Original Article

Polymerization with the Argon Laser: Curing Time and Shear Bond Strength

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Abstract: The objective of this study was to determine the efficiency of an argon laser in polymerizing a light-cured orthodontic adhesive. Metal brackets were bonded to 185 premolars, divided into 5 different protocol groups of 37 each as follows: light 40-second buccal, light 40-second lingual, laser 5-second lingual, laser 10-second lingual, and laser 15-second lingual. All bonded specimens were placed in distilled water for 30 days at 37°C followed by thermal cycling for 24 hours. Brackets were detached using a shear-peel load delivered by an Instron machine. The site of bond failure was examined under 10× magnification. The difference in the shear-peel bond strength between the light 40-second buccal (13.31 MPa) and the light 40-second lingual (11.95 MPa) groups was not statistically significant. The mean shear-peel bond strengths for the laser cured groups were quite similar for the 5-, 10- and 15-second laser groups (10.86, 11.32, and 10.80 MPa). The difference in mean lingual bond strength between the light 40-second and laser 5-second groups was not statistically significant ($t = 1.26$; $P = .212$). The adhesive remnant index analysis revealed principally cohesive bond failures. An increased frequency of enamel fractures at debond was noted in the lingual light-cured and 10-second laser-cured groups, at 35.1% (13/37) and 21.6% (8/37), respectively. All other groups displayed enamel fractures of 16.2% (6/37). A 5-second cure using an argon laser produced bond failure loads comparable to those obtained after 40 seconds of conventional light cure, with less than half the frequency of enamel fracture at debond. (*Angle Orthod* 2000;70:28–33.)

Key Words: Argon laser, Orthodontic bonding, Shear bond strength

INTRODUCTION

Notwithstanding improvements in orthodontic bonding materials,[1] decreased curing time for bonding orthodontic attachments is an important aspect of clinical success. Recently, the argon laser has been marketed as an alternative to conventional light-curing units for quick, safe, and effective polymerizing of composite resins.[2]

Camphorquinone, the photoinitiator in most visible-light–cured adhesives,[3,4] is highly sensitive to light in the blue region of the visible light spectrum and has a peak area of absorption at 470 nm.[3–5] Wavelengths outside this blue band have little or no effect in stimulating camphorquinone to initiate the polymerization reaction.[4,5] The light-output characteristics of commonly used visible-light-curing units have been found to be inconsistent.[4,6] These units produce light that has a broad (120 nm) bandwidth that typically falls between 400 nm and 520 nm.[2,4,5] The resultant energy density is commonly around 400 mW/cm^2, with the light intensity decaying at geometric progression with distance.[2,5,7] In contrast, laser light has a single, narrow band of wavelength that travels in parallel waves that are in phase spatially and temporally.[2,7,8] The argon laser operates within a combined bandwidth[2] that encompasses 42 nm (between 454 nm and 496 nm) of the visible light spectrum, with an intensity that approaches 800 mW/cm^2. The wavelength specificity of the argon laser, coupled with the ability to consistently emit visible light with substantial energy density without any wasted or unusable emissions,[2] has been shown to enhance the physical properties of composite resins by achieving a more thorough cure with up to 75% shorter exposure time compared with conventional light-curing units.[9–12]

Attempts have been made to increase the output energy

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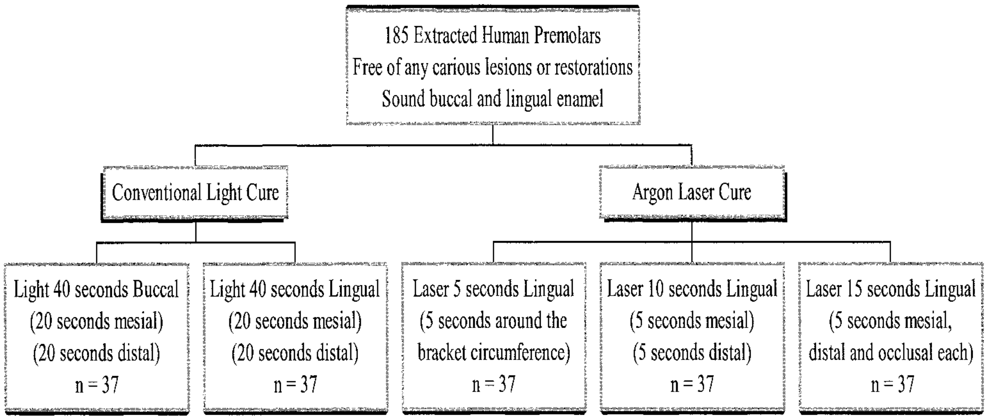

FIGURE 1. Diagrammatic representation of the study specimen group.

of conventional curing lights, but adding intensity without narrowing the bandwidth may be hazardous to the tooth due to heat buildup.[2] With the argon laser, the power output and curing time may be consequential determinants of its thermal effect upon the pulp.[13–15] However, Powell et al.[15] have determined that at energy densities needed for laser polymerization of light-cured materials, no apparent damage would be expected to the pulp or enamel.

The curing time required for bonding metal brackets using a conventional light unit is debatable. The manufacturer's directions for light-curing an individual metal orthodontic bracket with Transbond XT (3M Unitek, Monrovia, Calif) is a total of 20 seconds.[16] In contrast, a 40-second curing time has been suggested by Oesterle et al[16] and Wang and Meng[17] who separately found that brackets coated with Transbond and exposed to visible light for 40 seconds had stronger bonds than those exposed for only 20 seconds. Several researchers have used the argon laser shorter curing times and achieved bond strengths comparable to those attained by conventional light-curing units.[18–21] Sedivy and associates[20] concluded that at 1 watt (W) of power, a 4-second laser exposure of Transbond adhesive produced tensile strengths comparable to a 30-second exposure to a standard curing light. More recently, Kurchak et al[19] concluded that 10 seconds of argon laser exposure at 250 milliwatts (mW) produced tensile strengths similar to conventional light-curing methods for metal brackets. Weinberger and colleagues[21] found no difference in shear bond strengths of ceramic brackets between a 40-second light cure and a 10-second argon laser cure at 231 mW with Transbond.

Recent studies[18–21] are inconclusive regarding the ideal laser curing time; in vitro bonding tests have been performed with limited sample sizes and without thermal cycling. Fox et al[22] noted that ''If valid conclusions are to be drawn from in vitro bond strength testing, at least 20—and preferably 30—specimens should be used per test.'' Furthermore, Buonocore[23] advised thermal cycling of the specimens in order to assess the durability of the bond; otherwise, he warned, ''such results may not be indicative of the effect on bond strength of long-term immersions under oral moisture conditions.''

The intent of the present study was to determine the most appropriate in vitro curing time with an argon laser to polymerize a light-cured orthodontic adhesive; and to compare the shear-peel bond strength and the occurrence of enamel fracture between different curing methods and times.

MATERIALS AND METHODS

Initially, orthodontic bonding to buccal surfaces of 185 premolar teeth was attempted with a conventional curing light (3M Unitek; $n = 37$) and a portable argon laser ($n = 148$). However, the portable argon laser was found to be erroneously calibrated after bonding, and this rendered the laser-cured bond results invalid. Due to preference for using human premolars for bond strength testing in orthodontics, and their limited supply,[22] the study was revised to use the lingual surfaces of the same premolars and a different argon laser (ILT Systems, Salt Lake City, Utah). Previous research has shown that in vitro lingual bond strengths are comparable to labial bond strengths and that the parameters for labial and lingual bonding should be identical.[24]

The buccal surfaces of 37 premolars and the lingual surfaces of 148 premolars, all with sound enamel, were used. The specimens were divided according to curing method into 5 groups of 37 (Figure 1). The teeth were stored in distilled water at room temperature for the time interval between extraction and the bonding agendum, which was approximately 6 months. Thymol crystals were added to inhibit bacterial growth during storage of the specimens.

Stainless steel premolar brackets (.022 Roth Rx metal micromesh, ''A'' Company, San Diego, Calif) were bonded using Transbond XT light-cured adhesive. The bonding surfaces were cleaned for 15 seconds at slow speed with a slurry of fluoride-free pumice (Reliance Orthodontic Products, Itasca, Ill), rinsed with water for 15 seconds, and dried with oil-free compressed air. The enamel surface was etched for 30 seconds with 37% phosphoric acid gel (3M Unitek) followed by a 30-second water lavage. Transbond XT primer was painted onto the etched surface and thinned with a gentle stream of compressed air. The adhesive paste was applied to the bracket base and pressed with the dispenser into the undercuts of the base mesh. A Hollenback carver was used to press the bracket firmly at the center of the tooth. Excess adhesive was removed from around the bracket base without disturbing the bracket position.

The 2 curing devices used were the Optilux 500 (3M Unitek) conventional curing light and the ILT Argon Laser (ILT Systems). To ensure the specified power output, the manufacturers' recommendations on calibration densities were followed before and after use with each group. All curing was accomplished in a noncontact mode, with the curing device close to the tooth-bracket junction but not touching it.

All bonded specimens were placed in a 100% humidor for 24 hours, after which they were transferred to an incubator and stored for 30 days in distilled water at 37°C. Following incubation, the samples were stressed further by thermal cycling for 25 consecutive hours. Each thermal cycle consisted of immersing the bonded specimens in water for 30 seconds at 10°C immediately followed by 30 seconds at 55°C, for a total of 1500 successive cycles.

A reproducible method of debonding was employed by mounting each specimen in standardized 2.5 × 4.0 × 2.5 cm acrylic (Caulk Dentsply, Milford, Del) blocks to simulate the height of normal bone. The brackets were detached with a shear-peel load applied by an Instron universal testing machine (Instron Corp, Canton, Mass). To prevent the Instron plunger from deforming the brackets, each bracket slot was fitted with a segment of a 021 × 025 stainless steel wire ligated with a steel ligature. To limit variation in the direction of the debonding force, the plunger was placed perpendicular to the orthodontic bracket. Each specimen was then stressed at the junction of the bracket and adhesive in an occlusogingival direction with a 50 kg load cell at a crosshead speed of 0.5 mm/min.

The debond load exerted at failure was recorded in ink on a strip chart recorder. The kilogram value was divided by the bracket base size (13.654 mm^2) to provide the force per unit area or stress (kg/mm^2) required to dislodge the bracket. Bond strength values were converted to megapascals (MPa) by multiplying the kg/mm^2 values by 9.81.

Following debonding, the site on the tooth was examined under 10× magnification with a light microscope. The amount of residual adhesive left on the teeth was assessed according to the adhesive remnant index (ARI).[25] A score of 0 indicated no adhesive was left on the enamel, 1 indicated less than half the adhesive remained on the enamel, 2 indicated more than half the adhesive remained on the enamel, and 3 indicated that all the adhesive was left on the enamel. Debonds that resulted in enamel fracture were noted as EF.

TABLE 1. Shear Debond Strength (MPa) Required to Debond Orthodontic Brackets Attached with Resin and Cured Using the Conventional Light Source for 40 Seconds and the Argon Laser for 5, 10, and 15 Seconds

	Shear Debond Strength (MPa)*				
Variable	Mean	SD	Minimum	Maximum	n
Light 4-second buccal	13.31	3.80	4.80	21.86	37
Light 40-second lingual	11.95	3.71	3.69	20.82	37
Laser 5-second lingual	10.86	3.73	4.77	18.77	37
Laser 10-second lingual	11.32	5.06	3.78	24.11	37
Laser 15-second lingual	10.80	3.46	4.52	19.70	37

* MPa indicates megapascals; SD, standard deviation; and n, number of specimens per group.

A paired *t*-test was used to determine the statistical significance in the modified shear bond strengths between the light 40-second buccal and light 40-second lingual groups. A 1-way analysis of variance (ANOVA) was used to determine the statistical significance in the shear-peel bond strength between the 5-, 10-, and 15-second laser groups. Finally, a *t*-test was used to compare the mean lingual modified shear debond stress between the light 40-second and laser 5-second groups. P-values $< .05$ were considered statistically significant.

RESULTS

The mean shear-peel bond strengths, standard deviations, and ranges for all 5 curing methods are listed in Table 1. The 40-second light-cure group exhibited slightly stronger shear debond strength on the buccal surface (13.31 MPa) than on the lingual surface (11.95 MPa). A *t*-test ($t = 1.56$; $P = .124$) comparing the difference between the 2 means was not statistically significant. The mean shear debond strength for the 5-, 10-, and 15-second laser groups were 10.86, 11.32, and 10.80 MPa, respectively. The results of a 1-way ANOVA were not statistically significant ($F = 0.1768$, $P = .832$). The results of a *t*-test used to compare the mean lingual shear debond strength between the light 40-second and laser 5-second groups were not statistically significant ($t = 1.26$, $P = .212$.

Bond-failure analysis using the ARI revealed principally cohesive bond failures within the ARI range of 1 to 2 (Table 2, Figure 2). The frequency of enamel fracture at debond was 16.2% (6/37) for the light 40-second buccal, and laser 5-second and 15-second groups. In contrast, the incidence of enamel fracture was 21.6% (8/37) for the laser 10-second group and 35.1% (13/37) for the light 40-second lingual group.

DISCUSSION

Although occlusal loads show enormous individual variability, bond strength values of 60–80 kg/cm^2 (5.89–7.85

TABLE 2. Distribution of Adhesive Remnant Index (ARI) and Enamel Fracture Expressed as a Percentage (%) and Frequency (f) of Occurrence for All Curing Modes

	ARI = 0		ARI = 1		ARI = 2		ARI = 3		Enamel fracture		Total	
Variable	%	f	%	f	%	f	%	f	%	f	%	n
Light 4-second buccal	8.1	3/37	27.0	10/37	45.9	17/37	2.7	1/37	16.2	6/37	99.9	37
Light 40-second lingual	5.4	2/37	27.0	10/37	27.0	10/37	5.4	2/37	35.1	13/37	99.9	37
Laser 5-second lingual	8.1	3/37	29.7	11/37	40.5	15/37	5.4	2/37	16.2	6/37	99.9	37
Laser 10-second lingual	2.7	1/37	32.4	12/37	32.4	12/37	10.8	4/37	21.6	8/37	99.9	37
Laser 15-second lingual	8.1	3/37	40.5	15/37	5.1	13/37	0.0	0/37	16.2	6/37	99.9	37

* ARI scores are as follows: 0 indicates no adhesive was left on the enamel; 1, less than half the adhesive remained on the enamel; 2, more than half the adhesive remained on the enamel; and 3, all the adhesive was left on the enamel.

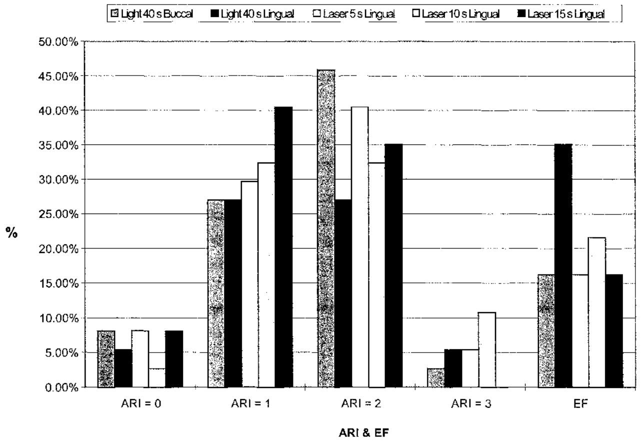

FIGURE 2. Distribution of the adhesive remnant index and enamel fracture (EF) as percent of occurrence.

MPa) have been reported to be clinically sufficient.[26] The use of lingual premolar surfaces for in vitro bond strength testing was deemed acceptable, given that the mean bond strength for the light 40-second buccal group (13.31 MPa) did not show clinical or statistical significance greater than the light 40-second lingual group (11.95 MPa). The methodology for bond strength testing in this study was identical to that reported by Meehan et al,[27] who found a mean shear debond strength of 11.23 MPa necessary to dislodge light-cured metal brackets bonded to the buccal surfaces of 40 premolars. The mean modified shear debond strength for the light and laser groups in this investigation ranged from 10.80 MPa to 13.31 MPa, indicating that acceptable bond strengths for orthodontic treatment purposes were achieved with both curing modalities.

The lack of standardization in the various bonding protocols[18–21] limits interstudy comparison;[22,28] nevertheless, the decreased curing time obtained with the argon laser in this study agrees with previous investigations.[18–21] Kupiec and colleagues[18] found no significant difference in the shear bond loads between the laser 15-second (12.40 MPa), laser 20-second (10.76 MPa), and light 40-second (11.69 MPa) groups; however, the same 3 groups had statistically significant higher bond strengths than the light 20-second (8.60 MPa) group.

To standardize the direction of the debonding force, each specimen was mounted in acrylic blocks. Fox et al[22] cautioned that a pure shear test may not be ensured, and factors such as the curvature of the enamel surface may influence the results. Furthermore, the ARI values are subjective; nevertheless, the index was useful in determining the percentage of bond failure sites by an ordinal ranking of the amount of resin remaining on the tooth after debond. O'Brien et al[29] determined that the ARI score was dependent upon many factors, including the bracket-base design and adhesive, and not simply the bond strength at the interface.

For all groups, an ARI score of 0 ranged from 2.7% to 8.1%, and an ARI score of 3 ranged from 0% to 10.8%. The rarity of an ARI score of either 0 or 3 suggested that adequate mechanical retention was present between the adhesive and bracket base and between the adhesive and enamel and that the weak link was within the adhesive itself. Increasing the laser curing time did not substantially affect the fracture site at debond. The ARI scores and rates of enamel fracture at debond for the 5-, 10-, and 15-second laser groups were comparable with each other and with the labial light group.

An interesting finding in this study was that enamel fracture at debond was more than twice as prevalent in the light-cured 40-second lingual group (13/37 ≈ 35%), suggesting that undesirable enamel damage may occur more frequently with in vitro lingual debonding of light-cured specimens. Enamel cracks are common in adolescent dentition regardless of orthodontic treatment, and this may increase the risk of eventual tooth fractures.[30] Retief[31] reported that the lowest bond strength at which fracture within the enamel at debond occurred was 9.7 MPa. Diedrich[32] earlier found that teeth with enamel fractures required tensile forces from 9 MPa to 11 MPa during bracket removal. The shear debond stress resulting in enamel fracture for the light 40-second lingual group in this investigation ranged from 3.69 MPa to 17.66 MPa, with a mean of 10.71 MPa. Enamel fracture for this group cannot be explained solely by bond strength at the interfaces, and therefore other factors may be responsible.[24,32–34]

The differences in fracture site observed in this study may be explained by an unpredictable response of the superficial enamel layer to the etching process. Similar to this study, Chumak et al[24] found that enamel fractures with loss of enamel fragments occurred with greater frequency on lingual surfaces when compared with labial surfaces. Diedrich[32] found that, in spite of identical pretreatment with phosphoric acid, the distribution and appearance of the enamel on the same tooth and from one tooth to another varied significantly. Diedrich[32] suggested that the location of the fracture site was dependent on the strength of the micromechanical retention produced by acid pretreatment.

Although speculative, the lower frequency of enamel fracture at debond for the laser groups may stem from a direct effect of the argon laser on enamel. Powell et al[33] found that demineralization was reduced when human enamel was exposed to the argon laser. Kelsey et al[34] found that the ‘‘exact parameters of laser power and exposure time seem to be material specific, with greater variation being noted in power setting than in exposure time.’’ Therefore, in addition to detailing the biological response of the enamel to the argon laser, future investigations will also be required to evaluate the optimum power and exposure times for other commercially available adhesives and orthodontic attachments.

SUMMARY AND CONCLUSIONS

An in vitro investigation was undertaken to determine the polymerization efficiency of the argon laser. A light-cured adhesive was used to bond metal brackets to 5 groups of 37 premolars, which were differentiated according to the curing mode and curing time. The findings were as follows:

1. With 40 seconds of light curing, the mean buccal-surface bond strength did not differ significantly from that of the lingual bonded group, which suggests that the lingual surface of premolars is acceptable for in vitro bond strength testing.
2. The efficacy of the argon laser as an alternative curing modality was resolved by the finding that mean lingual debond loads were comparable for the light- and laser-cured groups.
3. Increasing the argon laser curing time beyond 5 seconds did not result in significantly greater bond strength.
4. Lingual enamel fracture at debond was twice as common in the lingual light-cured group at 40 seconds compared with the other groups.
5. The ARI value at debond was not associated with laser-curing time.
6. At 300 mW of power, the argon laser required 87.5% less time than the conventional light-curing unit to obtain similar in vitro bond results. Therefore, it is recommended that the laser-curing time for bonded metal brackets be 5 seconds around the bracket circumference.

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