary clinical study. Lasers in Surgery and Medicine 12: 467–470

Serebro L, Segal T, Nordenberg D, Gorfil C, Bar-Lev M 1987 Examination of pulp following laser beam irradiation. Lasers in Surgery and Medicine 7: 236–239

Stratmann U, Schaarschmidt K, Schurenberg M, Ehmer U 1995 The effect of ArF-excimer laser irradiation of the human enamel surface on the bond strength of orthodontic appliances. Scanning Microscopy 9: 469–476

Strobl K 1992 Laser-aided debonding of orthodontic ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 101: 152–158

Visuri S R, Gilbert J L, Wright D D, Wigdor H A, Walsh J T Jr 1996 Shear strength of composite bonded to Er: YAG laser-prepared dentin. Journal of Dental Research 75: 599–605

Walsh L J 1991 Enamel fusion using a carbon dioxide laser: a technique for sealing pits and fissures. Clinical Preventive Dentistry 13: 16–20

Walsh L J 1996 Split-mouth study of sealant retention with carbon dioxide laser versus acid etch conditioning. Australian Dental Journal 41: 124–127

Walsh L J, Abood D, Brockhurst P J 1994 Bonding of resin composite to carbon dioxide laser-modified human enamel. Dental Materials 10: 162–166

Zach L, Cohen G 1965 Pulp response to externally applied heat. Oral Surgery, Oral Medicine, Oral Pathology 19: 515–530