An investigation of bond strengths achieved in both clean and saliva-contaminated fields using Self Etching Primer

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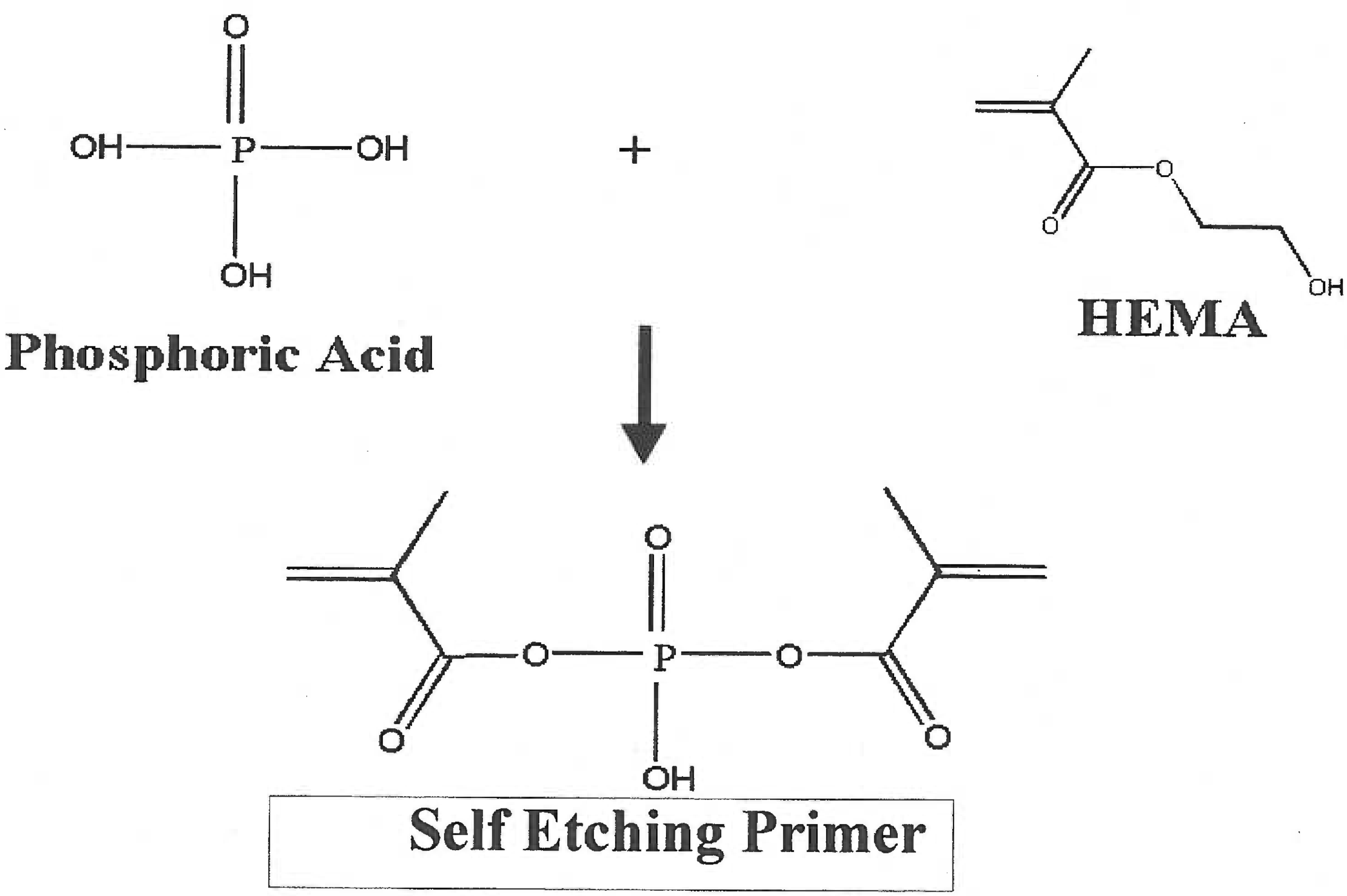
Introduction

Orthodontics has seen many great advances over the last few decades. One of the most dramatic has been the development of a technique which allows the clinician to directly bond appliances to enamel. Bonding technology has made the orthodontic experience more esthetic for the patient as well as decreasing the work load and time required by the orthodontist by eliminating the need to band every tooth.

Bonding requires that the enamel surface be etched (normally with 37% phosphoric acid) and then a primer applied after which the bracket can be bonded to the tooth surface using composite. This process requires that the tooth surface be cleansed, etched, rinsed, primed, and cured before the actual bonding can take place. This process involves many steps and can be time consuming for the orthodontist and staff.

Recently 3M Unitek has developed a new material that not only eliminates many of the steps involved in the current bonding process but also reduces the time required for the individual steps. This new material is called Self-Etching Primer (SEP). SEP is created by combining a phosphoric acid molecule with a HEMA molecule (see fig. 1). Unitek's SEP allows the clinician to bond to enamel using less steps and time and thus increase clinical efficiency. Of course, this is only an advantage if SEP can deliver bond strengths equal to or greater than those already achieved using the conventional method.

Figure 1 Self-Etching Primer



Literature Review

The acid-etch technique for bonding composite resins to enamel has revolutionized the practice of restorative dentistry. The ability of clinicians to bond restorative materials to enamel has fundamentally changed such diverse areas as cavity preparation, caries prevention, and esthetic treatment options (Swift, 1995). The previous statement also applies to the field of orthodontics.

The foundation for adhesive restorative and preventive dentistry was laid in 1955, when Buonocore (1955) proposed that acids could be used to alter the surface of enamel to "render it more receptive to adhesion." His hypothesis was based on the common industrial use of phosphoric acid to improve adhesion of paints and acrylic coatings to metal surfaces. Buonocore found that acrylic resin could be bonded to human enamel that was conditioned with 85% phosphoric acid for 30 seconds. Prophetically, he proposed several potential uses for this new "bonding" technique, including Class III and Class V restorations and pit and fissure sealants.

Subsequent work by Gwinnett and Matsui (1967) and Buonocore (1968) and others suggested that the formation of "resin tags" was the primary attachment mechanism of resin to phosphoric acid-etched enamel. Acid etching removes about 10um of the enamel surface and creates a porous layer ranging from 5 to 50um deep. When a low-viscosity resin is applied, it flows into the microporosities and channels of this layer and polymerizes to form a micromechanical bond with the enamel. Etching creates an enamel surface that is high-energy and hydrophilic resulting in increased surface tension, wettability, and surface area (Gwinnett, 1971;Retief, 1973). It was shown by Newman (1971) that water applied to an untreated enamel tooth surface resulted in a contact angle larger than 50 degrees. However, enamel treated with phosphoric acid resulted in a contact angle of zero when water was applied to the tooth surface (Newman, 1971). Studies also confirm an improved bond strength when enamel is pretreated with acid without significant long term damage to the tooth structure (Newman 1968).

Gwinnett (1971) and Silverstone (1975) described three patterns of etching in enamel. The most common, or Type 1, etching pattern involves preferential removal of enamel prism cores; prism peripheries remain relatively intact. The Type 2 etching pattern is the reverse process; ie, the peripheries are removed, leaving the cores intact. The Type 3 etching pattern is less distinct. It includes areas resembling each of the other patterns, as well as regions in which the etching pattern appears unrelated to prism morphology.

Various concentrations of phosphoric acid have been evaluated as enamel etchants, and some form precipitates that might interfere with resin bonding (Gwinnett, 1965). One study showed that 60-second applications of 50% phosphoric acid produce a precipitate (monocalcium phosphate monohydrate) that can be easily removed. However, concentrations of less than approximately 27% form a precipitate that cannot be easily removed (Chow, 1973).

Silverstone (1974) reported that phosphoric acid concentrations of between 30% and 40% provide enamel surfaces that have the most retentive appearance. Also, calcium dissolution and etching depth increase with phosphoric acid concentration until the acid concentration reaches 40%. Stronger solutions dissolve less calcium and result in smaller etching depths.

As a result of these studies, most commercial enamel etchants are 30% to 40% (frequently 37%) concentrations of phosphoric acid. However, lower concentrations have been shown, in some studies, to provide bond strengths similar to those obtained with 30% to 40% phosphoric acid (Gottlieb, 1982).

A 60-second application time traditionally has been recommended for etching enamel with 30% to 40% phosphoric acid. One study concluded that shorter etching times resulted in lower tensile bond strengths (Mardaga, 1982). However, other studies with scanning electron microscopy (SEM) have indicated that etching times as brief as 15 seconds provide essentially the same surface roughness as a 60-second etching time (Nordeuvali, 1980). Laboratory tests have also shown that shear bond strengths and marginal microleakage are similar for 15-second and 60-second etching times (Crim, 1987; Shaffer, 1987; Gilpatrick, 1991). In addition, clinical studies have shown that sealant retention is not adversely affected by reduced etching time (Stephen, 1982).

Several new adhesive systems rely on simultaneous etching of dentin and enamel with weaker acids than traditional 30% to 40% phosphoric acid etchants. Some studies indicate that acids such as 10% phosphoric acid, 10% maleic acid (Aasen, 1993), and 2.5% nitric acid (Berry, 1990) etch enamel as effectively as 37% phosphoric acid. However, data from other studies indicate that the weaker acids provide significantly lower shear bond strengths when the manufacturer's recommended application times are used to etch enamel (Swift, 1993). The clinical consequences of etching enamel with weaker acids are not yet fully known.

ORTHODONTIC BONDING

Conventionally, patients requiring orthodontic therapy had been treated with fixed appliances using stainless-steel bands welded with various brackets and attachments. These bands were cemented directly to the teeth. Although effective as a system for obtaining controlled tooth movement, the use of the banded technique has certain inherent problems (Ceen, 1980). These include the need for separation of teeth, use of an intermediate cementing medium, and loss of arch circumference because of interproximal band thickness. Banded appliances, especially in the anterior part of the mouth, are unattractive, and bands in patients with poor oral hygiene habits contribute to gingivitis (Dietz, 1975).

In 1966, in the Orthodontic Department of the Eastman Dental Center, a direct-bonding technique was developed and used for the first time on several patients. The experimental round metal brackets had single-groove 0.018 X 0.025-inch bracket slot with a plastic resin attached to the base. The adhesive was the same used in previous experiments by Cueto and Bounocore (1967) for the sealing of pits and fissures. This experiment was done to see if it was feasible to attach a bracket directly to tooth enamel without the use of orthodontic bands.

The adhesive consisted of a liquid monomer, methyl-2-cyanoacrylate, and a silicate filler. This mixture had a working time of about 1 minute and a setting time of 2 to 4 minutes. Before application of the adhesive, the enamel surface was cleaned with pumice, rinsed with water, isolated with cotton roles, and completely dried with air. A mixture of 50% phosphoric acid and 7% zincoxide was applied to the enamel with a cotton-roll pellet and allowed to remain on the surface for 45 seconds. The teeth were again rinsed with water, isolated with cotton rolls, and dried with air. A white area, indicating a superficial decalcification of the enamel, was now noticeable. The powder-liquid adhesive was then mixed, and a small amount was placed on the back of the bracket. The brackets were placed in the correct position with cotton pliers. Only the four anterior teeth, and in some cases the upper canines, were bonded in this way. During subsequent visits, arch wires were placed.

From a period of 8 to 18 months, only a small percentage of brackets failed to remain bonded. In one case, the brackets remained in position for the duration of the treatment - 1.5 years. In another case, the brackets remained for 9 months, at which time the teeth were debonded.

There are, however, earlier references to the use of direct bonding in orthodontics. In 1960, the work reported by Dr. David Mitchell in his masters thesis described a clinically successful adhered appliance (Mitchell, 1960).

This appliance contained several attachment modifications on or in a round hat-shaped metal base that incorporated a mechanical lock for the adhesive. The mechanical lock consisted of stainless wire or tubing soldered across the innermost part of the attachment base. The attachment types were tube, channel, and edgewise. Dr. Mitchell was hesitant to describe his research due to his fear in 1959 of describing what he really came to do, acid etch teeth. He stated that regardless of our present day attitudes and cavalier use of etching, in 1959 and 1960 placing acid on teeth for the purpose of etching was unthinkable. He sincerely believed that if he had revealed what he was doing to keep the brackets on the teeth, he would not have been awarded his degree. In fact, a survey in the late seventies or early eighties by one of the commercial orthodontic companies indicated that 50% of the approximately 7,000 orthodontists did not use the bonded appliance (Mitchell, 1992). The main reason given was the fear of acid etching the teeth.

Etching and bonding teeth is now widely accepted and is by far the most common method of attaching appliances to teeth. The bonding process usually consists of several steps that the clinician must follow. The teeth are generally etched with 37% phosphoric acid for 15 to 30 seconds. The etchant is then rinsed off and the teeth are dried. A primer is then applied to the teeth and cured. The bracket can then be bonded to the tooth using composite. Contamination at any stage in the bonding process will usually result in a lower bond strength which in turn results in loose brackets and wasted time down the treatment road.

3M Unitek has recently introduced a new product called Transbond Plus Self Etching Primer (SEP). This product allows the clinician to perform two stages of the bonding process at the same time. The product etches and primes the tooth in one short step and claims to be effective on wet, saliva contaminated, or dry teeth.

In preparing a single tooth for bonding using the current method it must first be cleansed, dried, etched for at least 15 seconds, rinsed, dried again, then primed and cured for 10 to 20 seconds before the actual bonding can take place. Using the Transbond Plus Self Etching Primer the tooth is cleansed, primed for 3 seconds, blown with air for 3 seconds and is then ready to be bonded, thus significantly reducing the time required to bond.

Not only does SEP use fewer materials and is less time consuming, but 3M claims that SEP's hydrophilic material allows consistent and reliable bond strengths to be achieved in wet and saliva contaminated fields. Multiple studies confirm that saliva contamination during the bonding process will have an adverse effect on the final bond strength. Silverstone (1984) stated that the single most important requirement to achieving good bonding after etching is the application of resin to an etched surface which has not been contaminated with saliva. SEM studies demonstrate that saliva contamination of the etched surface actually affects the morphological characteristics of the surface and that the proteins in the saliva block many of the micropores which were formed during the etching process, so entry of the resin into the micropores to establish mechanical retention is prevented to some degree (Hormati & others, 1980). In addition, saliva acts as a film barrier at the contact level between resin and the enamel and also lowers the surface energy of the enamel, which inhibits good adhesion.

The ability to use SEP to achieve adequate bond strengths in contaminated fields coupled with its simpler and shorter clinical requirements sounds like a great advancement in the bonding routine which can save significant time in the busy orthodontic practice. However, if this new process does not actually result in a bond strength similar to or stronger than the current method, more brackets will become loose during treatment requiring the orthodontist to rebond and possibly step back in wires. If this is the case, the overall treatment time and chair time required to treat the individual patient may actually increase significantly, thus eliminating any advantage gained by the quicker bonding process.

It is the goal of this research project to compare the bond strengths of the current etch(15s)-rinse-dry-prime-cure(20s)-bond method to the new method of prime(3s)-blow(3s)-bond using Transbond Self Etching Primer in both clean and saliva contaminated fields.

MATERIALS and METHODS

Preparation of samples

Twenty extracted maxillary canines and central incisors were prepared for bonding. The crowns were sectioned from the roots and an area on the facial surface of each crown was sanded flat with 600 grit silicon carbide paper being careful not to expose any dentin. There is no evidence which suggests that flattening the enamel has an effect on adhesion in bond strength tests (Gange, 1995). This created a flat enamel area on the facial surface of each crown large enough to completely encompass the base of a Unitek Victory maxillary central incisor bracket (.153in. X .123in.). The crowns were then placed on the surface of a table with the sanded surface of each tooth flush with the table surface. Plastic cylinders with the proper diameter to allow for mounting in the Instron machine were then placed over the crowns and filled with cold-cure acrylic (fig. 2). Once the acrylic had set it was removed from the plastic cylinder resulting in a solid cylinder of acrylic with only the flat sanded enamel surface of the embedded tooth exposed at one end (fig. 3). This resulted in an exposed tooth surface which was exactly 90 degrees to the long axis of the acrylic cylinder which would later allow the force from the Instron machine to be applied in shear to the cured with the Ortholux light for 20 seconds. A precoated bracket was then placed on the enamel surface of each sample making sure that the entire bracket base was on enamel. Gentle pressure was applied to the brackets to express excess composite which was removed using an explorer. The composite was then cured using an Ortholux XT (3M Unitek, Monrovia, CA) light unit which had been previously calibrated to the recommended clinical standards. The composite on each sample was cured for 20 seconds from the bracket's incisal aspect and 20 second from the bracket's gingival aspect for a total cure time of 40 seconds for each bracket. Forty seconds is the recommended light cure time as indicated by studies (Oesterle, 1995). Each sample was then stored in 100% humidity for 24 hours.

Figure 4 Transbond adhesive system (Etchant, primer, precoated bracket)

base of the bonded bracket. The prepared tooth samples were then stored in 100% humidity at room temperature.

Figure 2 Sample mounted in plastic tubing

Figure 3 Sample removed form tubing

Bonding to Samples

Unitek Victory APC 1 brackets precoated with Transbond XT composite resin (3M Unitek, Monrovia, CA) were used in the bonding process. All samples were thoroughly cleansed using pumice and were then rinsed and dried. Samples 1 through 10 (Group #1) were prepared for bonding by first etching the enamel surface for twenty seconds using Ultra-etch 35% phosphoric acid gel (Ultradent, South Jordan, UT) and then rinsing the surface thoroughly with water for ten seconds and dried with air. A thin layer of unfilled resin bonding agent Transbond XT Light Cure Adhesive Primer (3M Unitek, Monrovia, CA) was then applied with a brush and light-

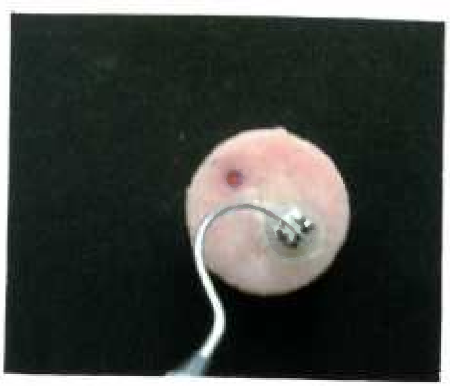
Figure 5 Steps in the standard bonding process

Step 1 - etch for 20 seconds

Step 2 - Rinse for 10 seconds and dry

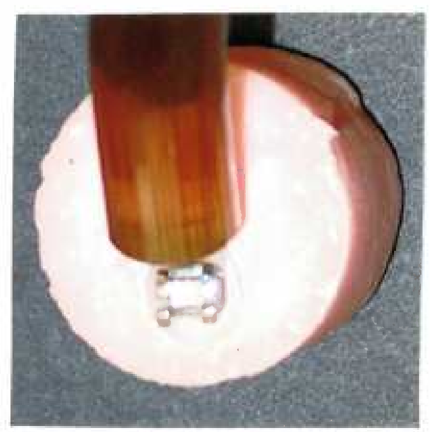
Step 3 - Apply primer

Step 4 - Cure primer for 20 seconds



Step 5 - Apply precoated bracket

Step 6 - Incisal cure 20 sec.



Step 7 - Gingival cure 20 sec.

Samples 11 through 20 (Group #2) were bonded using Unitek's SEP by actively rubbing the SEP on the enamel surface for three seconds and drying with an air burst for three seconds. Precoated brackets were then applied to the prepared enamel surfaces and bonded as previously described. Each sample was then stored in 100% humidity for 24 hours.

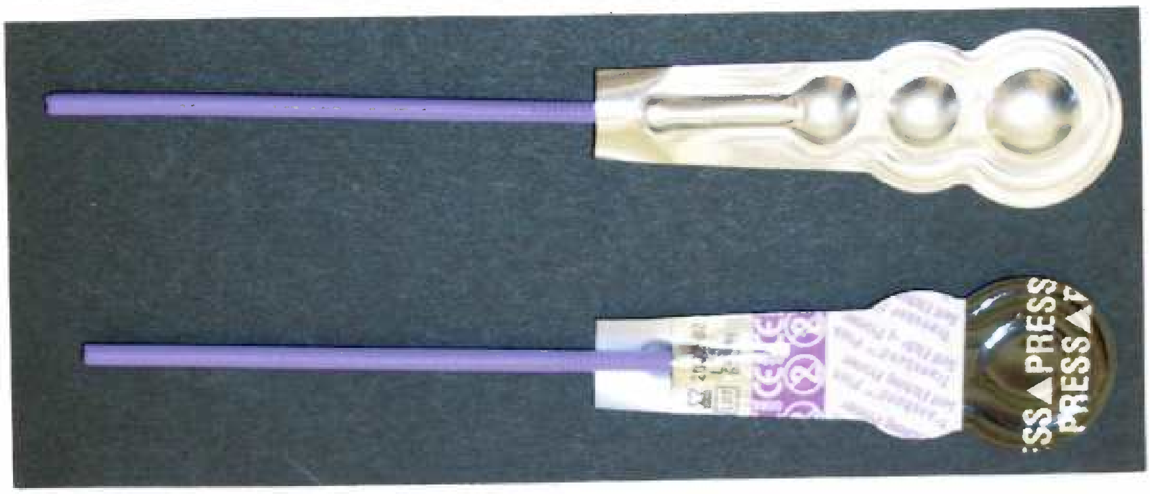
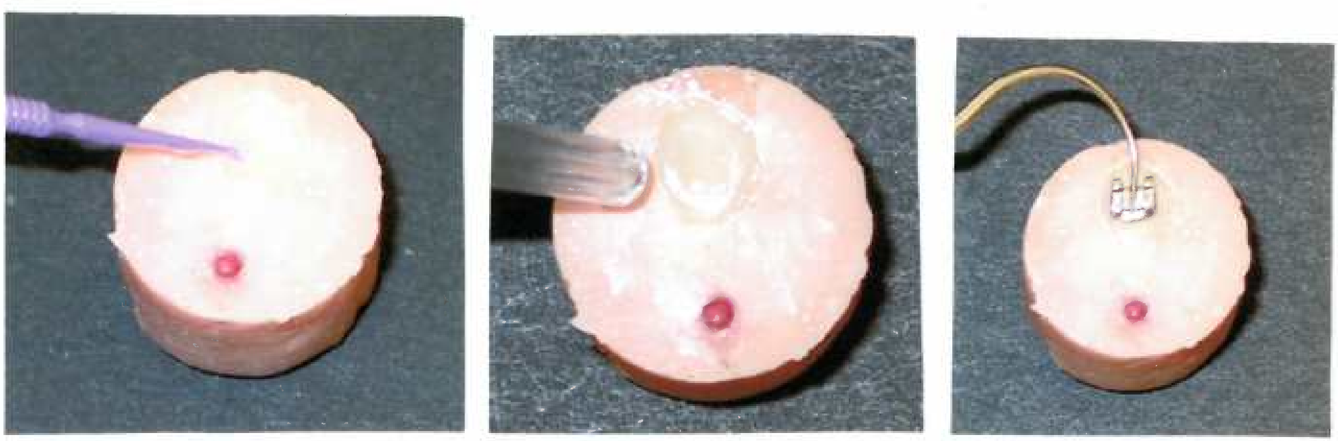


Figure 6 Self Etching Primer (3M Unitek)

Figure 7 Bonding steps using SEP



Step 1 - Actively apply SEP for 3 sec. Step 2 - Dry for 3 sec. Step 3 - Apply precoated bracket

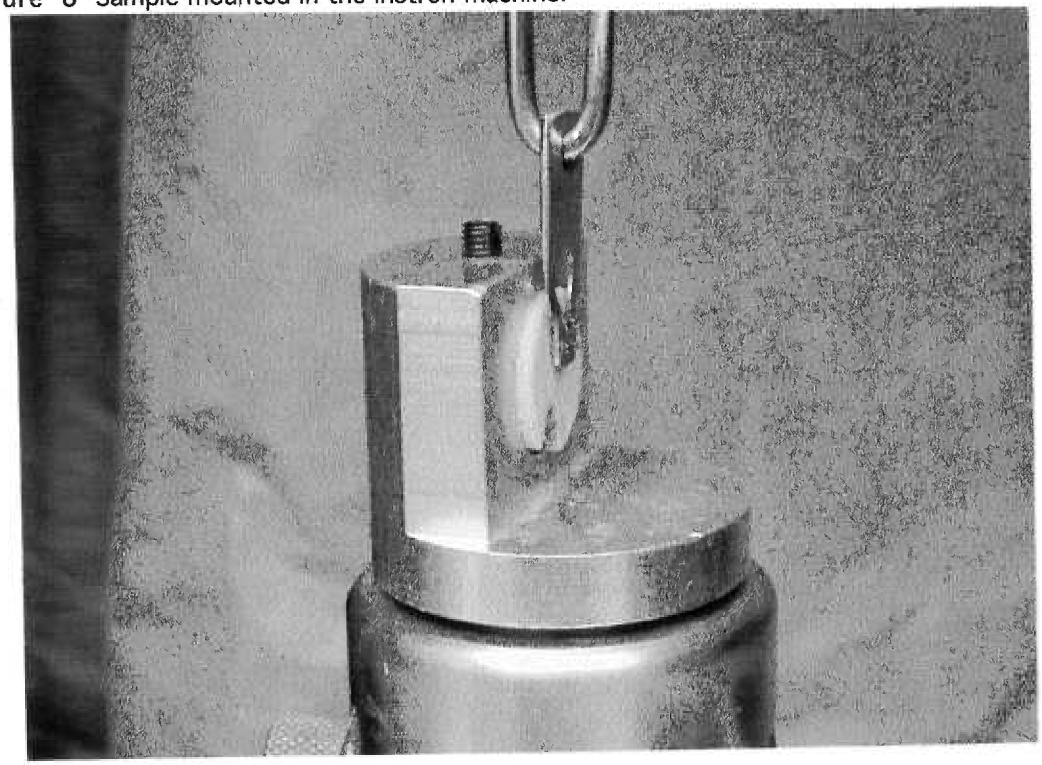
The brackets were then light-cured exactly as in Group 1.

The Instron Machine (Instron Corp., Canton, Mass.) was then utilized to apply a shear force to each bracket until bond failure. The cross-head speed was set at 0.1 inches per minute. The acrylic mounted teeth were placed in a holding apparatus with the brackets uniformly oriented as much as possible. A debonding jig was fit over the gingival wings of each sample and force was then applied by the Instron machine until failure (Fig. 9). Shear bond strength and the site of failure were recorded for each sample. The samples were then stored in 100% humidity at room temperature.

The samples were then prepared for the next phase of the experiment. The enamel surfaces of all samples were sanded with 600-grit silicon carbide paper in order to reestablish an uncontaminated enamel surface that could be used for bonding a second time. Group #3 consisting of samples 21 through 30 was prepared in a way to determine the effects of saliva contamination on the bond strengths achieved using the Self Etching Primer by contaminating the enamel surface prior to the application of the SEP. The enamel surfaces were thoroughly pumiced, rinsed, and dried. Using a brush, enough saliva (freshly aquired form a dental student) to coat the entire enamel surface with a thin film was then applied to the samples followed by the application of SEP without cleansing the saliva from the enamel surface.

Bonding then proceeded exactly as described in Group #2.

Figure 8 Sample mounted in the Instron machine.



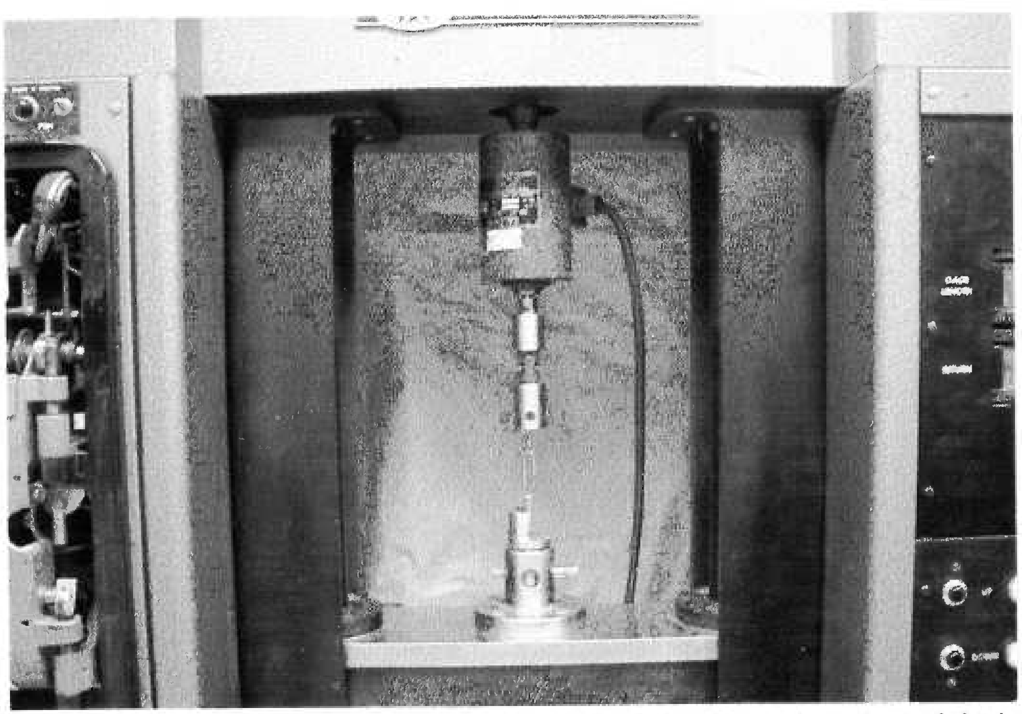


Figure 9 Sample being debonded with debonding jig fit under the gingival wings of the bracket.

Group #4 consisting of samples 31 through 40 was prepared to determine the effects of saliva contamination on bond strength when the tooth becomes contaminated after the application of the SEP and before the placement of the bracket. Samples were pumiced and rinsed. SEP was actively applied to the enamel surfaces for three seconds and dried with air for three seconds. Each sample was then contaminated with saliva in exactly the same method used in Group #3 and the bonding was then completed as described in the previous groups. The Instron Machine was then used to determine shear bond strength for each sample in groups #3 and #4 in exactly the same manner as in groups #1 and #2.

Results

Table 2 displays the mean shear bond strength and standard deviation for each group. The mean shear bond strengths are also displayed in a bar graph in figure 10. The shear bond strengths between the four groups were statistically analyzed using a one-way ANOVA (Table 3) and Tukey's Multiple Comparison test at the $p \leq 0.05$ level (Table 4). The ANOVA showed no statistical difference between any of the groups. Tukey's Multiple Comparison when applied to the two groups having the largest difference between any two of the groups (group 4 and group1 with a difference of 1.69) showed no statistical difference and therefore no statistical difference between any of the groups.

Table 1. Summary of sample groups.

Group	Technique	Contamination	Sample size
1	standard	no	10
2	SEP	no	10
3	SEP	Yes, saliva prior to SEP application	10
4	SEP	Yes, saliva after SEP application	10

Table 2. Mean bond strengths and standard deviations in MPa for each group.

Group	Mean Bond Strength (MPa)	Standard Deviation
1	10.91	1.65
2	11.04	1.44
3	11.68	2.12
4	12.60	1.70

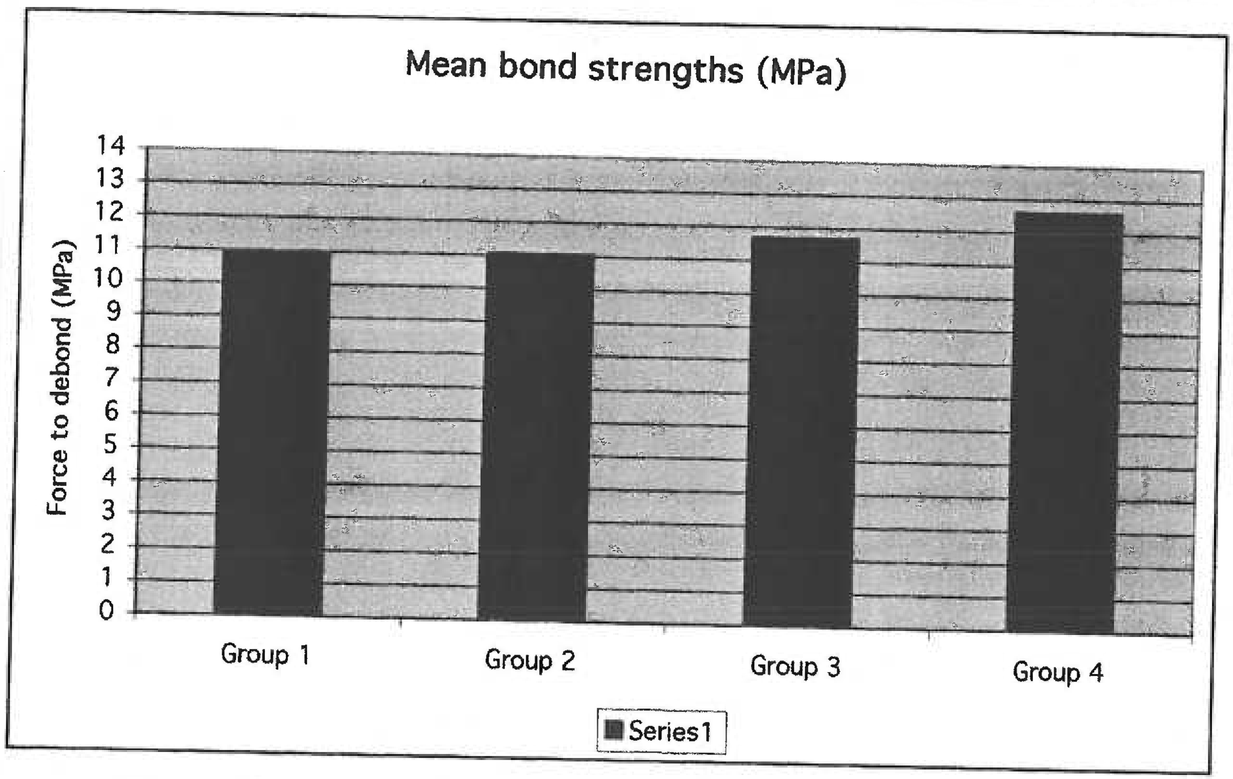


Figure 10. Mean bond strengths

Table 3 One-way ANOVA used to analyze the mean bond strengths between the groups. A P value of 0.1347 was not significant.

Source	DF	Sum of Squares	Mean Square	F value	Appx P
Total	39	947.78			
Treatment	3	134.09	44.7	1.98	0.1347
Error	36	813.68	22.6		

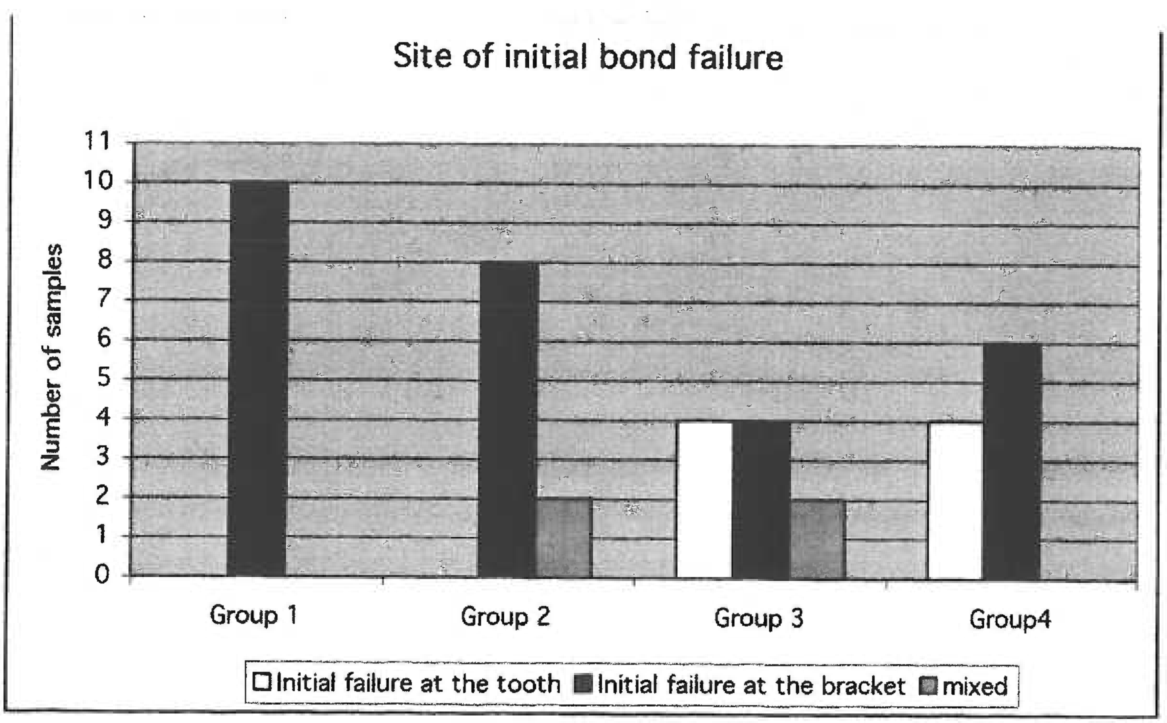
Table 4 Tukey's Mult. Comp. Test analyzing the mean bond strengths between the four groups. No statistical difference was found between any of the groups.

Tukey's Mult. Comp.	Difference	Q	Critical q (0.05)
Mean (4) – Mean (1)	4.63	3.08	3.813
Mean (4) – Mean (2)	4.27	Do not test	
Mean (4) – Mean (3)	2.53	Do not test	
Mean (3) – Mean (1)	2.1	Do not test	
Mean (3) – Mean (2)	1.74	Do not test	
Mean (2) – Mean (1)	0.36	Do not test	

Site of Failure

Figure 11 demonstrates graphically the site at which bond failures (at the bracket or at the tooth) were initiated for each of the four groups. Group #1 demonstrated 100% of bond failures initiating at the bracket. In Group #2, 80% of the failures were initiated at the bracket, with 20% of the failures being mixed (initiation of failure at the tooth and bracket simultaneously). When examining the site of failure in Groups 3 & 4 in which saliva contamination was introduced at different steps in the bonding process the percentages change drastically. Group 3 demonstrated 40% of bonding failures initiating at the bracket, 40% at the tooth, and 20% mixed. 60% of the bond failures in Group #4 were initiated at the bracket with the remaining 40% occurring at the tooth.

Figure 11. Site of bond failures for each of the groups



Summary of Results

1. Non contaminated groups utilizing the standard etch-prime-cure technique (Group 1) and the SEP technique (Group 2) showed no statistical differences in bond strengths.

2. The step in the bonding process in which saliva contamination was introduced, prior to SEP application (Group 3), or after SEP application (Group 4), had no significant effect on the bond strengths achieved between the two groups.

3. When the mean bond strengths of the four different groups were measured, no statistical differences were found between any of the groups.

4. Differences in the site (at the tooth or the bracket) at which bond failures were initiated were found between the groups. Groups 1 & 2 showed failure initiating at the bracket-adhesive interface in 100% and 80% of the samples respectively. However, only 40% of the samples in Group 3 and 60% of the samples in Group 4 showed failure initiating at the bracket-adhesive interface.

Discussion

The statistical similarity of mean bond strengths achieved using the standard etch-cure technique (Group 1) and the uncontaminated SEP technique (Group 2) has clinical orthodontic implications. This study indicates that SEP may be used in place of the standard etch technique to achieve mean bond strengths which are clinically acceptable. Thus, the orthodontist may use the SEP technique to bond orthodontic appliances with the advantages of decreased chair time and fewer materials. Also, the orthodontist should not experience an increase in the number of bond failures during treatment when utilizing the SEP technique and thus not offsetting the initial advantage of decreased chair time during the initial bonding procedure.

Another advantage of the SEP technique may be the ability to obtain an adequate bond strength even in the presence of saliva contamination. This may be due to the hydrophilic nature of SEP allowing it to mix with the saliva and still adequately wet the tooth surface. This study found no statistical difference in the mean bond strengths between the contaminated and the uncontaminated groups. These findings may indicate that SEP may be a valuable tool when dealing with bonding situations in which isolation is extremely difficult and contamination is likely.

When analyzing the site at which bond failure was initiated among the four groups, a difference was found between the uncontaminated and contaminated groups. The contaminated groups displayed a much higher percentage of bond failures at the tooth-adhesive interface. Possibilities for this occurrence may be that proteins in the saliva block many of the micropores which were formed during the etching process or that saliva creates a barrier which does not allow close approximation of the adhesive to the tooth surface. This may indicate that contamination may weaken the tooth-adhesive bond but did not result in a mean bond strength which was statistically different from the uncontaminated groups. An explanation for these results may be that the weak link in the uncontaminated samples is the bond strength at the bracket-adhesive interface as demonstrated by the large majority of bond failures in Groups 1 & 2 initiating at this interface. Saliva contamination may weaken the bond strength at the tooth-adhesive interface to a level comparable to the bond strength found at the bracket-adhesive interface. Thus, in the contaminated samples, failure may be just as likely at either interface without reducing the overall bond strength because the strength of the strongest link (tooth-adhesive interface) was reduced to a level comparable to the weakest link (bracket-tooth interface) but not below this level.

Conclusions

1. The results indicate no statistical difference in bond strengths achieved utilizing the standard technique versus the SEP technique.

2. No statistical difference was found between the bond strengths of the uncontaminated and contaminated groups.

3. Contaminated groups showed a higher percentage of bond failures at the tooth-adhesive interface when compared with uncontaminated groups.

4. The results of this study indicate that the SEP technique provides a bond strength statistically similar to the standard technique. These findings validate the SEP advantages of reduced chair time and fewer materials necessary to bond appliances to enamel.

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