Hybrid crowns – bonding protocols and shear bond strength

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Aims: The objective of the present study was to evaluate the effect of three different surface treatment protocols on the shear bond strength (SBS) of metal brackets to Vita Enamic® and Lava™ Ultimate CAD/CAM hybrid ceramics.
Methods: A total of 60 crowns were milled and divided into one of three etching groups which used 9.6% hydrofluoric acid, 35% phosphoric acid and 50 μ aluminum oxide microetching. The surface morphology of the ceramic was observed after each etching treatment using a scanning electron microscope to characterise the etched surface. Lower left first molar tubes (Ormco™) were bonded with light-cure composite, stored in artificial saliva for one week and subsequently thermocycled. The SBS test was performed using an Instron 5566 machine. Adhesive Remnant Index (ARI) scores were also assigned to determine the mode of bond failure. Data were analysed using an Independent Sample *t*-test.
Results: The SBS of all groups, except the HFA Enamic® group, were significantly lower than the mean SBS of the enamel control group (8.8 MPa). The mean shear bond strength values of Enamic® were significantly higher than those of Lava™ Ultimate (p-values < 0.05).
Conclusions: Statistically, only Enamic® treated with HFA exhibited sufficient SBS when compared with the enamel control. Adhesive failures between the bracket base and adhesive were the predominant mode of failure in all groups except in the PA Lava™ Ultimate group.
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Introduction

Adults comprise an ever-increasing percentage of contemporary orthodontic practices.[1] Older patients often have extensive posterior restorations, which include full-coverage crowns that necessitate banding or the bonding of brackets. To avoid additional appointments, and therefore time away from work, it is often beneficial to bond an attachment to a crowned tooth rather than use a band. Additionally, as CAD/CAM dentistry increases in popularity in restorative dentistry, all-ceramic posterior restorations are becoming increasingly common.[2,3] New and improved materials are constantly being introduced as the pursuit of the ideal all-ceramic posterior crown material continues.

Within the last few years, two new all-ceramic crown materials have been produced. Both are considered to be ceramic/polymer hybrids that boast the benefits of resin and ceramic in one material. Enamic®, engineered by Vita (CA, USA), is composed of a hybrid of feldspathic ceramic (86%) and polymer composite (14%) that has claims of strength and flexibility.[4] Lava™ Ultimate by 3M ESPE (MN, USA), an alternative material, is referred to as a Resin Nano

Ceramic (RNC) composed of Nano Ceramic (~80% wt) and resin (~20% wt), which has similar claims of strength and flexibility to Enamic®.[5]

A solitary study was found that investigated the shear bond strength (SBS) of adhesive resin related to the attachment of an orthodontic bracket to an incisor restoration of Vita Enamic®.[6] However, no information has been provided regarding the most efficient etching protocol for bonding and removing an attachment on a posterior restoration using hybrid ceramics. Furthermore, the protocol that will produce the least amount of damage to the hybrid ceramic surface is currently unknown. Hydrofluoric acid (HFA) etch and silanation has been commonly accepted as a necessary preparation for bonding to porcelain.[7,8] However, HFA is very caustic and its potential to cause soft tissue damage is high if used incorrectly.[9] An alternative method of preparation is sandblasting of the porcelain surface with aluminum oxide particles, also known as 'microetching'.[10] Additionally, etching porcelain with 35% phosphoric acid (PA) with subsequent silanation produces acceptable SBS.[11] Because of the possible harm incurred by the intraoral use of HFA, an alternative protocol (ie. microetching, PA etching) for adequate porcelain preparation would be of great benefit for the clinician and potentially safer for the patient. Therefore, the aim of the present study was to evaluate which preparation protocol would be most effective in bonding brackets to the new class of hybrid ceramics, while producing minimal damage to the restored surface.

Materials and methods

The flow-chart of the sample preparation process used in the present study is shown in Figure 1. Sixty hybrid ceramic samples were randomly divided into three

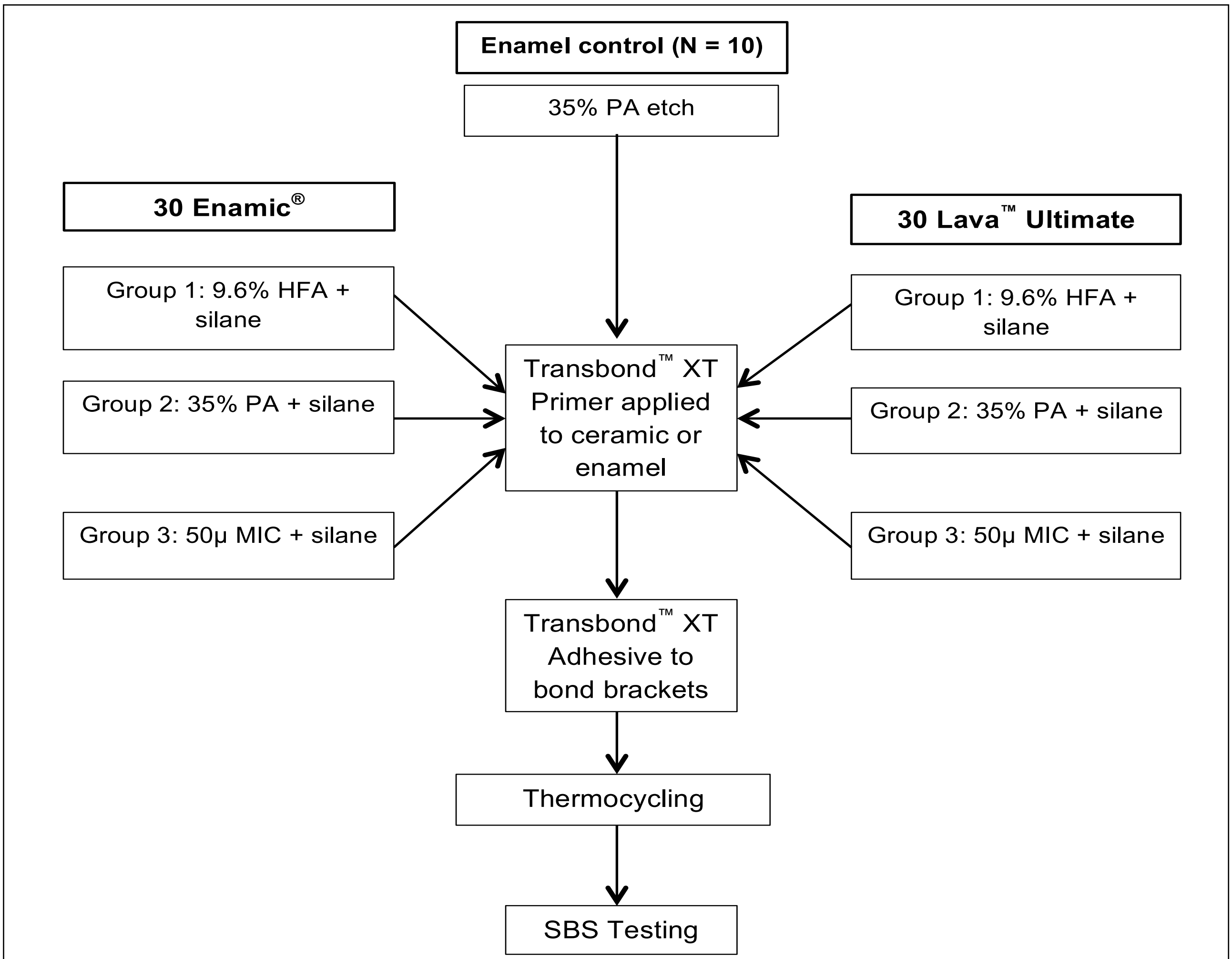

Figure 1. Flow-chart of the sample preparation process used in this study.

groups (N = 10) for each of the two different materials (30 Vita Enamic® and 30 3M Lava™ Ultimate). The number was based upon the sample size in similar previous studies.[12,13] The samples were milled on a CEREC CAD/CAM unit (NC, USA), the process of which was interrupted halfway through to ensure an accurate representation of the buccal surface of a mandibular left first molar. Interrupting the milling process maintained a broad, flat area that imparted the needed strength and stability during SBS testing with the Instron 5566 machine (MA, USA).

After milling, each sample was polished to mimic the smooth surface that would be present when a crown is delivered in vivo. The Enamic® crowns were polished with a rubber polishing wheel (Komet, SC, USA, part number 94013F.HP.170) and the Lava™ Ultimate crowns were polished with flour pumice on a rag wheel as recommended by the manufacturers. One SEM image (S-2700 Scanning Electron Microscope, Hitachi, Tokyo, Japan) of each material was taken prior to etching to characterise the polished surface for later comparison.

Ten extracted mandibular left first molars, serving as a control group, were embedded with the facial surface facing up in an auto-polymerising acrylic resin block. The molars were etched with 35% phosphoric acid (3M Unitek, CA, USA) for 30 seconds and rinsed for 10 seconds. An adhesive primer, Transbond™ XT Primer (3M, CA, USA) was applied for five seconds and lightly air-thinned for one second. This follows the recommendations of the manufacturer and is in accordance with the protocol followed in previous studies.[14,15] Mandibular left first molar tubes (Ormco™, CA, USA) were bonded with Transbond™ XT (3M Unitek, CA, USA) and light cured with an Ortholux™ LED curing light (3M Unitek, CA, USA) for 40 seconds, 10 seconds from each direction incisal, gingival, mesial, and distal.

Each sample group (N = 10) received a different etching protocol: Group 1 was treated with Porc-Etch (9.6% hydrofluoric acid gel) and Porcelain Conditioner (silane primer) by Reliance (IL, USA). Group 2 samples were treated with 35% phosphoric acid gel (3M Unitek, CA, USA) and a silane primer. Group 3 samples were microetched (MIC) with 50 µm aluminum oxide particles for 10 seconds and subsequently treated with the silane primer (Figure 1).

After etching, one random sample from each of the six groups and its facial surface was captured by an SEM image to display the amount of surface roughness produced by each etching protocol. These were compared with the polished, pre-etched surface SEM image of each material.

All chemical reagents were used according to the manufacturer's recommendations. The 9.6% HFA was applied for four minutes, and then rinsed thoroughly for 30 seconds. A thin coat of silane primer was applied to the porcelain surface and allowed to dry. A thin layer of universal bonding resin, Transbond™ XT Primer (3M, CA, USA), was applied and air-thinned onto the silane treated surface. The same protocol was used for Group 2, but using PA as a substitute for HFA. After all chemical and/or mechanical pretreatments, mandibular left molar single buccal tubes (Ormco™, Titanium buccal tube, CA, USA) were bonded onto each sample using 3M Transbond™ XT (CA, USA). The mean surface area of the molar tube pad was obtained from the manufacturer and reported as 22.19 mm^2. A mounting jig (Figure 2) was fabricated to the facial surface of the molar on the ceramic blocks from A+ Essix (Dentsply Raintree Essix, FL, USA) material.[16] This allowed for standardised bonding of the brackets to the same location on each sample to help minimise variables. The tubes were light cured with an Ortholux™ LED curing light (3M Unitek, CA, USA) for 40 seconds, 10 seconds from each direction incisal, gingival, mesial, and distal.

In an effort to mimic the internal oral environment, thermocycling was utilised to artificially age the samples. Thermocycling has a dramatic effect on bond strengths, and results in significant decreases

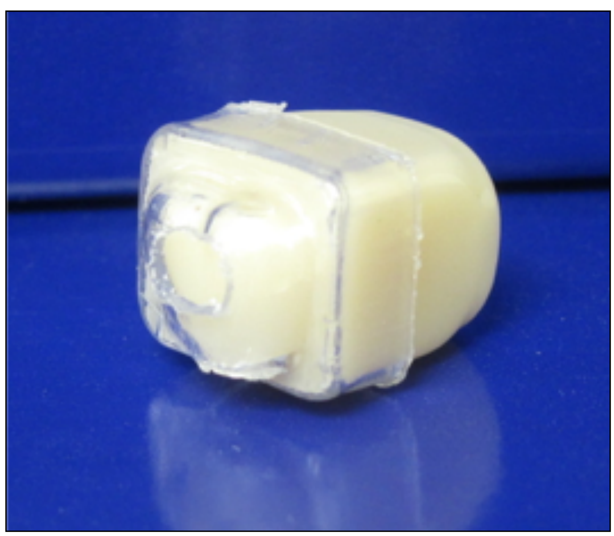

Figure 2. Essix bonding jig.

Table I. Minimum, maximum, and mean values for each test group.

	Min (MPa)	Max (MPa)	Mean (MPa)	Std. Dev.
Enamel	4.48	11.77	8.81	2.26
Group 1 Lava (HFA)	4.13	6.61	5.69	0.94
Group 2 Lava (PA)	4.44	6.49	5.65	0.71
Group 3 Lava (MIC)	4.50	6.56	5.95	0.59
Group 1 Enamic (HFA)	4.64	11.02	7.30	1.88
Group 2 Enamic (PA)	5.99	8.64	6.99	0.95
Group 3 Enamic (MIC)	5.00	7.49	6.69	0.74

Table II. Comparison of enamel control SBS values with each test group.

Comparison group	Material	Protocol	*p*-value	Result
Enamel	Lava	HFA	0.001	Significant
		PA	0.001	Significant
		MIC	0.003	Significant
Enamel	Enamic	HFA	0.121	Not significant
		PA	0.03	Significant
		MIC	0.016	Significant

in the bond values.[17,18] Therefore, all specimens post-bonding were stored in PBS buffer solution at room temperature for one week and subsequently thermocycled 1000 times between 5°C and 55°C with a dwelling time of 30 seconds.[17,18]

The shear bond strength was tested using an Instron 5566 Universal Testing Machine at a crosshead speed of 1 mm/minute. The SBS was calculated in MPa using the formula MPa = F/A; where F is the maximum load, and A is the bracket base area in mm^2. The mean, maximum, minimum, and standard deviation SBS values for each sample group including the enamel control were calculated (Table I). An Independent Sample *t*-test (IBM SPSS Statistics 22.0, NY, USA) was performed in order to compare the mean SBS for each of the groups with that of enamel (control).

To evaluate and quantify the effect that the combination of adhesive and debonding protocol had on the porcelain, separate samples (N = 5) in each of the six test groups were examined using 4.0× magnification loupes (Surgitel®, MI, USA) to determine the Adhesive Remnant Index (ARI) of each sample. These samples were debonded using bracket-debonding pliers (Hu-Friedy plier 678-220L, IL, USA) to simulate the clinical removal of the bracket.

Results

Table I shows the shear bond strength of brackets attached to the different materials using the different etch methods. Only the mean SBS of Group 1 Enamic® (HFA) was similar to the SBS of enamel. All other groups had a lower SBS compared with enamel (Table II). Independent Sample *t*-tests were also performed for a comparison of the two materials when the same protocol was used. The results indicated that the mean SBS of Enamic® showed higher values, which were significantly different than those of Lava™ Ultimate (Table III). There was no difference in the SBS measurements when the same material was compared against the different protocols.

Representative SEM images (×1000) of each polished material are presented in Figure 3. It is evident in Figure 4 that the surfaces of both materials are similar to that of the polished surfaces even after being etched with PA. Figures 5 and 6 characterise the changes in the surface texture with formation of irregularities and micropores after etching with both MIC and HFA, respectively. This surface structure allows micromechanical retention as resin tags from the bracket adhesive infiltrate the micropores.

Except for the Group 2 Lava™ Ultimate (PA), the mean ARI scores for each group fell between 2 and 3

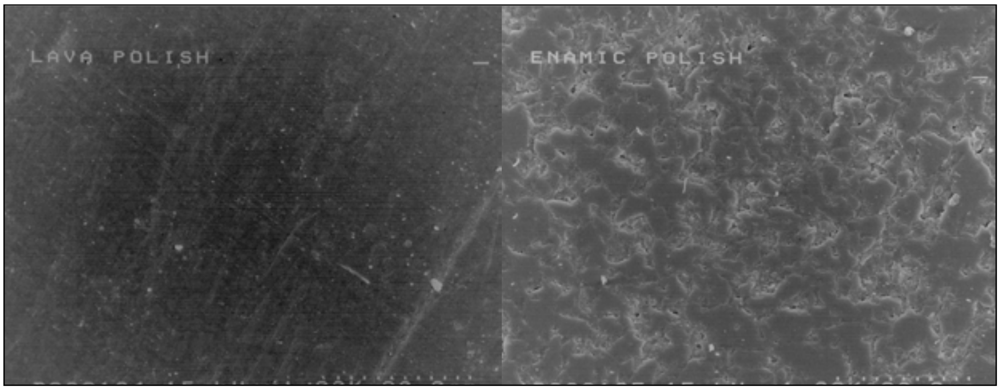

Figure 3. Surface architecture prior to etching.

Figure 4. 35% Phosphoric acid etch.

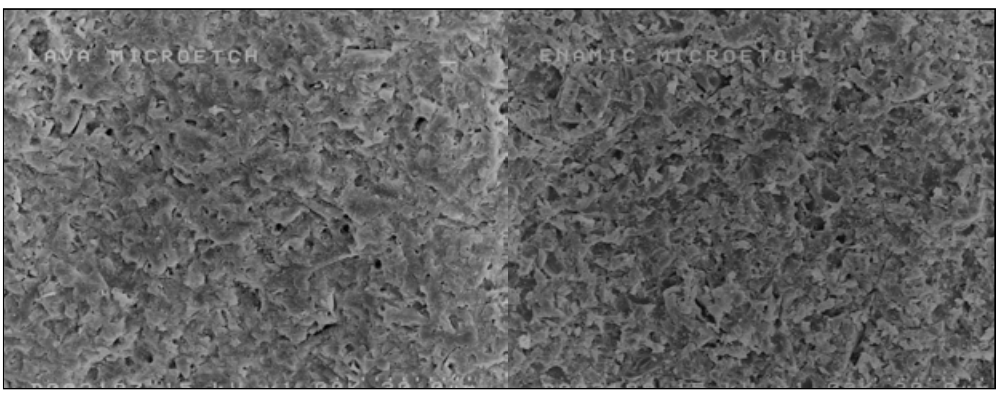

Figure 5. 50 μ Aluminum oxide microetching.

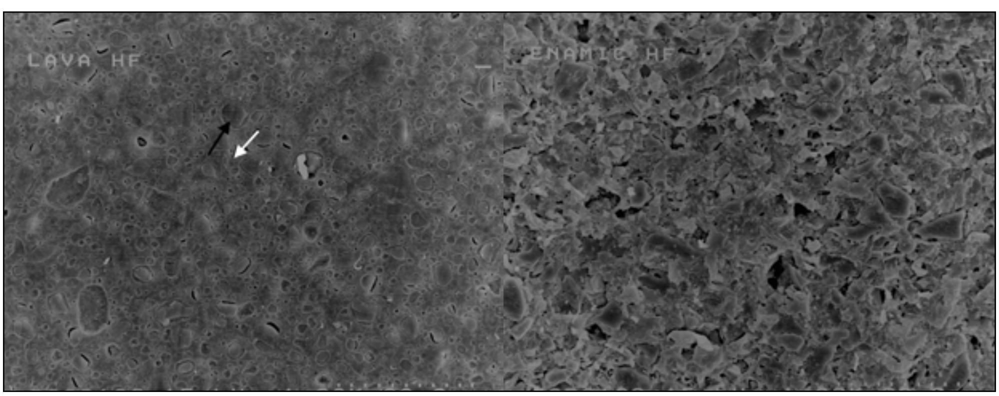

Figure 6. 9.6% Hydrofluoric acid etch. On left: Black arrow represents the polymer phase and the white arrow represents the ceramic phase.

Table III. Comparison of Lava™ Ultimate values with Enamic® for each etching protocol.

Comparison group	Material	Protocol	*p*-value	Result
Lava	Enamic	HFA	0.026	Significant
Lava	Enamic	PA	0.002	Significant
Lava	Enamic	MIC	0.026	Significant

Table IV. Adhesive Remnant Index (ARI) scores.

	0	1	2	3	Mean
Group 1 Lava (HFA)	0	0	2	3	2.6
Group 2 Lava (PA)	4	0	1	0	0.4
Group 3 Lava (MIC)	0	0	1	4	2.8
Group 1 Enamic (HFA)	0	0	2	3	2.6
Group 2 Enamic (PA)	0	0	2	3	2.6
Group 3 Enamic (MIC)	0	0	0	5	3.0

(Table IV). The Group 2 Lava™ Ultimate (PA) mean ARI score was below 1, indicating the mode of failure occurred between the adhesive and the hybrid ceramic.

Discussion

Since this class of hybrid ceramic material is relatively new, the effects of various etching protocols on the SBS of orthodontic attachments to these materials are unknown. Maximum SBS is not necessarily always the goal. Debonding with minimal porcelain surface damage is also critical.[9] Therefore, the current study intended to establish which porcelain surface preparation is most clinically suited for this class of materials. The ideal bond strength would be the one that is sufficient to withstand appliance forces but would debond favourably and demonstrate acceptable finishing of the porcelain surface after attachment removal.

The enamel control group was used to determine the difference between SBS of enamel versus hybrid ceramics. It also served as a calibration and reference point from which to compare the hybrid ceramic SBS for each of the three ceramic treatment groups. It has been generally accepted that clinically adequate bond strength for a metal orthodontic bracket to enamel should be between 6 and 10 MPa.[19] In the present study, the enamel control mean SBS was 8.81 MPa, indicating that calibration fell within previous accepted values and allowed comparison of the hybrid ceramic SBS values with confidence.

Statistically, the only group that exhibited a shear bond strength similar to the enamel control was the Group 1 Enamic® (HFA) (7.29 MPa). This value agrees with previously published results which reported the bonding of a metal bracket to an anterior Enamic® restoration etched with HFA. It should be noted that Enamic® etched with PA had a mean SBS of 5.63 MPa, which disagrees with the results of the current study.[6] All other groups' SBS values were statistically significantly different (lower) compared with that of the enamel control. However, the entire Enamic® group SBS values, regardless of the etching protocol, were above the accepted threshold of 6–10 MPa. Therefore, it is suggested that, although the Group 2 Enamic® (PA) and Group 3 Enamic® (MIC) were statistically different from the enamel control, bonding brackets to Enamic®, using any of the three etching protocols, is a viable option that yields clinically acceptable bond strengths. With this knowledge, it would be preferable to avoid the use of HFA when bonding a bracket to a crown made of this material.

The Lava™ Ultimate SBS values were all below the 6–10 MPa threshold and it is therefore suggested that banding of these crowns is prudent due to inadequate SBS. As previously noted, 3M ESPE removed the full coverage crown indication for Lava™ Ultimate midway through this investigation. The 3M ESPE website indicated that the crowns were debonding at 'higher than anticipated rates' and 'not meeting 3M's high standards'.[20] The decision was therefore made to continue the investigation, anticipating that clinicians would still encounter patients with Lava™ Ultimate full coverage posterior crowns. Lava™ Ultimate is still indicated for veneers so the possibility of bonding an anterior bracket remains a problem for the clinician. Perhaps the lack of adequate SBS in the three Lava™ Ultimate test groups is related and similar to the reasons causing debonding at higher than anticipated rates. However, this hypothesis requires further investigation.

The Adhesive Remnant Index (ARI) is a 0–3 scale in which a '0' indicates that none of the adhesive was left on the tooth after debonding (least desirable), a '1' indicates that less than 50% remained, '2' indicates more than 50% remained and a '3' indicates that all of the adhesive remained on the tooth after bracket removal (most desirable).[21] This not only helped to determine where the bond failure occurred, but also aided in identifying damage to the porcelain during bracket removal. Both factors directly relate to the ability to restore the porcelain crown surface to its original finish. In the present study, the mean ARI scores fell between 2 and 3 for all groups except the Group 2 Lava™ Ultimate (PA), which had a mean ARI of 0.4. This low ARI score suggests that the failure of the bond occurred at the adhesive/ceramic interface and has the potential to produce ceramic pull-out or crack propagation upon removal of the bracket. This is an unfavourable outcome and further solidifies the premise that a higher ARI score is desirable and leaves the adhesive removal in the clinician's hands. When removing adhesive remnants with careful use of selected tungsten carbide burs operated at speeds of around 25,000 rpm (and no water coolant so that adequate contrast is obtained), the risk of inducing iatrogenic damage is minimal.[22]

The results of this and similar studies suggest that close communication between orthodontists and restorative dentists is necessary. Orthodontic clinicians should not presume that one bonding protocol is acceptable for all materials used in dentistry.

The limitations of this in vitro study include the fact that, although measures were taken to minimise variation in the bonding protocol, slight procedural inconsistencies may have occurred that could have affected the SBS value.

Conclusions

1. Statistically, SBS values for all groups, except Enamic® treated with HF acid etch, were significantly different from that of the enamel control.
2. Clinically, all three of the tested etching protocols are an acceptable option when bonding to Enamic®.
3. It is recommended that posterior teeth with Lava™ Ultimate ceramic restorations be banded rather than bonded.
4. Regardless of the etching protocol, finishing of the ceramic surfaces after bracket removal was acceptable in both the Enamic® and Lava™ Ultimate materials.

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