Original Article

Comparison of Bonding Time and Shear Bond Strength Between a Conventional and a New Integrated Bonding System

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Abstract: Conventional adhesive systems use 3 different agents, an enamel conditioner, a primer solution, and an adhesive resin during the bonding of orthodontic brackets to enamel. A characteristic of some new bonding systems is that they combine the conditioning and priming agents into a single application as well as precoat the bracket with the adhesive in an attempt to save time during the bonding procedure. This study compared the total bonding time and shear bond strength (SBS) of 2 bracket-bonding systems: (1) an integrated system that incorporates a self-etching primer and precoated brackets and (2) a conventional system in which the etchant and primer are applied separately and the adhesive applied to the bracket by the clinician. The results of the SBS and the total bonding time comparisons ($t = 3.451$) of the 2 adhesive systems showed a significant difference ($P = .0001$). The mean SBS was 9.4 ± 3.7 MPa for the new bonding system and 6.2 ± 4.4 MPa for the conventional system. The mean total bonding time was 36.5 s/tooth for the new system and 46.7 s/tooth for the conventional system. The clinician has to decide whether the increase in bond strength, the decrease in the total bonding time, and the steps saved during the bonding procedure with the new bonding system balance the increased cost incurred. (*Angle Orthod* 2005;75:237–242.)

Key Words: Self-etch primers, Bonding time, Shear bond strength, Bonding systems

INTRODUCTION

Orthodontists use the acid-etch bonding technique as a means of attaching brackets to the enamel surface. A primary concern of the clinician is maintaining a sound unblemished enamel surface after debonding. As a result, bond failure at the bracket-adhesive interface or within the adhesive is more desirable (safer) than at the adhesive-enamel interface because enamel fracture and crazing have been reported at the time of bracket debonding, especially with ceramic brackets.[1] Researchers have tested alternative enamel conditioners, such as maleic acid and acidic primers, to determine if they can attain clinically useful bond strength while decreasing the depth of enamel dissolution and decreasing the number of steps during the bonding procedure.[2–4]

When bonding orthodontic brackets to enamel, conventional adhesive systems use 3 different agents, ie, an enamel conditioner, a primer solution, and an adhesive resin. Some new bonding systems in operative dentistry combine the conditioning and priming agents into a single acidic primer solution for simultaneous use on both enamel and dentin.[5–8] Prompt (ESPE Dental AG, Seefeld, Germany) was introduced as an all-in-one adhesive for composites and compomers. Clinicians can light cure the material separately or after the application of the cavity restoration or the orthodontic adhesive. Prompt contains methacrylated phosphoric acid esters.[9] In recent studies, the use of this self-etch primer for bonding orthodontic brackets provided significantly lower (but clinically useful) shear bond strength (SBS) when compared with the use of phosphoric acid and a sealant.[9,10]

Combining conditioning and priming into a single treatment step eliminates the need for rinsing and results in a

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reduction in bonding time. To further save chair time through more efficient bonding, manufacturers precoated the brackets with the adhesive. The suggested advantages of such innovations include reducing the number of steps in the procedure, convenience to the clinician, minimizing enamel dissolution, predictable consistency and thickness of the composite, and unlimited working time.[11,12]

Exposure to a halogen light for 10–20 seconds will cure the adhesive under the bracket. Prolonged curing times risk saliva contamination and cumulatively inconvenience the patient and clinician. High-intensity light curing units avoid this time restraint.[13–15] The plasma arc curing lights are high-intensity units that can cure composite in as little as 3 to 5 seconds. Sfondrini et al[13] demonstrated that high-intensity light curing units produced clinically acceptable bond strengths when used on orthodontic brackets. Klocke et al[14] compared the effect of using a xenon plasma arc light (intervals of 2 and 6 seconds) with the conventional halogen light source (20 seconds) on bond strength of orthodontic brackets. They recommended 6 seconds of curing time for bonding stainless steel brackets with xenon plasma arc light source to achieve acceptable bond strength values. Noel et al[15] evaluated the effect of a 5-second argon laser on SBS of orthodontic brackets and reported that the mean SBS was similar to that attained with a 40-second conventional light curing unit. They also concluded that argon lasers used for bonding orthodontic brackets save a significant amount of chair time.

A recent development in light curing sources has been the introduction of light-emitting diodes (LEDs),[16] which require less power and operate with rechargeable batteries. As a result, manufacturers introduced various cordless, lightweight units used in both operative dentistry and orthodontics. Other advantages of LED units include an extended life (thousands of hours) and a constant light intensity, because it does not degrade with time, and less heat production.[16]

Aljubouri et al[10] compared the mean bonding time of a light cure composite using a self-etching primer and a conventional 2-stage etchant primer system when bonding metal brackets. They found that the bonding time with the self-etching primer was significantly less by 59.0 seconds than that in conventional bonding (115.5 vs 170.5 seconds) when direct bonding 30 teeth. The difference between the two bonding approaches averaged approximately 1.97 s/tooth. Aljubouri et al[10] further reported that the self-etching system had a significantly lower SBS (by approximately 25%) than the conventional 2-step (etch/prime) system.

Clinicians can save time during the bonding procedure by using these newer systems, but they cost more. As a result, the cost-benefit ratio of such innovations must consider the increased cost of materials, the time saved, and the convenience for both the patient and clinician; ie, clinicians must determine whether the new systems significantly improve the efficiency and efficacy of therapy.

This study compared the total bonding time and the SBS of two different bracket-bonding systems:

- A new integrated system that incorporates a self-etching primer, brackets precoated with the adhesive, and an LED curing light
- A conventional system that applies an etchant and a primer separately, spreads the adhesive over the bracket base, and cures with a halogen light.

MATERIALS AND METHODS

Teeth

Eighty freshly extracted human molars were collected and stored in a solution of 0.1% (weight/volume) thymol. The criteria for tooth selection included intact buccal enamel, not subjected to any pretreatment chemical agents, eg, hydrogen peroxide, no cracks due to the presence of the extraction forceps, and no caries. The teeth were cleansed and then polished with pumice and rubber prophylactic cups for 10 seconds.

Brackets used

A total of 80 central incisor brackets were used in this study: 20 metal brackets (Victory Series), 20 Clarity ceramic brackets, 20 APC™ PLUS™ metal brackets, and 20 APC™ PLUS™ Clarity ceramic brackets (3M Unitek, Monrovia, Calif). The base surface area for the metal brackets was determined to be 12.0 mm^2 and that for the ceramic brackets 14.6 mm^2.

Bonding protocols

The brackets were bonded to the teeth according to 1 of 4 protocols.

Protocol I (conventional system). Twenty human molar teeth were bonded with the conventional Transbond XT bonding system (3M Unitek) using the following procedure.

Teeth were cleaned and polished for 10 seconds and mounted in phenolic rings (Buehler Ltd, Lake Bluff, Ill). Groups of 5 teeth were bonded at a time to simulate the bonding of each quadrant in the oral cavity. Thirty-seven percent phosphoric acid was applied for 15 seconds. The teeth were washed for 10–15 seconds. The teeth were dried so that the enamel appeared to be chalky white (approximately 10 seconds). The Transbond XT MIP primer was applied to the tooth using a brush. A gentle airburst was applied for 2 to 5 seconds. The adhesive paste was applied to the metal bracket base, and the bracket was applied to the tooth. Three-hundred grams of force was applied to each bracket to ensure a uniform thickness of the adhesive. Excess adhesive was removed with a sharp scaler. The adhesive was light cured using a halogen light (Ortholux XT, 3M Unitek) for 20 seconds (10 seconds on each side). The time taken to complete these steps was calculated in seconds.

Protocol II (integrated system). Twenty human molar teeth were bonded with the precoated APC PLUS metal brackets using the following procedure.

Teeth were cleaned and polished for 10 seconds and mounted in phenolic rings. Groups of 5 teeth were bonded at a time to simulate the bonding of each quadrant in the oral cavity. The Transbond Plus self-etching primer was activated and mixed for 5 seconds and rubbed on the teeth for 3 seconds. The self-etch primer was lightly dried with air for 1 second to 2 seconds. The APC PLUS metal bracket was removed from the well and applied to the tooth. Three-hundred grams of force was applied to the bracket to ensure a uniform thickness of the adhesive. Excess adhesive was removed with a sharp scaler. The adhesive was light cured using the Ortholux LED light (3M Unitek) for 10 seconds (5 seconds on each side). The time taken for performing these steps was calculated in seconds.

Protocols III and IV. The same protocols as in I and II were repeated using 20 uncoated (group III) and 20 precoated (group IV) Clarity ceramic brackets. One difference in the bonding procedure between metal and ceramic brackets was that the light curing time for the ceramic brackets was reduced to 10 seconds (vs 20 seconds for stainless steel) using the Ortholux XT and to 5 seconds (vs 10 seconds for stainless steel) when using the Ortholux LED.

All brackets were debonded within 30 minutes from the time of initial bonding to simulate the clinical conditions when archwires are tied to the newly bonded teeth.

Variables considered during the experimental design

When calculating the bonding time for the 2 systems, the following assumptions were made in an attempt to simulate the clinical conditions.

All bonding materials and brackets were readily available for use and were at room temperature. An assistant was available during the bonding procedure to handle the material. The teeth were isolated to avoid contaminations. The curing lights were in good working order and ready to use. The operator followed the manufacturer's instructions on the use of the 2 adhesive systems and the light curing times recommended. The time taken to bond the teeth was measured by an independent investigator who was not involved in the bonding procedure. A stop watch accurate to 0.01 of a second was used to time the different steps of the procedure. These criteria eliminated variables not directly related to the bonding procedure regardless of the system used.

Definitions of various times measured

Etching time. For the conventional bonding system, the etching time was measured from etchant application until the tooth was washed and dried to a chalky white appearance. For the new bonding system, the etching time was measured from its mixture until the completion of its application to the tooth.

Bonding time. For the conventional bonding system, the bonding time was measured as the time required for the adhesive to be applied to the bracket and the final bracket placement on the tooth. With the new bonding system, it was measured as the time required to properly place the precoated bracket on the tooth.

Total bonding time. The total bonding time was calculated by separately adding the above times for each system.

Debonding procedure

Each tooth labial surface was oriented to be parallel to the force during the shear strength test. A steel rod with one flattened end was attached to the crosshead of a Zwick test machine (Zwick Gm bH & Co, Ulm, Germany). An occlusogingival load was applied to the bracket, producing a shear force at the bracket-tooth interface. A computer, electronically connected with the Zwick test machine, recorded the results of each test. SBS were measured at a crosshead speed of 5 mm/min.

Statistical analysis

Descriptive statistics including the mean; standard deviation; minimum and maximum values for the etching, bonding, and total times as well as the SBS were calculated for each of the 4 test groups. The analysis of variance was used to determine whether significant differences were present in the etching times, bonding times, and the combined etching and bonding times as well as the SBS between the 4 groups. When significant differences were present, post hoc tests (Tukey HSD) were used to determine which means were significantly different from each other. In addition, Student's *t*-test comparisons were performed by combining the 2 bracket types that were bonded with the same bonding protocol. Significance for the statistical tests was predetermined at $P \leq .05$.

RESULTS

The descriptive statistics for the bonding times and the SBS of the 4 bracket-bonding systems evaluated are shown in Tables 1–8.

SBS according to bracket type and bonding system

The results of the analysis of variance ($F = 6.771$) indicated that there were statistically significant differences ($P = .0001$) between the 4 groups evaluated (Table 1). The Tukey HSD comparisons of the mean SBS indicated that the metal brackets bonded with the conventional system had significantly lower SBS (mean = 4.6 ± 3.2 MPa) than all other groups.

TABLE 1. Descriptive Statistics and Results of the Analysis of Variance Comparing the Shear Bond Strength (in MPa) of the Metal and Ceramic Brackets Bonded with the Conventional and New Bracket/Bonding Systems[a]

Bracket/Bonding System	n	Mean	SD	Range	Tukey HSD
Metal brackets:					
Conventional	20	4.6	3.2	0.4–11.1	A
New	20	8.6	2.6	3.4–12.0	B
Ceramic brackets:					
Conventional	20	7.8	4.9	0.6–19.8	B
New	20	10.0	4.5	3.1–17.9	B

[a] F ratio = 6.771; P = .0001.

TABLE 2. Descriptive Statistics (in MPa) and Results of *t*-Test Comparisons of the Shear Bond Strength of the Conventional and New Adhesive Systems (Metal and Ceramic Brackets Combined)[a]

Bonding System	n	Mean	SD
Conventional	40	6.2	4.4
New	40	9.4	3.7

[a] *t*-test = 3.451; P = .0001.

TABLE 3. Descriptive Statistics and Results of the Analyses of Variance Comparing the Etching Time (in Seconds Per Tooth) of the Metal and Ceramic Brackets Bonded with the Conventional and New Bonding Systems[a]

Bracket/Bonding System	n	Mean	SD	Range	Tukey HSD
Metal brackets:					
Conventional	20	13.6	1.1	12.0–16.0	A
New	20	14.0	1.8	11.0–16.0	A
Ceramic brackets:					
Conventional	20	15.6	1.5	14.0–18.0	B
New	20	16.7	1.8	14.8–19.0	C

[a] F = 15.965; P = .0001.

SBS between bonding systems

When the SBS of the metal and ceramic brackets bonded with the same system were combined, the *t*-test comparisons (t = 3.451) indicated that the SBS with the new bonding system (mean = 9.4 ± 3.7 MPa) was significantly (P = .0001) greater than the SBS with the conventional system (mean = 6.2 ± 4.4 MPa) (Table 2).

Etching time according to bracket type and bonding system

The results of the analysis of variance (F = 15.965) comparing the etching time of the 4 groups evaluated indicated that there were significant differences (P = .0001) between the groups (Table 3). The results of the Tukey HSD post hoc test indicated that the etching times for the ceramic brackets were significantly different and took an average of 1 to 2 seconds longer, regardless of the bonding system used.

TABLE 4. Descriptive Statistics and Results of *t*-Test Comparisons of the Etching Time (in Seconds Per Tooth) for the Conventional and New Systems (Metals and Ceramic Brackets Combined)[a]

Bonding System	n	Mean	SD
Conventional	40	14.6	1.7
New	40	15.4	2.3

[a] *t*-test = 1.683; P = .096.

TABLE 5. Descriptive Statistics and Results of the Analysis of Variance Comparing the Bonding Time (in Seconds Per Tooth) of the Metal and Ceramic Brackets Bonded with the Conventional and New Bonding Systems[a]

Bracket/Bonding System	n	Mean	SD	Range	Tukey HSD
Metal brackets:					
Conventional	20	31.8	1.3	30.0–34.0	A
New	20	21.7	5.7	14.0–27.0	B
Ceramic brackets:					
Conventional	20	32.4	4.5	27.0–40.0	A
New	20	20.6	0.8	19.2–21.0	B

[a] F = 58.64; P = .0001.

Etching time between bonding systems

When the etching times of the teeth prepared with the same bonding system were grouped together, the results of the *t*-test comparisons (t = 1.683) indicated that there were no significant (P = .096) differences between the 2 groups (Table 4). The mean etching time with the new bonding system (15.4 ± 2.3 s/tooth) was essentially similar to the conventional system (mean = 14.6 ± 1.6 s/tooth).

Bonding time according to bracket type and bonding system

The results of the analysis of variance (F = 58.64) comparing the bonding time of the 4 groups evaluated indicated that there were significant differences (P = .0001) between the 4 groups (Table 5). The results of the Tukey HSD post hoc test indicated that bonding the metal or ceramic brackets with the conventional system (mean = 31.8 ± 1.3 s/tooth and 32.4 ± 4.5 s/tooth, respectively) took significantly more time than when the identical brackets were bonded with the new system (mean = 21.7 ± 5.7 s/tooth and 20.6 ± 0.8 s/tooth, respectively).

Bonding time between bonding systems

When the bonding time of the metal and ceramic brackets bonded with the same system were grouped together, the results of the *t*-test comparisons (t = −13.29) indicated that the bonding time with the new system (mean = 21.1 ± 4.0 s/tooth) was significantly (P = .0001) shorter than the bonding time with the conventional system (mean = 32.1 ± 3.3 s/tooth) (Table 6).

TABLE 6. Descriptive Statistics and Results of *t*-Test Comparisons of the Bonding Time (in Seconds Per Tooth) for the Conventional and New Bonding Systems (Metal and Ceramic Combined)[a]

Bonding Systems	n	Mean	SD
Conventional	40	32.0	3.3
New	40	21.1	4.0

[a] t-test = −13.29; P = .0001.

TABLE 7. Descriptive Statistics and Results of the Analysis of Variance Comparing the Total Bonding Time (in Seconds) of the Metal and Ceramic Brackets Bonded with the Conventional and New Bonding Systems Per Tooth[a]

Bracket/Bonding System	n	Mean	SD	Range	Tukey HSD
Metal brackets:					
Conventional	20	45.4	1.6	43.0–48.0	A
New	20	35.7	5.4	28.0–44.0	B
Ceramic brackets:					
Conventional	20	48.0	5.9	41.0–58.0	A
New	20	37.2	1.7	35.8–40.0	B

[a] F ratio = 41.78; P = .0001.

TABLE 8. Descriptive Statistics and Results of *t*-Test Comparisons of the Total Bonding Time (in Seconds Per Tooth) for the Conventional and New Adhesive Systems (Metal and Ceramic Brackets Combined)[a]

Bonding Systems	n	Mean	SD
Conventional	40	46.7	4.4
New	40	36.5	4.0

[a] t-test = −10.767; P = .0001.

Total bonding time according to bracket type and bonding system

The results of the analysis of variance (F = 41.78) comparing the total bonding time (etching and bonding) of the 4 groups evaluated indicated significant differences (P = .0001) between the 4 groups (Table 7). The results of the Tukey HSD post hoc test showed that the mean total bonding times for the metal (35.7 ± 5.4 s/tooth) and the ceramic (37.2 ± 1.7 s/tooth) brackets using the new bonding system were significantly shorter than with the conventional system (45.4 ± 1.6 s/tooth and 48.0 ± 5.9 s/tooth for metal and ceramic brackets, respectively).

Total bonding time between bonding systems

When the teeth bonded with either the conventional or the new systems were grouped together, the results of the t-test comparisons (t = −5.502) revealed that the mean total bonding time of the new system (36.5 ± 4.0 s/tooth) was significantly (P = .0001) shorter than the mean with the conventional (46.7 ± 4.4 s/tooth) system (Table 8).

DISCUSSION

The direct bonding of orthodontic brackets has revolutionized and advanced the clinical practice of orthodontics. However, improvements continue through the introduction of new materials and more effective light curing sources. These improvements minimize enamel loss, save time, and do not compromise bond strength.

Although recent bonding systems work well, improvements that minimize technique sensitivity as well as reduce chair time simplify the bonding procedure and make it more predictable. Traditionally, the use of acid etchants followed by a primer allowed good wetting and penetration of the sealant into the enamel surface.[3,4] Researchers have not fully evaluated the new self-etch primers, but in general, these new primers are thought to simplify the clinical handling of the adhesive systems by combining the etchant and the primer in one application.[2,5,7,9–11] Earlier generations of acidic self-etch primers were selectively compatible with some adhesives; this resulted in significantly lower bond strength and required more working time.[2]

In this study, 2 bonding systems were compared, a conventional system in which the etching, priming, and adhesive placement on the brackets were done in separate steps during the bonding procedure and a new system in which the etching and priming were combined and the brackets were preloaded with the adhesive and ready for placement. The results of the present study indicated that the total time saved per tooth using the new system was 10.2 seconds for a total of 204 seconds when bonding 20 teeth.

The finding in Table 3 regarding the 1- to 2-second increase in the etching time with the use of ceramic brackets with either of the 2 bonding systems could be the result of either random operator variability or because of the very small standard deviations in the etching time in all the groups compared, or both. Regardless, the differences are of no clinical significance.

The elimination of steps during the new bonding procedure minimizes the probability of contamination because the etchant and the sealant are applied simultaneously without an intermediary step of washing and drying the tooth between these 2 applications. Furthermore, having the adhesive precoated to the bracket base reduces an additional step and also provides a uniform thickness of the adhesive layer between the bracket and the tooth surface. The clinician has to decide whether the time and steps saved during the bonding procedure as well as decreasing the chances of contamination balances the increased cost incurred when using the new bonding system.

Clinicians should remember that this was an in vitro study and the results are not necessarily the same as those that would be obtained in the oral environment. In addition, more research is needed to determine the SBS of this new integrated system over a longer time period, eg, 24 hours and 1 week after bonding as well as after thermocycling.

CONCLUSIONS

By reducing the number of steps during bonding, clinicians can save time as well as reduce the potential for error and contamination during the bonding procedure. The results of this study indicate that the newly introduced bonding system using a self-etch primer and brackets precoated with the adhesive as well as an LED light source can reduce the total bonding time for each tooth by 10.2 seconds. In addition, the SBS of the new system was significantly stronger in the first half hour after initial bonding than with the conventional system.

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