Original Article

Bracket Bond Strength with Transillumination of a Light-Activated Orthodontic Adhesive

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Abstract: The literature describes transillumination as a means of curing orthodontic light-cured composite adhesive. The literature also recommends a 2 to 3 times increase in light exposure time when light curing using transillumination. The purpose of this study was to determine the transmittance of the curing light through human enamel and the effect of transillumination on the bond strength of orthodontic brackets. One hundred extracted human maxillary incisors were used in this study. Brackets with orthodontic composite adhesive were placed on the labial surface of the incisors and light cured from either the labial or the lingual (transillumination). The control sample was cured from the labial for a total of 40 seconds of light exposure. Experimental samples were cured from the lingual (transillumination) for 20, 30, 40, or 50 seconds. The shear-peel bond strengths were tested at 30 minutes and 24 hours after light application. The results of this study demonstrated no statistically significant difference between 40 seconds of labial curing and most of the lingually cured groups. The only experimental group that differed statistically from the control group was the 40-second lingual cure group tested at 30 minutes after light application. Actual bond strengths, however, were lower for all experimental samples. The samples tested at 24 hours that received 50 seconds of transillumination were nearly the same as the control values. This study demonstrated that transillumination of maxillary incisors is an acceptable method of curing orthodontic adhesive, particularly if the exposure time is increased from 40 to 50 seconds. (*Angle Orthod* 2001;71:307–311.)

Key Words: Bonding; Brackets; Light cured; Transillumination

INTRODUCTION

The use of light-cured composite material for bonding orthodontic brackets has become increasingly popular among orthodontists. The advantages of increased time available to remove excess adhesive material from around the bracket base and to position the bracket outweigh the disadvantage of increased light curing time. The literature reports that labial curing of bracket adhesive for 40 seconds per bracket provides a balance between optimal strength and light-application time.[1]

Transillumination from the lingual to light cure composite resin material has been advocated. Transillumination directs light through the tooth to the composite material on the opposite side of the tooth. This method has been recommended when metal covers the majority of the composite material on the tooth, such as in cases of bonded fixed partial dentures[1] and metal orthodontic brackets.

Although transillumination has been suggested to cure composite under orthodontic brackets, there is little in the orthodontic literature to confirm its usefulness. It has been suggested as a means of curing composite under the older perforated metal bonding pads,[2] the newer metal foil-covered mesh bonding pads, lingual brackets,[2] lingual bonded orthodontic attachments,[3] and retainers.[3]

In the few studies reported, the sample size has either been small[4] or the study involved other than labially placed brackets.[4] One study reported placing orthodontic composite with brackets on the labial surface of the teeth of human volunteers. In one group of patients, the composite was cured by transillumination, and in the other group, the composite was cured by direct labial illumination. The composite of both groups was tested for microhardness. They reported that the microhardness and the degree of composite polymerization were less when the composite was cured from the lingual than when it was cured from the labial.[4]

Various authors have recommended increasing the length of time of light exposure when using transillumination. One author suggested tripling the curing time,[5] while another used 2 minutes of curing time when using transillumina-

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tion.[6] One study examined the bond strength of transilluminated lingual brackets on bovine teeth.[4] While bovine teeth have been shown to provide similar but lesser bond strengths than human teeth, the bovine enamel is much less regular and the tooth much larger than a human incisor tooth.[6] Although the authors found no relationship between tooth thickness and bond strength, the use of bovine enamel and the lack of a same-side-curing control leave open the question of the effect of transillumination on bond strength in human teeth.

The purpose of this study was to determine the curing light transmittance through human enamel and the effect of transillumination on the bond strength of orthodontic brackets.

METHODS AND MATERIALS

The sample used consisted of 100 extracted human maxillary central and lateral incisors. The curing light used was an Optilux 401 Curing Light (Kerr Dental Products, Orange, Calif), a conventional tungsten-quartz halogen light. An Ophir Power Meter (Ophir Optronics Inc, Littleton, Colo) was used to measure the power output in milliwatts (mW) under the various test conditions. The meter had a sensitivity of 10 mW.

Sixty of the incisors were selected for light transmission tests and were measured facolingually in the middle of the area where the bracket was placed. The measurements were made with a digital caliper held at right angles to the long axis of the tooth. The tooth, without a bracket in place, was then tested for light transmission. The curing light and the Ophir Power Meter were stabilized in a position that allowed a tooth to be placed between the curing light guide tip and the power meter sensor. The power meter is built with the light sensor surrounded by a large heat sink. This arrangement did not allow placement of the tooth directly on the sensor but rather above the sensor. In the standardized position, the center of the light guide tip was 13.43 mm from the center of the power meter sensor. The standardized position used was the closest possible position that allowed insertion of the tooth between the power meter and the light guide tip with the lingual surface of the tooth against the light guide tip. A light blocker was used that surrounded the tip of the light guide and sealed the lingual of the incisor tooth. The blocker was constructed individually for each tooth from green modeling clay. The blocker permitted the light to only strike the tooth and not shine around the tooth and affect the power reading. All of the light measured emanated from the labial surface of the tooth. Since the blocker varied with the size and shape of the tooth, a representative average reading of the power meter was made with 27 blocker/tooth combinations.

The adhesive utilized in this study was Transbond APC Adhesive (3M Unitek Corp, Monrovia, Calif) that is supplied by the manufacturer preapplied to the bracket base. A maxillary right central incisor Mini-Twin .018 bracket 2017-201 with a bonding surface area of 0.0153 in^2 or 9.8710 mm^2 (3M Unitek Corp) was used throughout the study for all samples.

Following receipt of the incisors, they were stored in a refrigerated Cloramine-T/distilled water solution. The extracted human maxillary incisors were cleaned and mounted in acrylic cylinders for ease of placement in the testing machine. A total of 100 samples were tested in test groups of 10 samples each. The enamel was etched with 37% phosphoric acid gel for 30 seconds, rinsed under running water for 20 seconds, and dried with oil- and moisture-free compressed air followed by warm air for 20 seconds from a warm-air dryer designed for bonding. Immediately following the drying, the samples were inspected for the characteristic dull, white, frosted appearance of adequately etched enamel before applying and air thinning the manufacturer-supplied primer. The bracket with the adhesive material was placed on the tooth, pressed firmly onto the enamel surface, any excess adhesive removed, final-positioned to the long axis of the mounting cylinder, and exposed to the curing light for the required time and direction.

For the control group, the light guide tip was held as close as possible to the adhesive layer by placing the guide tip on the tooth surface and the bracket face. The adhesive was cured for 20 seconds on the mesial of the bracket and 20 seconds on the distal of the bracket for a total curing time of 40 seconds. For the experimental group, the light was held as close to the lingual surface of the tooth as possible, opposite to the bracket, for exposure times of 20, 30, 40, and 50 seconds. Samples were tested at both 30 minutes and 24 hours after light curing. The 30-minute samples were allowed to bench cure in ambient light until testing. The 24-hour samples were stored in distilled water in a dark incubator at 37°C between bonding and testing.

The samples were tested for bond strength using an Instron universal testing machine (Instron Corp, Canton, Mass) in the shear-peel mode. For testing, the samples were placed in the lower jaw of the testing machine such that the bracket base was parallel to the direction of force. A stainless steel wire loop attached to the upper jaw of the testing machine was engaged under the gingival bracket wings to produce a shear-peel force parallel to the bracket base. The samples were stressed at a crosshead speed of 1 mm per minute in a gingivo-incisal direction and the maximum force at bond failure was recorded. Following bracket failure, the enamel surface was examined under a dissecting microscope and the amount of adhesive remaining on the tooth recorded using the adhesive remaining index (ARI).[6] The criteria for scoring were as follows: 0 = no adhesive on tooth; 1 = less than half of adhesive on tooth; 2 = more than half of adhesive on tooth; and 3 = all adhesive on tooth.

Appropriate statistical analyses of the results were performed on both the 30-minute and 24-hour data sets. For

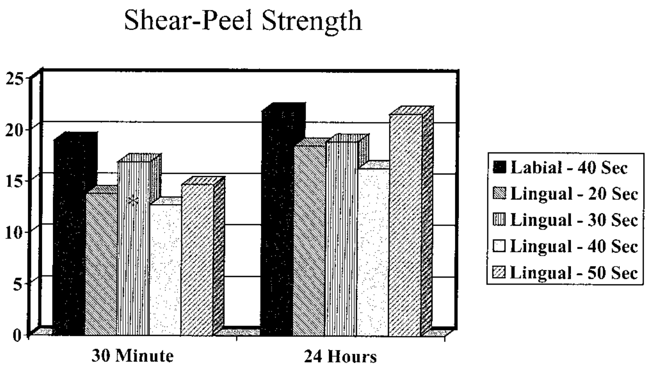

FIGURE 1. Mean shear peal strengths of the bracket bond in megapascals (MPa) for each test condition. The 40-second labial exposure was used as the control. Statistically significant differences from the control are indicated by *. Significance was determined at the $P < .05$ level.

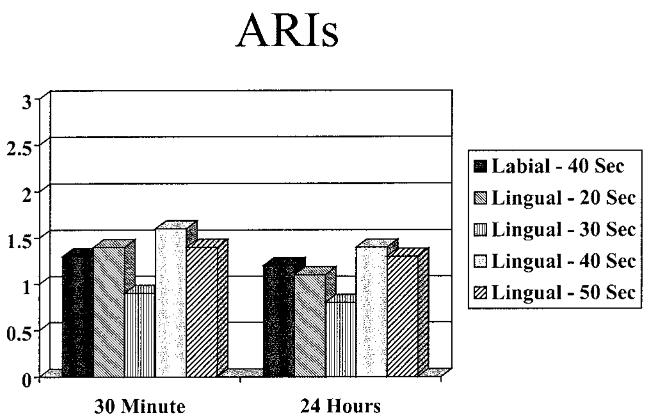

FIGURE 2. Mean adhesive remaining index (ARI) values of the bracket bonds for each test condition. The criteria used for scoring were 0 = no adhesive on tooth; 1 = less than half of adhesive on tooth; 2 = more than half of adhesive on tooth; and 3 = all adhesive on tooth. Statistically significant differences from the labially cured control are indicated by *. Significance was determined at the $P < .05$ level.

continuous numbers produced in bond strength testing, an analysis of variance with both a Scheffe and a Tukey post hoc test was used to determine any differences within each of the testing times. A Kruskal-Wallis nonparametric test was used to determine the existence of any statistical differences in the ordinal ARI values. Significance for all tests was established at the $P < .05$ level.

RESULTS

The results of this study are provided in graph form in Figures 1 and 2, with the actual data in Figures 3 and 4. The shear-peel bond strengths of all of the teeth cured from the lingual were lower than the labially cured control values. The values demonstrated an increase in bond strength with increasing light exposure except for the samples given 40 seconds of lingual light. In both the 30-minute and the

Mean and ARI Data

Light Exposure	30 Minutes		24 Hours	
	Mean & Std Dev (MPa)	ARI	Mean & Std Dev (MPa)	ARI
Control 40 Seconds Labial	18.8±3.6	1.3±1.3	21.7±3.3	1.2±1
20 Seconds Lingual	13.7±5.5	1.4±0.8	18.4±4.7	1.1±0.9
30 Seconds Lingual	16.8±2.7	0.9±0.3	18.8±5.1	0.8±0.4
40 Seconds Lingual	*12.6±5.0	1.6±0.8	16.2±3.9	1.4±1.3
50 Seconds Lingual	14.5±3.4	1.4±0.8	21.4±8.3	1.3±1.5

FIGURE 3. Means and standard deviations for the maximum force (MPa) required for debonding the brackets and the adhesive remaining index (ARI) means and standard deviations. Statistically significant differences from the labially cured control are indicated by *. Significance was determined at the $P < .05$ level.

Light Transmittance	
Average Tooth Thickness	4.21±0.40 mm
Light Power – tip fully against sensor	450 mw
Light Power – tip & meter standardized position	270 mw
Light Power–standardized position + clay blocker	186±15 mw
Light Power—stand. position+clay blocker+tooth	4.0±4.9 mw

FIGURE 4. Light transmittance data showing the mean and standard deviation of the labiolingual thickness of the measured teeth. Light power recorded for the standardized and test conditions.

24-hour test data, the 40-second samples demonstrated lower actual values than either the 30-second or 50-second values. However, the differences in bond strength between the control and the experimental samples reached a level of statistical significance only in the 40-second samples at the 30-minute test time. All other bond strengths were statistically similar to the control values. The amount of adhesive remaining on the tooth after debonding was not statistically significantly different from the control in any of the samples.

The labiolingual thickness of the teeth measured at the middle of the bracket position was relatively consistent between the human maxillary incisors, with a standard deviation of less then 0.5 mm. The light power recorded by the meter decreased significantly from the fully engaged position to the more distant standardized position. The output of the light was 450 mW when placed directly against the sensor but only 270 mW when the light guide was in the standardized position. The difference in power readings from direct positioning of the light guide tip and the standardized position was due to the increased distance from the sensor. The blocking of the light by the clay blocker further decreased the light reaching the meter's sensor. When the tooth was superimposed between the light and the meter, the light power reaching the meter sensor fell to very low levels, with the highest reading at 10 mW, the limit of the meter, and on many samples the power was below the limits of the meter and a 0 mW reading was recorded. The power level recorded did not vary with the thickness of the teeth.

DISCUSSION

Many reports have suggested the use of transillumination to cure composite adhesive. The general assumption has been that directing the light through the opposite enamel, the dentin, the pulp chamber, and through the adjacent dentin and enamel to reach the composite material would require considerably more light energy.

The curing of the composite is affected by the total light energy reaching it. Total light energy is the combined effect of the intensity of the curing light (density of the light in mW/cm^2), the duration of the light exposure, and the distance between the light guide tip and the composite (light energy decreases by the square of the distance). Studies have demonstrated that the greater the total light energy applied to the composite, the greater the polymerization, the greater the flexural strength, and the greater the bracket bond strength.[5,7–13] Therefore, it is logical to assume that transillumination will require greater total light energy than same-side-of-the-tooth curing light application to obtain similar bond strengths. This assumption is commonly repeated in the literature. Suggestions of tripling the curing time,[5] using 2 minutes of curing time,[6] and the necessity of using higher powered lights for transillumination[14] have all been made.

One of the problems with increasing the total light energy through the use of higher powered lights or longer exposure time is the transmitting of heat as well as light energy to the tooth and the dental pulpal tissues. The exothermic reaction of the polymerizing composite also generates additional heat. Increases in pulpal temperature above 42.5°C are reported to produce irreversible damage to the pulpal tissues.[15,16] Therefore, increases in pulpal temperature of more than 5° to 6°C must be avoided. Temperature increases within the polymerizing resin itself have been measured as high as 20°C.[17,18] Fortunately, the enamel and dentin have insulating properties that provide protection. In a Class II restorative preparation with 1 mm of dentin between the composite and the pulp chamber, the temperature registered on a pulpal probe measured a 6°C temperature increase with 40 seconds of continuous exposure from a conventional tungsten-quartz curing light or a 10-second exposure from one of the newer high intensity xenon plasma arc lights.[19] The enamel and dentin are much thicker when the full thickness is considered in the instance of transillumination and should provide much greater pulpal insulation than in the above study. However, caution must be taken not to use extended transillumination times that would transmit too much damaging heat to the pulpal tissues.

The results of previous studies support increased exposure times for transillumination. Cheng et al[8] found the microhardness of an orthodontic composite to be less when cured by transillumination from the lingual then when cured from the labial of human incisors in vivo. In that study, the authors placed only the composite on the labial surface with no bracket. King et al[4] studied transillumination but used bovine teeth and lingual brackets. They combined 60 seconds of transillumination with 40 seconds of incisal curing and 20 seconds of light exposure over the bracket but had no same-side-of-the-tooth control. This is a tripling of exposure time from the recommended 40 seconds to 120 seconds of total exposure. In this study using human maxillary incisors, the results were much more encouraging. While all of the bond strengths using lingual transillumination in this study were lower, only 1 of those bond strengths reached the level of a statistically significant difference. All of the comparable bond strengths were greater when tested after 24 hours of curing than after 30 minutes of curing time. At 24 hours, the bond strength of a 50-second lingual transillumination cure was nearly equal to a 40-second labial cure.

The shear bond strengths obtained in this study are higher than would be expected from the light transmittance data. As with a previous study,[4] no clear relationship was found between the thickness of the tooth and the bond strength or, in this study, the amount of light transmitted through the tooth. The amount of light energy transmitted to the meter in the light transmittance portion of the study clearly demonstrated the dramatic decrease in light power with distance. Moving the light guide tip from direct contact with the meter sensor to the standardized position that placed the center of the light guide tip 13.43 mm from the center of the meter sensor decreased the power reading from 450 mW to 270 mW. Further reducing the area with the clay blocker further reduced the power reading to 186 mW. When the tooth was placed between the sensor and the light guide tip, little light energy reached the meter sensor. This occurred even though the labial surface of the transilluminated tooth glowed with the transilluminated light. The lack of a strong power reading was probably due to both blocking of the transilluminated light and scattering of the light by the tooth dentin and enamel. Unfortunately, the construction of the meter with the actual sensor buried in a heat sink-protected well did not allow direct contact of the tooth's labial surface with the sensor. If actual contact had been possible, the sensor probably would have captured more of the scattered light with consequent higher power readings.

The results of this study do not demonstrate the decrease in bond strength that might be expected from the above literature references and light transmittance data. The reason for this is probably due to the metal bracket bases. The light is not applied directly to the adhesive even when the light is directed from the same side of the tooth as where the bracket is placed. In order for the light to reach the composite adhesive, the light must be reflected within the enamel and dentin back to the composite beneath the metal bracket base. Additionally, the physical presence of the bracket prevents the light guide tip from being placed directly on the tooth surface, further decreasing the total light energy as a function of distance. This is similar to the light interference and the increased distance that occurs in transillumination, where the light must be transmitted and reflected through the increased thickness of enamel, dentin, and pulpal tissues.

CONCLUSIONS

This in vitro study using extracted human maxillary incisors is encouraging for the use of transillumination to cure light-cured composites beneath orthodontic brackets. Lingual transillumination of maxillary incisors will adequately cure light-cured orthodontic composite on labially placed brackets. Small increases (10 seconds) in curing times with transillumination of maxillary incisors will result in bond strengths comparable to labial curing. Small increases in exposure time have less risk of overheating and damaging pulpal tissues. No effect is seen on the amount of adhesive remaining on the tooth after debonding using lingual transillumination.

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