Review

The use of hydroflouric acid as a surface treatment material on bond strength in cohesive fractures of fused to metal porcelain restoration

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ABSTRACT
Porcelain fused to metal (PFM) restoration is one of the most common restorations for fixed dentures because of its high strength, durability, biocompatibility, and satisfactory esthetics. The brittle nature of ceramic makes it easily fractured. Porcelain fracture is the second largest failure after caries. Repairing porcelain directly using composite resin becomes an option because it is cost-effective and easy to apply. The repair process requires chemical and mechanical bonding to create a strong resin bond. Hydrofluoric (HF) acid can be used as a surface treatment material to achieve good bonding. Concentration and etching time affect the bond strength. However, HF becomes harmful when in contact with soft tissues. Strict protocols in its application are observed and prolonged use in the mouth is avoided. This article reviews the effect of HF as a surface treatment material on bonding strength between porcelain and composite resin. Knowing the HF bonding strength changes to time and concentration as a surface treatment material for direct repair. It is concluded that minimizing the contact of HF on soft tissues, applying HF in the mouth for a short time without reducing its function to achieve good bonding strength.
Keywords: porcelain fused to metal, surface treatment, hydrofluoric acid

INTRODUCTION
Porcelain-fused-to-metal (PFM) restoration is a metal-porcelain restoration consists of a metal substructure that supports mechanically and chemically bonded porcelain veneers. Burning technique is carried out to obtain chemical components in the bond.[1,2] The type of metal material that mostly used is Ni-Cr,[1] while the most commonly used type of porcelain is feldsphatic.[1,2] The combination of these materials in PFM restorations is the most common. It is a popular choice for crown and bridge restorarations with a 10-year success rate of about 95%.[2] PFM restoration has also been used extensively for about 50 years to produce improvements in function, esthetics and longevity.[3] In the literature reported survival rates of 98% after 5 years, 97% after 10 years, and 85% after 15 years on intraoral use.[4] However, there are drawbacks to PFM restorations due to the brittle nature of porcelain which causes failure of PFM restorations.

Failure of PFM restoration generally occurs in porcelain for about 2.3-8% and is the second largest cause of failure after caries.[5,6] This condition is a dental emergency, especially when it is located in anterior region.[4] Clinically failure starting from porcelain fracture caused by improper coping design, poor preparation, technician error, contamination, physical trauma, or premature occlusion.[3,7,8] In addition, factors such as impact, fatigue, occlusal load and mismatch between the physical properties of metal and porcelain can produce fractures of porcelain which are often cohesive.[7,8] The majority of 65% failures are in the anterior region. Other failures occurred in the labial for about 6%, 27% buccal, 5% incisal, and 8% in the occlusal region. This fracture generally occurs in the maxilla (75%), predominantly occurs in the labial surface.[7]

Friedman classifies PFM restoration fractures into three types, namely static fracture, fracture occurs in porcelain but the restoration remains intact; cohesive fracture, failure occurs in body porcelain; adhesive fracture, failure occurs at the bonding surface between porcelain and metal so that metal becomes visible. While Haelton et al specifically described the fracture of PFM restorations as follows; simple fracture, occurs only in porcelain; mixed fracture, occurs in metal and porcelain; complex fracture, where the metal area is widely exposed.[5,8]

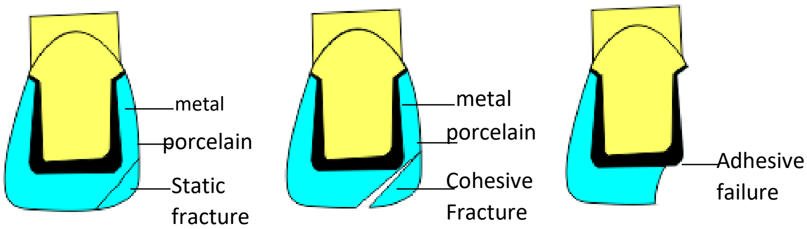

Figure 1 Pictorial representation of Friedman's classification for porcelain fractures; **A** static fracture, **B** cohesive fracture, **C** adhesive fracture.[8]

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A fracture of the porcelain layer or cohesive fracture does not necessarily mean that the PFM restoration has failed. However, it becomes a problem when it occurs on the front teeth for aesthetic reasons.[6] In certain situations, replacing the PFM restoration in the clinic is not a solution to dealing with the fracture problem. Not only a matter of time and cost, the risk of damage to the abutment when removed can occur. Repairing porcelain fracture intraorally is another treatment which is easier and cheaper.[8] Several porcelain repair techniques in PFM fractures have been introduced, including direct and indirect repair.[9,10]

LITERATURE STUDIES

Porcelain repair technique

Porcelain repair technique is divided into 2 types, namely direct and indirect. Indirect repair is carried out in the laboratory using porcelain without or removing the restoration first. Meanwhile, direct repair is a technique that is carried out directly in the mouth on damaged restoration by applying composite resin.[5,6,9-11] According to Robert, porcelain repair technique is divided into 3, namely rebonding porcelain fracture to fix restoration; making porcelain veneer to reattach them to the porcelain fracture; using composite resin to repair porcelain fracture.[5,7,12]

The advantage of the indirect technique is more aesthetic because it is made through laboratory procedure using porcelain material. Disadvantages of indirect technique require additional time and cost. Fracture of the abutment and porcelain veneer can occur when removal of a PFM restoration is required.[5] Some of the advantages of the direct technique include shorter time required, lower cost and easy to application. While the disadvantages are lower strength, quality of use and lack of aesthetics.[11,13]

The direct repair procedure using composite resin is carried out in several stage, including the beginning with an examination of the fracture portion of the PFM restoration. Isolation of the fracture part using a rubber dam. Form a bevel on the porcelain lain fracture suffix using a low-speed green stone bur. Apply HF acid to the porcelain surface, rinse with water and dry. Application of silane material on porcelain surfaces. The bonding material was applied to the porcelain fracture surface and then light cured. The application of the composite resin restorative material using incremental technique and light cured with each layer. Finishing and polishing using a disc bur with conventional method.[12] The success of porcelain repair by direct technique is clinically determined by the intact bond between ceramic and composite resin. This complete bond is achieved by chemical and mechanical bond. Chemical bonding is obtained from the application of silane on the porcelain surface, while mechaninical bonding is obtained from the surface treatment performed on the porcelain surface.[6,7,9,14]

Surface treatment

Clinical application of the adhesive method on porcelain requires surface treatment to optimize the adhesion of the composite resin to the porcelain.[15] Surface treatment on porcelain is performed to produce mechanical retention which can increase the bond strength of porcelain repair from the roughened porcelain surface.[4,16] This surface roughness results in a micromechanical bond between the porcelain and the repair material obtained from the surface treatment. This makes surface treatment procedures important in determining the success of intraoral repair.[17] Several surface treatment methods that have been carried out include a) diamond bur. Surface treatment with a diamond bur creates an irregular sharp surface and micro-cracks in the ceramic causing stress concentration and subsequent fracture.[18] Roughing with a diamond bur must be carried out using a high speed to avoid the production of cracks. Cracks in the ceramic margins result from low-speed vibration of the handpiece. The roughening of the diamond bur should be combined with other surface treatment methods to achieve higher adhesion values.[18-20] Pameijer et al and Kussano et al have reported that the surface roughness of porcelain with diamond bur alone results in lower adhesion value than the other surface treatment method.[20]
b) air abrasion. Surface treatment with the use of abrasive particles driven by compressed air or other gases is an air abrasion or sandblasting process.[1] The particles that are commonly used are aluminium oxide and silica coated. Sandblasting is carried out with a high-speed flow of pure aluminium oxide particles (30-250 µm) transmitted through air pressure (2-3 bar or 30-42 psi) for approximately 15 seconds.[19,20] For cleaning, roughening, enlarlarging and activating the surface by sandblasting with 50 µm aluminium oxide particles at 2-3 bar air pressure. The main drawback of this air abrasion is the potential to damage the intended surface, thereby affecting the long-term use of the restoration. When the aluminium oxide particles hit the material with high energy, they produce small surface defects. This is because the porcelain material is fragile, so that cracks usually start from this surfa-

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ce defect. The condition occurs even in the strongest ceramic materials such as zirconia and alumina and becomes particularly problematic in weaker porcelains.[17]

c) laser. Recently, the newest technique for surface treatment is using laser as an alternative to acid etching and air abrasion to get the surface roughness of porcelain. Lasers can be CO2, erbium: yttrium-aluminum-garnet (Er:YAG) and neodymium:yttrium-aluminum-garnet (Nd:YAG), which are used to enhance micromechanical bonding. The porcelain surface is melted by an Nd:YAG laser then solidifies and finally the surface is blistered. In contrast to the CO_2 laser, which produces conchoidal tears on the porcelain surface which helps mechanical retention.[4] Sarac et al concluded that the Er:YAG laser as a surface abrasive did not produce the desired porcelain resin bond although CO_2 and Nd:YAG lasers showed better results, but the effect is lower when compared to HF etching.[21] Surface treatment with this method is still considered because of the heat generated.[4]

d) acid etching. Acid etching provides a clean surface by increasing the capacity for micromechanical retention and, as a consequence, increasing potential bond strength.[22] Acid etching on dental ceramics was first suggested by Simonsen et al in 1983. Since then, several types of acid, such as orthophosphoric (OP), sulfuric, nitric, ammonium hydrogen difluoride, acidulate phosphate fluoride (APF) and HF acid are recommended as surface treatment materials for ceramic restoration. The most commonly used acid etching is HF acid.[14] Acid of HF is an inorganic acid capable of etching the surface of glass.[23] HF acid reacts with silicon oxide (SiO_2) in the glass phase of ceramics, resulting in surface microporosity, which allows the formation of mechanical interlocks with the composite resin.[20,22]

HF acid is considered a relatively weak acid from a chemical point of view because of its low tendency to dissociate into H+ and F- ions. This does not mean that HF is harmless. Quite the opposite; HF has the ability to easily penetrate skin tissue (often without causing external burns) due to its low dissociation potential. These conditions can cause extensive internal tissue damage, as well as alter blood calcium levels (due to CaF_2 formation), which can lead to cardiac arrhythmias.[23] The use of HF during intra-oral repair procedures, exposes the patient to a high risk of acid damage, in particular, soft tissue. Thus, specific protocols should be followed including isolation of the rubber dam, careful use of a triple air water syringe, removal of excess acid and use of a high-volume aspirator to maximize preventive measures.[22]

HF acid with a concentration of 4-10% is the type commonly used in etching porcelain veneers and intraoral repair of porcelain fractures. HF acid can be safely used in dental procedures within this concentration range, including intraoral repairs, with caution and reasonable care when used.[23] Recommended HF etching time is in the range of 20 seconds to 20 minutes, depending on acid concentration and type ceramics.[20,22] Kimmich recommends etching HF acid with a concentration of 2.5–10% for 60 seconds for clinical surface preparation of porcelain cohesive fractures.[4] Concentration of etching on feldsphatic ceramic is usually recommended for the preparation of surface treatment using acid. HF 9-10% for 60 seconds.[24] For example, some of the HF-containing porcelain repair materials available in the market are Ultradent® Porcelain Repair Kit (Ultradent, Utah, USA) and Ceram-Etch (Gresco Products Inc Stafford, Texas, USA).[22]

Surface treatment using HF acid to obtain adequate adhesion between feldsphatic ceramic materials and composite resin is acceptable. Etching of feldsphatic ceramics also has the potential to significantly increase the bond strength of composite resin. Generally, porcelain consists of a glass matrix phase and a crystalline phase.[23] HF acid as an acid that selectively dissolves the glass matrix in porcelain so as to increase the porosity of the surface, it is high energy, microretentive and provides a large surface area for the bonding of composite resin.[25] In principle, these conditions are the same as enamel surface after etching with phosphoric acid.[23] The hydroxyl groups are also exposed after etching using HF which are important for chemical bonding through the solute-pairs present in the silane.[25]

The success of adhesion between porcelain and composite resin is determined by the concentration of HF acid and etching time. The formation of a special "honeycomb" pattern was seen microscopically by SEM on the porcelain surface which was etched using HF acid. The pattern was formed at 4% HF acid concentration for 5 minutes and 9-10% HF acid concentration for 90 seconds, creating a high-energy, retentive and hydrophilic surface. In addition, the adjustment of HF acid concencentration and time also depends on the type of porcelain. The use of high concentrations of HF acid over a long period of time can weaken the bond between porcelain and composite resin.[23]

The use of composite resin to repair fractures in

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Table 1 Comparison of various surface roughening methods on ceramics.[4]

Type of Ceramic	Diamond Burs	HF Acid Etching	Sand blasting	Tribochemical Silica Coating	Lasers	Recommended Method
Feldsphatic Porcelain e.g. IPS Classic (Ivoclar Vivadent, Inc., Amherst, New York), VITA Mark II (Vident, Brea, California)	Effective	Most effective	Effective	Long term low Stability	Low bond strength	HF Acid Etching
Lithium Disilicate based Ceramic e.g. IPS e.max Press, Ivoclar Vivadent, Inc., Amherst, New York	Effective	Most effective [56]	Reduces bond Strength	n/a	Low bond strength	HF Acid Etching
Leucite-Reinforced Glass Ceramic e.g. IPS Empress, Ivoclar Vivadent, Inc., Amherst, New York	Effective	Low bond strength [57]	Effective	Effective	Low bond strength	Sand blasting with alumina particles
Glass-infiltrated Aluminium oxide Ceramic e.g. In-Ceram Alumina; Vita Zahnfabrik, Bad Säckingen, Germany	Ineffective	Ineffective	Effective	Most effective [58, 59]	Low bond strength	Tribochemical Silica Coating
Densely Sintered Aluminium Oxide Ceramic e.g. Procera All-Ceram, Nobel Biocare,USA, Inc., Yorba Linda, California	Ineffective	Ineffective		Most effective [58, 59]	Low bond strength	Tribochemical Silica Coating
Zirconia based Ceramics e.g. In-Ceram Zirconia (Vita Zahnfabrik, Bad Säckingen, Germany), Cercon (Dentsply, York, PA, USA), Lava (3M ESPE, St.Paul, Minnesota)	Ineffective	Ineffective [59]	Effective	Most effective [58, 60]	Low bond strength	Tribochemical Silica Coating

porcelain has been introduced in various methods.[7] Micromechanical retention of composite resin can be obtained from all surface treatment methods performed on porcelain surface.[9,17] However, etching porcelain using HF acid is a commonly used procedure. The use of HF acid to achieve a clean microretention surface before bonding or repairing porcelain can be produced. This is because the acid can dissolve the glass matrix on the porcelain, thereby creating a mechanically retentive surface.[7] Several selections of surface treatment methods on porcelain surfaces that provide effective results can be seen in table 1.

Silane coupling agent application

The application of silane coupling agents serves as a chemical surface preparation for porcelain attachment. The use of silane can increase the adhesive strength of the repair porcelain, because the silica content in porcelain causes the silane coupling agent to be an important factor in achieving the bonding of the composite resin to the porcelain.[2,3,6,9] Silane coupling agent forms a chemical covalent bond between the silica on the porcecelain surface and the composite resin. This bond will increase the micromechanical interlock.[3]

Silane as a class of organic molecules containing one or more silicon atoms. 3-methacryloxypropyltrimethoxysilane is a silane used in dentistry for the intraoral repair and treatment of ceramic restoration prior to cementing.[23] Silanes are activated by acids to form silanol group which react with hydroxyl group (OH) on the surface of the substrate by a condensation reaction (Si-OH + HO substrate => Si-O substrate) when applied to a treated surface, for example on a porcelain surface. The reaction between the organo-functional groups of silanes (with C-C bonds), and the functional groups of resin monomers containing C-C bonds is induced by reactive free radicals generated by photoactivation of initiator components in the resin matrix. As a result, the silane coupling agent connects the composite resin to the porcelain surface.[6,19,26]

Porcelain surface which is treated with HF acid and silane of failure type is a cohesive type of porcelain. Likewise, in the research conducted by Khoroushi et al. It has been reported that the observed failure in the repair of the composite resin on the porcelain is the cohesive form in the porcelain.[3] This means that the bond strength between the composite resin and the porcelain formed in the repair porcelain has good adhesive strength. The combination of silane-bonding should theoretically provide stability and longevity in the repair of porcelain fracture.[3] Therefore, silane is necessary to increase the bond strength between composite resin and porcelain.

DISCUSSION

Failure of PFM restorations can cause aesthethetic and functional disturbances that will be felt by patient.[4,18] Indirect porcelain repair by replacing PFM restorations is the best option to correct these disorders, but it is a matter of time, the cost and risk of damage to the abutment can cause more complex problems when the treatment is an option.[4]

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The selection of direct repair is the treatment of choice to minimize the risks that occur when indirect repair is carried out. However, direct repair also has its own challenges in achieving maximum retention of the mechanical bonding system between the porcelain and composite resin surfaces. Mechanical bonding is obtained by surface treatment performed on the porcelain surface. Surface treatment using HF acid is a method that has been developed for a long time.[17]

The HF acid as a surface treatment material also has drawbacks. This material becomes dangerous when in contact with soft tissues. So, its use in the mouth for as short time as possible is a consideration to minimize the possibility of contact with the tissue, without compromising its function in achieving mechanical adhesion strength. The minimum bond strength that must be achieved by the porcelain ripper material is 8-9 MPa.[15] In vitro studies on the use of HF acid as a surface treatment material in the surface roughening of porcelain to produce maximum bond strength between resin and porcelain have been carried out, such as the effect of HF acid concentration and etching time on the increase in bond strength between porcelain and composite resin.[7]

The effect of time and concentration on increasing bond strength can be seen in the results of the study of Moura et al, there was a difference in the effect of time (60 seconds and 120 seconds) on the concentration of HF acid (5% and 10%) on the bond strength of feldsphatic ceramics. The results of the highest shear bond strength test were obtained at a concentration of 10% HF acid for 60 seconds (15.35±3.2 MPa), and the lowest with a concentration of 5% HF acid for 120 seconds (9.41± 2.8 MPa). The results of this study showed that there was an effect of bond strength on the concentration and time of application of HF acid.[24] Similar to the study conducted by Venturini et al., the effect of HF acid concentration on resin bonding to feldsphatic ceramics at different HF concentrations (1%, 3%, 5% and 10%) for 60 seconds. The highest bond strength results were obtained at HF 10% (15.7±2.8 MPa), 5% (14.9±2 MPa), 1% (14.5±3 MPa) and 3% (14.2±3.3 MPa). However, the highest value was at 10% HF acid concentration.[27]

A large concentration of HF acid or a long etching time on porcelain ceramics can result in "over-etching" and significantly weaken the porcelain surface.[23] This is supported by the research of Güler et al. Porcelain after increasing the time from 120 seconds (14.84 MPa) to 180 seconds (12.01 MPa) at 9.6% HF acid concentration.[7] Similar to the results of the study conducted by Moura et al, there was a decrease in bond strength after the addition of time carried out at 5% and 10% HF acid concentrations. The decrease in bond strength occurred at both HF acid concentrations when the time of 60 seconds was increased to 120 seconds.[25]

Over-etching on the etched porcelain surface is clearly visible as "white residue". This appearance is a combination of porcelain salts and porcelain flakes. Sometimes, due to the large amount of residue deposits, it can be very broad covering the porcelain surface, this is related to the concentration of HF acid, time and type of porcelain. The condition cannot be removed by air/water spray and wiping with acetone-soaked cotton. Cleaning can be done by placing it in ethanol followed by ultrasonication. It takes 15 minutes of ultrasonication to release the white residue.[23]

Chemical bonding is required to increase the bond strength between the porcelain and the composite resin. The use of silane coupling agents is very important to obtain increasing of bond strength. Khouroushi compared the bonding strength of composite resin to porcelain feldsphatic using silane or not after surface treatment using HF 9.6% for 3 minutes. The highest bond strength results were obtained in the sample that was given silane 20.47 MPa and in the sample that was not given silane 12.89 MPa. This proves that there is a significant increase in the bond strength between porcelain and composite resin. This is caused by the micromechanical interlocs on the surface of the etched porcelain forming a chemical covalent bond between the silica and the resin, which increases the bond strength.[3,17]

It is concluded that the use of HF acid as a surface treatment material in increasing the bond strength of porcelain and composites is an option that can be considered because the material is quite easy to obtain in the market, more economical, and easy to apply. However, this does not mean that this material is harmless, the use of a rubber dam in its application is necessary to avoid contact between HF acid and oral tissue. The right time and concentration of HF acid to obtain maximum bond strength between porcelain and composite is also a concern. The time and concentration of HF acid that are not possible cannot meet the needs of the bond strength value to be achieved in porcelain repair, which is around 8-9 MPa. Likewise, conditions where time and excessive concentration of HF acid will reduce the bond strength of porcelain and composites.

The selection of the right time and concentra-

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tion in the application of HF acid as a surface treatment material for direct repair of porcelain is needed to ensure that the bond between porcelain and composite resin becomes stronger and more durable. The application of HF acid in the mouth for too long is feared to be a risk of contacting the surrounding tissue. Therefore, the application within a short time without reducing the bond strength is absolutely necessary. The use of silane is necessary when etching porcelain using HF acid, which significantly contributes to increase bond strength between porcelain and composite. Further research is needed on the effect of time and concentration of HF acid as a surface treatment material on porcelain repair to obtain the maximum increase in bond strength between porcelain and composite resin. So that the minimum application time is obtained with the right concentration of HF acid.

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