ORIGINAL ARTICLE

# The effect of different porcelain conditioning techniques on shear bond strength of stainless steel brackets

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With the increasing demand for adult orthodontics, a growing need arises to bond attachments to porcelain surfaces. Optimal adhesion to a porcelain surface should allow orthodontic treatment without bond failure but not jeopardize porcelain integrity after debonding. In this study, 90 glazed porcelain facets were divided into three groups according to different conditioning techniques: (1) roughening with a coarse diamond; (2) hydrofluoric acid 8%; (3) microetching with 60µ aluminum oxide particles. Each group was divided into three groups and stainless steel brackets were then bonded to the conditioned porcelain with three different dental adhesives. The adhesives used were: (1) silane+Right-On; (2) silane+Concise; (3) High-Q-Bond without silane. Four additional facets (three of which conditioned as above and one intact) were analyzed macroscopically and by scanning electron microscopy. Shear bond strength was measured with an Instron universal testing machine and a macroscopic examination of the debonded porcelain surfaces was performed. Results showed that shear bond strength was highly influenced by both conditioning technique and the adhesive. Shear bond strength of the High-Q-Bond groups was significantly lower than both the silane+Right-On and the silane+Concise groups; nevertheless the shear bond strength achieved by High-Q-Bond was enough to sustain full orthodontic treatment duration (except for the group conditioned by roughening with a coarse diamond). Scanning electronic microscopy analysis revealed that diamond roughening and microetching produced only a surface-peeling pattern, whereas hydrofluoric acid conditioning produced an extensive in-depth penetrating pattern. Hydrofluoric acid preparation produced greater shear bond strength than both diamond roughening and microetching. After debonding by means of a shearing force, the percentage of damaged porcelain surfaces in the silane+Concise groups was significantly higher than the silane+Right-On and High-Q-Bond groups. (Am J Orthod Dentofacial Orthop 1998;114:387-92)

Many patients seeking orthodontic treatment have teeth restored with porcelain crowns or laminates. Therefore bonding orthodontic attachments to porcelain is becoming a common procedure. When bonding to porcelain, the orthodontist is presented with a two-edged sword. On the one hand, maximum bond strength is desired to minimize bond failure during the treatment period. On the other hand, after debonding of the orthodontic attachments, the porcelain restorations should be returned to their pristine glory.

To enhance bracket's bond strength to porcelain, pretreatment of the porcelain surface is required. The following methods of porcelain preparation have been suggested: (1) bonding to glazed porcelain with the assistance of a coupling agent (silane) as an interface between the porcelain and the bonding agent[1]; bond strength produced by this method is apparently inadequate for orthodontic purposes[2]; (2) deglazing the porcelain by roughening the surface (eg, with a coarse diamond, with a sandpaper disk or microetching with aluminum oxide ($Al_2O_3$) particles and then bonding with or without a coupling agent[2]; deglazing of the porcelain produced bond strengths comparable to bonding to acid etched enamel; and (3) chemical preparation of the porcelain with hydrofluoric acid (HF)[3] or acidulated fluoro phosphate (AFP).[4] Chemical preparation with HF produced bond strengths similar to or higher than bonding to etched enamel. On debonding, the porcelain surface is frequently damaged. Most of the porcelain repair materials are not capable of restoring the original porcelain surface texture, and even when surface luster is restored, all authors agree that surface defects produced on debonding are not fully reparable.

Recently, a new material named High-Q-Bond (HQB) has been produced. HQB is a dentin bonding agent[5,6] that belongs to the fourth generation of dental adhesives. It is composed of acrylic monomers methylmethacrylate (MMA) crosslinked with a multifunction-

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**Table I.** SBS of stainless steel brackets bonded to porcelain conditioned by various techniques and bonded with various adhesives (presented in MPa)

| | *Silane+Right-On* | *Silane+Concise* | *High-Q-Bond* |
|---|---|---|---|
| Hydrofluoric acid | 10.12 ± 3.04[a]<br>n = 9 | 16.24 ± 3.55[abc]<br>n = 9 | 11.03 ± 3.24[bef]<br>n = 10 |
| Microetching | 11.06 ± 2.68[gi]<br>n = 14 | 17.90 ± 3.65[dgh]<br>n = 10 | 6.78 ± 2.37[ehi]<br>n = 10 |
| Coarse diamond | 11.73 ± 3.25[j]<br>n = 9 | 12.20 ± 4.85[cdk]<br>n = 10 | 5.68 ± 1.28[fjk]<br>n = 9 |

Only figures with identical superscript letters (a-a, b-b etc.) are statistically significant at $P < .001$ level.

al agent (trimethylopropane-triacrylate), an adhesion promoter (glycidoxypropyltromethoxysilane), a co-monomer-aliphatic polyester (urethane acrylate), and initiators for self-curing process (dimethyl-p-toluidine and benzoyl peroxide). The HQB composition also includes PolyMMA, inorganic fillers, and coupling agents. According to the manufacturer, HQB provides high tensile bond strength and can be used for bonding to various substrates such as dentin, enamel, noble and base metal alloys, amalgam, composite, and porcelain.[7,8] It was this property of HQB that prompted us to use this adhesive for bonding metal brackets to porcelain and then to evaluate porcelain surface integrity after debonding of the HQB bonded brackets.

The aims of this study were: (1) to analyze the effect of the different conditioning techniques on porcelain surfaces with scanning electron microscopy (SEM); (2) to evaluate the effect of different porcelain conditioning techniques on the shear bond strength (SBS) of stainless steel brackets; and (3) to determine the mode of bond failure.

## MATERIAL AND METHODS

Ninety-four glazed porcelain facets resembling lower incisors were built from Ceramco II Vacuum porcelain (Ceramco, Burlington NJ) by the condensing technique and baked under vacuum at 940°C.

The porcelain facets were divided into three groups according to different conditioning techniques as follows: (1) roughening with a coarse diamond (roughening); (2) microetching with 60μ $Al_2O_3$ particles for 5 seconds at 100 psi (ME); and (3) chemical etching with 8% hydrofluoric acid for 4 minutes (HF). Each group was then divided into three subgroups according to the orthodontic adhesives used for bonding stainless steel brackets. The adhesives used were: (1) silane+Right-On (TP Orthodontics Inc, Laporte, Ind); (2) silane+ Concise (3M Dental Products Division, St. Paul, Minn); and (3) HQB (BJM Laboratories Ltd, Or-Yehuda, Israel) without silane.

An additional four porcelain facets were prepared (one sample of intact porcelain and the others of each conditioning technique) and were macroscopically photographed followed by SEM analysis. The samples were dried by a graded series of freon-113 in absolute ethanol. After triple rinsing in 100% freon, the samples were air dried by vigorous shaking. They were mounted on copper stubs, coated with approximately 10 nm of gold and examined with a Philips 505 SEM (Eindhoven, Netherlands) at an accelerating voltage of 30 KV.

The porcelain facets with the brackets bonded to them (GAC, standard edgewise siamese twin lower incisor, catalog no. 37-261-10, with a bracket base area of 0.0981 $cm^2$) were stored in saline solution at 37°C for 72 hours. Debonding was then performed with a shearing force using an Instron universal testing machine (Segensworth, Fareham, England) and a shearing instrument (Bencor multi-T, testing device for dental restorative materials, Danville Engineering, San Ramon, Calif). Crosshead speed was set at 0.5 mm/min. The force was recorded at bond failure.

Bond failure mode was analyzed macroscopically after debonding. The percentage of damaged porcelain surfaces in each group was recorded.

Statistical analysis was performed using the Mann-Whitney-*U*-test to determine differences between groups when tested per technique or per adhesive.

## RESULTS

The scanning electron photomicrographs of the porcelain surfaces conditioned by the various techniques are presented in Fig 1. In contrast to the smooth appearance of the intact glazed porcelain (Fig 1*A*), the conditioned surfaces show a markedly different picture. Roughening with a coarse diamond (Fig 1*B*) and mechanical microetching with $Al_2O_3$ particles (Fig 1*C*) show a similar picture of general random surface erosion or peeling. Hydrofluoric etching of the porcelain surface shows an extensive uniform in-depth penetration of the porcelain (Fig 1*D*).

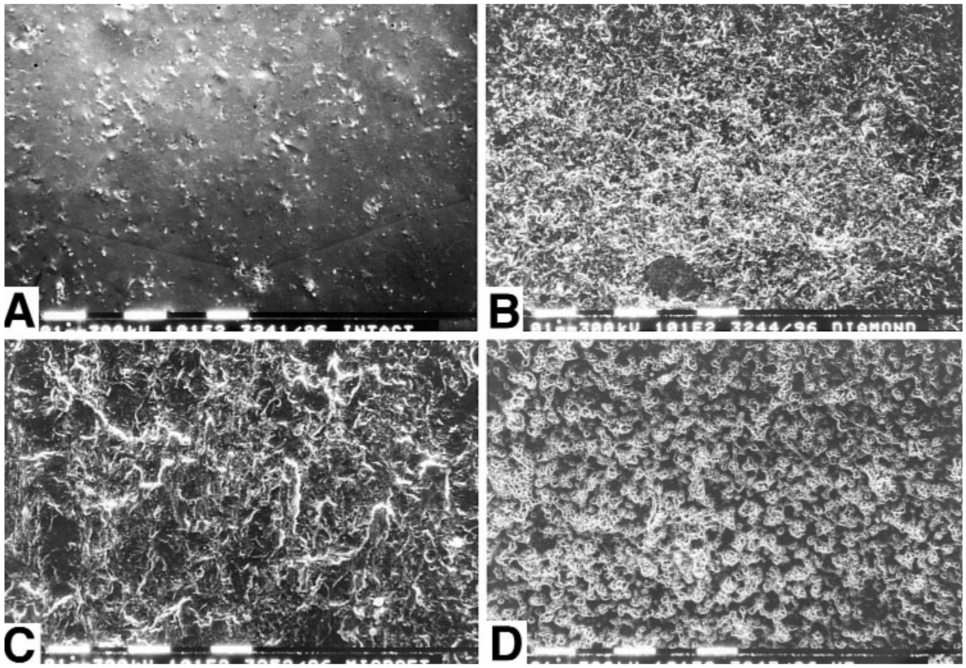

**Fig 1.** Scanning electron microphotograph. **A**, Intact porcelain; **B**, porcelain roughened with coarse diamond; **C**, microetched porcelain, and **D**, porcelain etched by hydrofluoric acid. (Original magnification ×100.)

Macroscopic evaluation revealed that roughening with a coarse diamond significantly affected the porcelain, showing deep grooves over the conditioned area. Microetched porcelain appeared moderately affected with a loss of porcelain glaze and a mild roughening of the conditioned surface. Exposing porcelain to hydrofluoric acid produced minimal change to the porcelain surface, with a slight dulling of the glaze resembling intact porcelain (Fig 2*A-D*).

The results of SBS were evaluated both per conditioning technique for each adhesive, and per adhesive for each conditioning technique (Table I). When the different porcelain conditioning techniques were evaluated for silane+Right-On, no differences were found in SBS. When the conditioning techniques were evaluated for the silane+Concise adhesive, a significant difference was found both between the HF and roughening and between the ME and roughening groups (16.24 versus 12.20, $P < .05$, and 17.90 versus 12.20, $P < .02$, respectively); however, no difference was found between the HF and ME groups. The SBS of the HQB adhesive after HF preparation was significantly higher than that of the ME and preparation by roughening (11.03 versus 6.78, respectively, $P < .01$ and 11.03 versus 5.68, respectively, $P < .01$); however, no such difference was found when comparing porcelain conditioning by ME versus roughening.

**Table II.** Percentage of damaged porcelain surfaces after debonding

| | *Silane+ Right-On* | *Silane+ Concise* | *High-Q-Bond* |
|---|---|---|---|
| Hydrofluoric acid | 10% | 60% | 10% |
| Microetching | 20% | 70% | 40% |
| Coarse diamond | 10% | 70% | 20% |

When comparing SBS of the different adhesives after porcelain conditioning by HF, silane+Concise was found to be significantly stronger than both silane+Right-On and HQB (16.25 versus 10.12, respectively, $P < .01$, and 16.25 versus 11.03, respectively, $P < .001$). No such difference was found between silane+Right-On and HQB. When comparing the SBS of the various adhesives after ME, the silane+Concise was higher than the silane+Right-On, and both were higher than HQB (17.90, 11.06, and 6.78, respectively, $P < .001$). When comparing SBS for the adhesives after roughening, the porcelain with a coarse diamond, both the silane+Concise and the silane+Right-On adhesives produced higher SBS than the HQB (12.20, 11.73, and 5.68, respectively, $P < .001$). No difference was found between the SBS of silane+Concise and silane+Right-On.

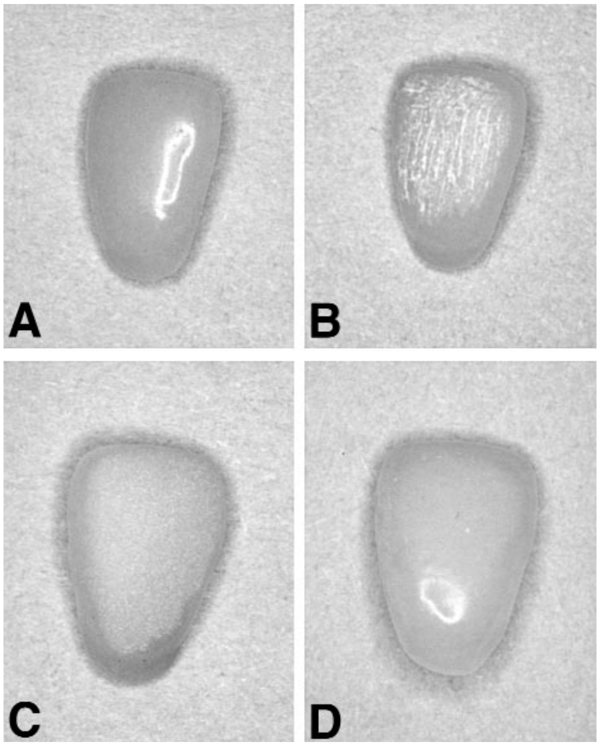


**Fig 2.** Clinical appearance of (**A**) intact porcelain, **B**, porcelain conditioned by roughening with a coarse diamond, **C**, porcelain conditioned by microetching with $Al_2O_3$, and **D**, porcelain conditioned by etching with hydrofluoric acid.

Bond failure mode, expressed as the percent of damaged porcelain surfaces in each group is presented in Table II. The silane+Concise adhesive produced significantly more damaged porcelain surfaces than both other adhesives.

Macroscopic examination of two debonded samples are presented (Figs 3, 4). The first is of severely damaged porcelain conditioned with hydrofluoric acid and bonded with silane and Concise (Fig 3). In contrast (Fig 4), the second sample demonstrates a cohesive bond failure with a small amount of adhesive remaining on the porcelain following conditioning by microetching with $Al_2O_3$ and bonding with HQB. No obvious porcelain damage can be detected.

## DISCUSSION

The present study showed that the SBS of stainless steel brackets bonded to porcelain is highly influenced by both the porcelain conditioning technique and by the type of adhesive used for the bonding procedure. These results are in agreement with previously published data.[9-14]

**Fig 3.** Severely damaged porcelain after debonding. Note the large amount of porcelain remaining on bracket base.

In the present study, the porcelain material was made of clinical crown porcelain and resembled a lower incisor; the brackets used were also for lower incisors thus ensuring optimal adaptation during bonding. Because there is no difference between thermocycling of the porcelain/bracket units and immersion in 37°C water,[1] only the latter was used in the present study.

Roughening the porcelain surface with a coarse diamond, produced a random peeling appearance thus enlarging the porcelain surface area with only shallow mechanical retention as revealed by SEM. Although the macroscopic appearance of the roughened porcelain gave the impression of a highly retentive surface (Fig 2*B*), its SBS was, in general, the lowest of the three conditioning techniques.

Microetching with $Al_2O_3$ particles produced a uniform peeling appearance of the porcelain with deeper penetration and more undercuts compared to roughening; this increased potential mechanical retention. Macroscopically the microetching caused only minor damage manifested by loss of porcelain glaze (Fig 2*C*). The SBS achieved in this manner was in general higher than that produced by roughening. Debonding after microetching preparation produced porcelain surface damage for all adhesives used. Similar results were observed by Kao et al.[9]

Hydrofluoric acid etching of the porcelain, produced a uniform in-depth penetration, similar to that produced by phosphoric acid on enamel. Although macroscopically, hydrofluoric acid etching left the porcelain surface nearly unchanged, the SBS achieved in this manner was, in general, much higher than that produced by the other techniques. Extreme care should be taken during intra-oral application of hydrofluoric acid because contact between the acid and soft tissues may cause severe tissue irritation.[12] Because of this potential danger, one may prefer alternative conditioning techniques.

The adhesive used for bonding, has a significant effect on SBS. Kao et al[9] showed that a heavily filled resin (Concise) produced higher SBS than a lightly filled resin (Unite), and that silanating the porcelain before bonding increased SBS. Indeed in the current study, the silane+Concise adhesive (a heavily filled resin) produced, in general, higher SBS than silane+ Right-On and HQB in a descending order (both lightly filled resins).

Bond failure of stainless steel brackets bonded to porcelain has four primary possible locations: (1) at the bracket-adhesive interface; (2) a cohesive failure (ie, within the adhesive layer); (3) at the adhesive-porcelain interface; and (4) within the porcelain, or any combination of these locations. Because porcelain surface integrity is of the utmost clinical concern after debonding, bond failure mode was noted according to presence or absence of porcelain damage.

Bond failure occurs at the area of least resistance. When stainless steel brackets are bonded to porcelain with silane+Concise, the SBS of the porcelain is lower than both that of the adhesive and of the adhesive-bracket interface, therefore bond failure occurs within the porcelain. This may explain the exceptionally high percentage of damaged porcelain surfaces in all the silane+Concise groups regardless of the conditioning technique. On the other hand, when silane+Right-On or HQB are the adhesives, the SBS of the porcelain is higher than that of the adhesive or the adhesive-bracket interface and bond failure occurs either as a cohesive fracture within the adhesive or at the adhesive-bracket interface leaving the porcelain undamaged.

Previous studies[15,16] have mentioned 6 to 10 MPa as the optimal range for bond strength of brackets to enamel. In our study, all of the SBS achieved were in this range or above it (except for the group conditioned by roughening and bonded with HQB). On debonding, the different conditioning/adhesive combinations showed different percentages of damaged porcelain surfaces. Thus, the effect of different porcelain conditioning techniques and adhesives on porcelain surface integrity during debonding may be divided into two groups: (1) clinically insignificant damage, the brackets remain bonded during the entire treatment period, and hardly any porcelain damage is observable after bracket debonding; and (2) clinically significant damage, after debonding severe porcelain surface damage occurs.

When restoring with porcelain, emphasis is focused on esthetics therefore debonding orthodontic brackets should leave the porcelain as esthetic as it was before bonding. Clinically or esthetically speaking, the dentition can be divided into anterior and posterior parts. When bonding brackets to anterior teeth, where esthetics is of major concern, an appropriate conditioning/ adhesive combination with SBS in the optimal range should be chosen in order to minimize potential damage to the porcelain surface after debonding. Posterior teeth, on the other hand, have a slightly less esthetic concern, and greater forces may need to be transferred to the teeth (according to root surface area). In the latter cases, either a high SBS combination may be chosen, risking porcelain surface integrity, or an alternative method other than direct bonding to posterior porcelain restorations may be used (eg, banding molars or use of the grasshopper technique[17]).

**Fig 4.** "Clean" cohesive bond failure. Note small amounts of adhesive remaining both on porcelain and on bracket base. No observable damage to the porcelain.

HQB in combination with porcelain conditioning by hydrofluoric etching produced adequate SBS and caused minimal damage to the porcelain surface upon debonding. HQB has been shown to efficiently bond stainless steel brackets to etched enamel (unpublished data), and currently we are establishing the bond strength of HQB to unetched enamel. We are also currently examining bonding tooth colored brackets (porcelain, polycarbonate, etc.) to porcelain with HQB and other adhesives.

## CONCLUSIONS

1. SBS of stainless steel brackets bonded to conditioned porcelain depends on both conditioning technique and adhesive.
2. Porcelain surface may be damaged both by conditioning and on debonding.
3. After debonding the silane+Concise combination, regardless of the conditioning technique, produced significantly more damaged porcelain surfaces than both other adhesives examined.
4. Clinically desired SBS can be produced by choosing different combinations of conditioning techniques and adhesives, the clinician may select different combinations for different situations.

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