Bond Strength and Clinical Efficiency for Two Light Guide Sizes in Orthodontic Bracket Bonding

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Abstract. *The purpose of this study was to establish a possible increase in efficiency in bracket bonding with light-cured adhesive by using a larger size on the light transmitting unit. Two light guides were compared, a standard-sized 11-mm light guide and a 19-mm elliptical extra broad light guide, the latter designed to allow simultaneously curing of two adjacent brackets. Fifty extracted human premolars mounted in five phantom maxillary arches were bonded according to a standard procedure with Mini Uni-Twin® stainless steel brackets. The two light guides were randomly chosen for each half of the maxillary arch. After bonding, all teeth were tested for tensile bond strength to failure.*

In the clinical study 30 patients were bonded according to a split mouth technique with the two light guides alternatively used randomly for each side of the jaw. Time for bonding and the occurrence of bracket failures were recorded.

The results showed no statistically significant differences between the standard and elliptical light guides regarding tensile bond strength, or bracket failure frequency. However, with the larger light guide size a significantly shorter total bonding time for each patient was required. It is therefore concluded that the elliptical light guide in combination with a light transmitting unit of sufficient quality gave a similar bonding result as the standard light guide, offering the clinician a reduction in chair side time during the bonding procedure.

Index words: Bond Strength, Clinical Efficiency, Light-cured Adhesives, Light Guide Size, Orthodontic Bracket Bonding

Refereed Paper

Introduction

Use of a larger light guide size in light-cured orthodontic bracket bonding may allow simultaneous polymerization of adjacent brackets and then increase efficiency in bonding. On the other hand, this could increase the risk of incomplete polymerization of the bonding material, which would effect bond strength and, consequently, also failure rate.

Many factors may affect the polymerization of light-curing acrylates, such as light intensity from the light transmitting unit and curing time (Lee and Greener, 1994). The intensity of the light guide is decreased when the distance between the light guide and the composite is increased. Furthermore, the colour and amount of fillers in the bonding material are of importance for the distribution of light-induced polymerization of the adhesive (Forsten, 1990). Intervening tooth structures or brackets can prevent curing in areas not accessible to light (Lee *et al*., 1976). Variations in adhesive thickness between tooth surface and curvature of the bracket base has been reported to decrease the tensile bond strength (Evans and Powers, 1985) and the shear bond strength (Pender *et al*., 1988) in no-mix, chemically cured composites, but may also influence the outcome for light-curing acrylates.

With light-curing systems inducing polymerization of diacrylate resins at a wavelength of 440–480 nm an improvement regarding curing depth has been achieved (Bassiouny and Grant, 1978; Ruyter and Öystad, 1982). In fact, the bond strength of visible light-cured resins have been found superior to that of a self-cured resin (Wang and Meng, 1992).

With the replacement of earlier light-curing systems using ultraviolet light with visible light-curing systems possible harmful effects of ultraviolet radiation can be avoided (Birdsell *et al*., 1977). Provided that lamp filter guarantees light curing within the safe wavelength spectrum and protective glasses are used, it would be possible to polymerize several brackets in the same phase, thereby, for example, reducing chair time in bracket bonding.

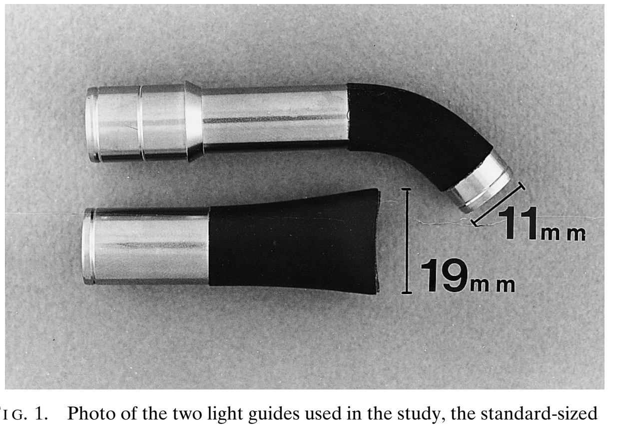

FIG. 1. Photo of the two light guides used in the study, the standard-sized 11-mm and the elliptical 19-mm light guide.

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It is the purpose of the present investigation to compare the tensile bond strength of two sizes of light guides (11 and 19 mm in diameter, Fig. 1), in a laboratory test and, furthermore, to evaluate clinically the time spending and bracket failure frequency for patients bonded with the two light guides.

Materials and Methods

Laboratory study

Fifty non-carious premolars, extracted for orthodontic reasons in patients aged between 12 and 16 years, were used for the bench test of tensile strength. After extraction the teeth had been rinsed with water and stored for 6 weeks in 70 per cent ethyl alcohol at room temperature. The teeth were placed all the way from the right second premolar region to the left second premolar region in specially prepared maxillary casts, simulating five intact dental arches (Fig. 2). Each tooth was placed in the cast according to an orientating device, indicating the occlusal plane and the lingual limitation of the dental arch. The maxillary casts had previously been oriented in an articulator according to a standard mean value mounting procedure. Maxillary premolars were used in three casts and mandibular premolars in the remaining two.

Before bonding, all tooth surfaces were gently cleaned with a fluoride-free pumice in a rubber cup, sprayed with water and dried in an air stream for about 15 seconds. The buccal surfaces of the right maxillary teeth were etched for 30 seconds with 37 per cent phosphoric acid (Etching liquid®, 3M Dental Products Division, St. Paul, MN, USA), rinsed with water, and dried in an air stream for another 30 seconds. The bracket used in the study was a stainless steel bracket for the first maxillary premolar with undercut milling of the base (Mini Uni-Twin®, 3M/Unitek, Monrovia, CA, 91016, USA). After the application of an adhesive primer (Transbond XT®, 3M/Unitek, Monrovia, CA, 91016, USA) to the prepared enamel surface and the bracket base, light-cured composite paste (Transbond XT®) was put on the bracket. The bracket was then placed in the correct position and pressed firmly towards the enamel surface for later removal of excessive bonding material with a scaler. This procedure was repeated for all teeth in the right half of the maxillary arch.

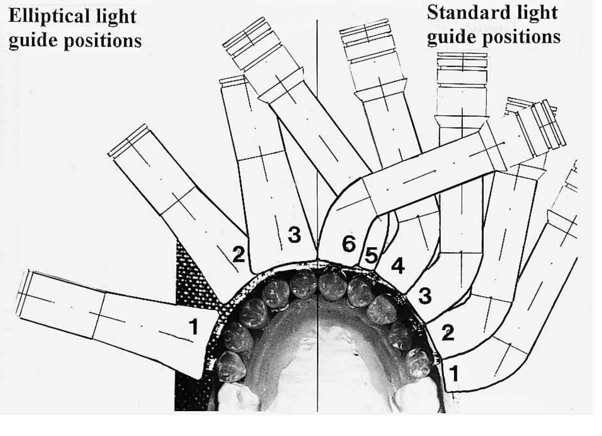

FIG. 2. The dental set up of the maxillary teeth for the laboratory testing. The different locations during light curing with the 19-mm light guide and the 11-mm light guide are indicated by dotted lines. A split mouth technique was used.

The adhesive was light-cured for 20 seconds in each interproximal position with an 11 mm standard circular light guide with the tip area of 95 mm^2 (180196, Demetron Research Corp., CONN, USA) applied to the light-transmitting unit (VCL 400®, Demetron Research Corp., CONN, USA). The tip of the light guide was mounted in a holding device, 5 mm perpendicular to the interproximal contact points between the bonded teeth. The bonded right half of the maxillary arch was screened off to avoid additional light-curing during bonding of the left side. The light intensity of the light transmitting unit was 700 milliwatt per square centimeter (mW/cm^2) in the 400–500-nm band as measured in the Demetron Curing Radiometer® (Demetron Research Corp., CONN, USA). For the corresponding opposite half of the maxillary arch a 19 × 6·5 mm elliptical light guide with a tip area of 111 mm^2 (21282, Demetron Research Corp., CONN, USA) was used for light-curing two brackets simultaneously for 20 seconds and in total three positions, with the same distance to the interproximal contact points of adjacent teeth (Fig. 2). The selection of light guide size (11 or 19 mm) for left and right segments of the maxillary arch was performed by random assignment (Table 2).

Immediately after bonding, all teeth were removed from the maxillary casts and glued to fixtures for the inferior holding device of a universal testing apparatus (Alwetron TC 5) for tensile bond strength testing. A jig was used for the orientation of the buccal surface of the tooth during the fixation. The test specimens were stored in distilled water at 24°C for 24 hours before testing. Application of a right angle stress towards the bracket slot area was achieved by using a harness to a piece of orthodontic wire (0·016 × 0·022″ stainless steel wire) ligatured to the bracket. Theoretically, this arrangement gives a pure tensile force vector. The tensile force was applied to the harness with a crosshead speed of 1 mm/minute. The ultimate tensile strength (F) in Newtons was recorded and the bond strength (BS) in Newton per square millimeter, was calculated by the following equation: $BS = F/A$, where A = nominal area in mm^2 of the bracket base. The brackets chosen in this study had a nominal area of 8·0 mm^2.

Clinical study

Thirty subjects registered for a fixed appliance therapy were consecutively selected for the study from the waiting list of the Department of Orthodontics, Umeå

TABLE 1 *Sex and age distribution of patients in the clinical study. Mean age, standard deviation (S.D.) and range of age at bonding (in decimal years)*

Sex	Patients (n)	Age at bonding (years)		
		Mean	S.D.	Range
Boys	14	14·3	1·8	12·6–19·7
Girls	16	14·1	4·6	11·4–30·5
Total	30	14·2	3·5	11·4–30·5

University Dental Clinic. Planned extractions of first premolars were ordered on 11 subjects before our study. The mean age of the subjects was 14 years and 2 months. The final composition of the sample with regard to sex and bonding age is given in Table 1.

The bonding procedure corresponded to the method described above in the laboratory study, with the same bracket type (Mini Uni-Twin®, Unitek/3M, Unitek Corp., Monrovia, CA, 91016, USA), light-cured adhesive (Transbond XT®) and light transmitting unit (VCL 400®). However, the upper and lower dental arches were divided into quadrants, so that in 15 subjects the maxillary left and mandibular right quadrants were light-cured with an 11-mm light-guide, and the remaining quadrants with a 19-mm light-guide. The reversed selection of light-guides were made on the remaining 15 subjects. Allocation of subjects to the two groups were made according to a random assignment. The elapsed time (from starting the light-curing unit until the cessation of the light-curing) was recorded.

The first aligning arch wire was applied immediately after the end of the bonding procedure. The patients were instructed by the assisting nurse about the importance of good oral hygiene, good dietary habits and correct tooth brushing techniques. In addition, all patients were instructed to call immediately for a new appointment in the event of bracket failure and recommended to use a fluoride containing toothpaste. Brackets dislodged during the first 3 months of active treatment were replaced with new brackets and bonded according to the original schedule. All bracket failures during the first 3 months and time spent at bond were recorded on special forms. All bonding was carried out by two of the authors (TF, LIN) to ensure a high degree of standardization throughout the clinical study.

Statistical analysis

The median values of tensile bond strength for the two light guides used in the laboratory study were computed, significant differences were tested by the use of Spearman rank-correlation. In the clinical sample mean values and standard deviations for frequency of bracket failures distributed on type of light-guide, jaw and quadrant were computed, as were also comparisons of light-curing time between the two light guides. Pearson's *t*-test was used for testing of significant differences between the two light guides. *P*-values ⩽ 0·05 were considered significant.

Results

Laboratory test

The results from the test of the tensile bond strength of brackets bonded with the two light guides are given in Table 2. The median tensile bond strength for the 11-mm sized light guide was 63·9 Newton (N) (7·98 MPa) and 65·4 N (8·18 MPa) for the 19-mm light guide. No significant differences between the two tested light guides were apparent. Nor did bracket position in the dental arch affect the outcome of the test.

Clinical study

The overall bracket failure rate during the three months long recording period was 10 per cent (Table 3). Comparison of failure rates for the 11- and 19-mm light guides showed no significant differences with regard to location. However, a noticeable higher incidence of bracket failures (19 per cent) occurred in the mandibular right arch for both light guides.

The time lapse for light-curing with the 19 mm light guide (mean value 89·9 seconds) was significantly shorter ($P \leqslant 0{\cdot}001$) in comparison with time needed for the 11 mm light guide (mean value 128·4 seconds) (Table 4).

Discussion

A 19-mm light guide for light curing of orthodontic bonding adhesives with visible light was here found to possess valuable time-saving properties compared with a standard 11 mm light guide. The 30 per cent reduction in chair side time was obtained without any decrease in tensile bond strength (laboratory test) and without effects on the incidence of bracket failures during orthodontic treatment (clinical study).

The clinical performance of light guides is determined by several factors such as performance deterioration of the lamp (*e.g.* due to blackening and frosting of the lamp bulb) and contamination of filter coatings in the unit, but

TABLE 2 *Laboratory Test. Comparison of tensile bond strength for two different sizes of light guides (11 and 19 mm)*

Location	Size 11 mm			Size 19 mm			Significance
	Obs (*n*)	Median bond strength (*N*)	Range	Obs (*n*)	Median bond strength (*N*)	Range	Spearman rank-correlation *P*-value
Total	23	63·9	21·5–100·4	23	65·4	28·3–82·3	0·4162[ns]
Centrals	5	84.8	60·8–100·4	5	73·2	58·2–82·3	0·2747[ns]
Laterals	5	60·2	49·4– 63·9	4	62·5	28·3–78·5	0·6559[ns]
Canines	4	62·2	34·0– 74·2	5	51·5	34·3–81·7	1·0000[ns]
1st Prem.	4	59·8	21·5– 85·9	5	49·2	32·2–71·3	0·8247[ns]
2nd Prem.	5	64·0	59·1– 83·2	4	62·2	45·7–76·0	0·3611[ns]

[ns] Not significant. Obs, observations; N, force in Newtons.

TABLE 3 *Clinical study. Comparisons of initial bracket failures* (n) *during the first 3 months for light guide size 11 and 19 mm according to location and sex*

Location and and sex	Size 11 mm				Size 19 mm				Total				Significance of difference
	Segments (*n*)	Teeth (*n*)	Failures (*n*)	Failure rate %	Segments (*n*)	Teeth (*n*)	Failures (*n*)	Failure rate %	Segments (*n*)	Teeth (*n*)	Failures (*n*)	Failure rate %	Pearson's *P*-value
Location													
Mx right	13	58	3	5	13	59	4	7	26	117	7	6	0·7358ns
Mx left	13	58	4	7	13	59	5	8	26	117	9	8	0·7985ns
Md left	14	63	5	8	11	53	4	8	25	116	9	8	0·9846ns
Md right	11	53	11	21	14	63	11	17	25	116	22	19	0·7108ns
Mx	26	116	7	6	26	118	9	8	52	234	16	7	06764ns
Md	25	116	16	14	25	116	15	13	50	232	31	13	0·9215ns
Sex													
Boys	20	86	13	15	20	87	6	7	40	173	19	11	0·3021ns
Girls	31	146	10	7	31	147	18	12	62	293	28	10	0·1735ns
All	51	232	23	10	51	234	24	10	102	466	47	10	0·8935ns

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.
ns Not significant.
Mx, maxillary arch; Md, mandibular arch, right and left sides.

also by a possible peak output in the center of the light guide with a drop of the intensity towards the peripheral parts of the tip. An oval shape and larger area of the tip of the 19-mm light guide may imply a drop of peripheral light intensity compared to the standard tip. Thus, an inferior light-curing ability of the bonding material with the 19-mm light guide could be anticipated due to the spread of the light over a larger area. Neither the results from the testing of tensile bond strength, nor the clinical evaluation of failure frequencies provide any evidence for a clinically significant deterioration of the light curing ability of the bonding adhesives with the larger light guide.

Curing of the adhesives will also be influenced by the distance between light guide and bonding material including distance effects caused by positional variation of teeth in their arches. The output (intensity) of the visible light for the VCL 400® with the standard 11-mm light guide was recorded to 700 mW per square centimeter in the 400–500-nm band, and 600 mW per square centimeter for the 19-mm light guide due to a larger area of the light guide tip.

The 19-mm light-curing tip thus gave a decrease of the energy/area, but was apparently of no clinical significance in this study. Most manufacturers recommend the use of a light unit producing a light intensity never falling below 400mW/cm^2 as measured at the tip of the light-transmitting unit. In a previous investigation Lee and Greener (1994) concluded that light intensities $\geqslant 250$ mWcm^2 produced equivalent mechanical properties with all composites. There also seem to exist a positive relationship between increased light intensity and curing depth of different bonding materials (Forsten, 1990; Lee and Greener, 1994). A way to further concentrate the light output is to use different filters (Forsten, 1984). In the present investigation a blue filter allowing an optimal intensity at 475 nm and suppressing wave lengths outside the blue spectrum (455–492 nm) was delivered with the lamp.

Bond strength

A large variation in recorded values has been found in most bond strength testing (*e.g.* Aasrum *et al.*, 1993). Comparison of papers is made difficult due to a lack of uniform test procedures (Fox *et al*., 1994). Bond strength of acrylic resins have been reported to vary between 5-25 MPa (*e.g.* Delport and Grobler, 1988; Gwinnet, 1988). A clinically successful bonding can be achieved at a shear bond strength ranging from 6–9 MPa (Reynolds and von Fraunhofer, 1975; Ferguson, Read and Watts, 1984; Martin and Garcia-Godoy, 1994). Corresponding values for tensile bond strength testing of light-curing adhesives (Transbond XT®) is 5·1 N/mm^2 (= MPa) (Aasrum *et al.*, 1993). The results from the present laboratory test show higher tensile strength for both light guides compared with the proposed minimal level for clinical success with 7·98 MPa for the 11-mm light guide and 8·18 MPa for the 19-mm light guide. For the 11-mm light guide 91·7 per cent of the tested brackets were above the critical level of 6 MPa in comparison with 87 per cent of brackets bonded with the 19-mm light guide.

TABLE 4 *Clinical study. Comparison of time relapse in seconds (sec) for bonding with the two types of light guides sizes (11 and 19 mm).*

Location and sex	Size 11 mm			Size 19 mm			Significance difference Pearson's *P*-value
	Segment (*n*)	Mean time (sec)	S.D.	Segment (*n*)	Mean time (sec)	S.D.	
Location							
Mx right	13	128·4	54·8	13	89·2	24·3	0·0270*
Mx left	13	129·1	29·3	13	96·9	37·1	0·0218*
Md left	14	134·0	31·5	11	93·5	17·4	0·0009***
Md right	11	120·4	25·6	14	81·3	30·8	0·0026**
Mx, right and left	26	128·7	43·0	26	93·1	31·0	0·0012**
Md, right and left	25	128·0	29·3	25	86·6	26·0	0·0000***
Sex							
Boys	20	117·5	29·2	20	86·1	21·6	0·0004***
Girls	31	135·4	39·5	31	92·4	32·4	0·0000***
All	51	128·4	36·8	51	89·9	28·6	0·0000***

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.
ns Not significant.

Failure frequency

Both light guides had a failure frequency for the first 3 months of 10 per cent, although a higher failure frequency was anticipated after use of the broader light-guide. The reduction in light output did, however, not seem to have any clinical significance as measured in failure frequency. An unexpected higher incidence of bracket failures occurred in the right mandibular arch with 21 and 17 per cent failures for the 11 and 19 mm light guide, respectively. Such high incidence of bracket failures in the lower arch could possibly be explained by difficulties in obtaining optimal bonding conditions due to moisture contamination (Zachrisson, 1976, 1977).

Conclusion

We conclude that the 19-mm light guide in combination with a light transmitting unit of sufficient quality gives a similar bonding quality in terms of tensile bond strength and bracket failure rates as the 11-mm standard light guide. The larger guide tip area will offer the clinician an opportunity to reduce the chair side time during the bonding procedure.

Acknowledgements

We are grateful to Mrs Lisa Arvidsson and Linnea Lövdahl for skilful technical assistance.

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