Surface Treatment Protocols in the Cementation Process of Ceramic and Laboratory-Processed Composite Restorations: A Literature Review

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ABSTRACT

The clinical longevity of indirect restorations made of ceramics or indirect composite resins depends on their successful treatment and cementation. The cementation technique is determined by the type of restorative material—ceramics or indirect composite resins; thus, their intaglio surface treatment should be performed according to their particular compositions. The aim of this literature review was to define surface treatment protocols of different esthetic indirect restorative materials. A PubMed database search was conducted for in vitro studies pertaining to the most common treatment protocols of tooth-colored materials. Articles that described at least the surface treatment procedure, its effects on adhesion, its relationship with the material's composition, clinical aspects, and expected longevity were selected. The search was limited to peer-reviewed articles published in English between 1965 and 2004 in dental journals. Sandblasting, etching techniques, and silane coupling agents are the most common procedures with improved results.

CLINICAL SIGNIFICANCE

Tooth-colored restorative materials vary considerably in composition and require different protocols for adhesive cementation.

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The advances of adhesive dentistry have an increasing importance to the esthetic aspect of dental care. Among tooth-colored restorative materials, ceramics and indirect composite resins can be used to replace partially or completely metal-supported restorations or even as inlays, onlays, laminated veneers, and crowns.[1]

Ceramic materials have some important properties, such as translucency,[1–3] chemical stability,[2,4] fluorescence,[1,3–6] biocompatibility,[1,4,7–9] a high resistance to compression, and a coefficient of thermal expansion similar to tooth structure,[10,11] in spite of some clinical disadvantages and limitations, such as friability and susceptibility to fracture propagation.[3,9–11] Those properties indicate that ceramics are materials capable of mimicking human enamel. Several alternatives have been developed to increase their mechanical properties and expand their clinical applications, based on the principles of reinforcement with ceramic oxides, manufacturing

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technique, and improvement of adhesion to dental structure.[2,3,12–17]

The use of feldspathic ceramic reinforced with a large amount of leucite,[3,12,18,19] lithium disilicate,[1,3,20–23] aluminum oxide, and zirconium has resulted in better fracture resistance.[3,12,14,15,24–26] However, according to Borges and colleagues, the clinical success of ceramic restorations depends on the cementation process, which varies according to the composition of the ceramic material.[1]

As with the ceramic materials, composite resins also present satisfactory characteristics such translucence, surface polishing, resilience, and positive esthetics.[27] According to Ferracane,[28] direct composite resins have limited indications because they present volumetric contraction during the process of polymerization resulting in stress concentration at the adhesive interface,[29] cusp flexure,[30] postoperative sensitivity,[31] microleakage, and secondary caries.[31] In the face of those disadvantages, the first generation of laboratory-developed resins was developed in the early 1980s to overcome some of the inherent deficiencies of composite resins, including polymerization shrinkage, inadequate polymerization, and restoration of proximal contacts and contour.[32] In spite of this, those materials are characterized by a small amount of inorganic microfillers, presenting both low resistance against wear and undesirable clinical results.[27] This situation stimulated the manufacturers, in the early 1990s, to develop a second generation of laboratory resins, laboratory-processed composite resins. These present a composition similar to that of current direct composite resins,[33] although they are processed by sophisticated techniques that combine heat, pressure, vacuum, and high light intensity.[29,34]

These new composite resins might present either high amounts of filler content—such as Targis (Ivoclar, Schaan, Liechtenstein), Artglass (Heraeus Kulzer Inc., South Bend, IN, USA), and belleGlass (SDS-Kerr, Orange, CA, USA)—which makes them adequate for restoring posterior teeth, or a intermediate filler volume fraction, such as Solidex (Shofu Inc., Kyoto, Japan), enabling better esthetics. However, the smaller amount of inorganic particles in this latter group makes them specially indicated for anterior teeth.[27,33,35,36]

The penetration of monomers into demineralized dentinal structure after polymerization promotes a micromechanical bond through the formation of a hybrid layer.[37] The same principle of this retention process can be similarly reproduced in the intaglio surface of ceramic or laboratory-processed composite resin restorations through the use of different treatments. Depending on the restorative material, this fact is based either on mechanical bond obtained with aluminum oxide or diamond sandblasting, or on chemical bond, conferred by the application of a silane bonding agent or even with its inside structural modification.[3,12,38–42]

The treatment of the intaglio surface of indirect restorations is dependent on the composition of the restorative material.[1,33] In the presence of a large amount of different indirect restorative materials showing different composition and surface treatment options, it seems adequate to analyze the literature to look for methods that guide the clinician during the cementation of indirect restorations made of ceramics or indirect composite resins, in an attempt to simplify a procedure of such great importance to clinical longevity of restorations.[33]

Therefore, the aim of this study was to discuss the most common surface treatment protocols of different indirect restorative materials by means of reviewing the literature. This literature review was based on a PubMed database search limited to peer-reviewed articles in English that were published between 1965 and 2004 in dental journals. The following key words were used in the PubMed search: "ceramic surface treatment," "composite resin surface treatment," "ceramic and laboratorial resin restorations," and "silane surface treatment." Articles that described at least the surface treatment procedure, its effects on adhesion, its relationship with the material's composition, clinical aspects, and expected longevity were selected. Although not an exhaustive review, the concepts included here were obtained from the surface treatment protocols literature. Some illustrative clinical situations are presented as examples of the suggested techniques.

TREATING CERAMIC RESTORATIONS

The types of ceramic surface treatments and their corresponding compositions are summarized in Table 1.

Mechanical Treatment

The clinical success of ceramic restorations seems to be dependent on the bonding quality developed over the entire prepared dentin.[3,43] Composite cements present low solubility and good adhesion to the dental structure.[44,45] These materials constitute a primary link when considering the interaction between the restoration and the tooth structure. The micromechanical retentions to be created on the internal surface of indirect restorations are essential to the process of bonding to the composite cement.[1,3,7,33,46,47]

Conventional dental porcelain is a vitreous ceramic based on a silica

TABLE 1. CERAMICS COMPOSITION AND SURFACE TREATMENT PROTOCOLS.

Restorative Material	Composition*	Surface Treatment Protocols
Feldspar ceramics: Noritake EX3 (Noritake, Nagoya, Japan), Duceram (Degussa Dental/Dentsply, Hanau, Germany)	SiO_2; K_2O, Al_2O_3, $6SiO_2$; Na_2O, Al_2O_3, $6SiO_2$ application	9.5% hydrofluoric acid for 2 to 2.5 min; 1 min washing; silane application
Leucite-reinforced ceramics: IPS Empress, Cergogold	SiO_2, Al_2O_3 , K_2O, Na_2O, CeO_2, other oxides	9.5% hydrofluoric acid for 60 s; 1 min washing; silane application
Lithium di-silicate–reinforced ceramic: IPS Empress II	SiO_2 (57–80%), Li_2O (11–19%), Al_2O_3 (0–5%), La_2O_3 (0.1–6%), MgO (0–5%), P_2O_5 (0–11%), ZnO (0–8%), K_2O (0–13%)	9.5% hydrofluoridric acid for 20 s; 1 min washing; silane application
Glass-infiltrated aluminum oxide ceramic: In-Ceram alumina	Al_2O_3 (82%), La_2O_3 (12%), SiO_2 (4.5%), CaO (0.8%), other oxides (0.7%)	Sandblasting: synthetic diamond particles (first choice) or 50 µm Al_2O_3 particles; restoration by washing with water for 1 min; *or* retentive preparation design Cements: phosphate-monomer-containing resin cement (first choice), conventional resin cement, glass ionomer, or zinc phosphate
Zirconium-reinforced ceramic: In-Ceram zirconium	Al_2O_3 (62%), ZrO_2 (20%), La_2O_3 (12%), SiO_2 (4.5%), CaO (0.8%), other oxides (0.7%)	Retentive preparation design; alternative: sandblasting with 50 µm Al_2O_3 particles Cements: phosphate-monomer-containing resin cement (first choice), conventional resin cement, glass ionomer, or zinc phosphate
Densely sintered, aluminum oxide ceramic: Procera AllCeram	Al_2O_3 (99.5%)	Retentive preparation design; alternative: sandblasting with 50 µm Al_2O_3 particles Cements: phosphate-monomer-containing resin cement (first choice), conventional resin cement, glass ionomer, or zinc phosphate

*According to manufacturers.

(SiO_2) network and potash feldspar (K_2O, Al_2O_3, $6SiO_2$) or soda feldspar (Na_2O, Al_2O_3, $6SiO_2$), or even both components. In spite of its esthetic qualities and high compatibility to metal alloys, the feldspathic ceramics are not resistant to tension and shear, presenting serious limitations to their being employed as metal-free restorative materials.[2,3,4,14,48–50]

For the feldspathic ceramics, the chemical etching time should be from 2 to 2.5 minutes with hydrofluoric acid in a concentration varying between 8 and 10%,[46,51] which promotes a morphologic change of the ceramic surface, creating a honeycomb-like topography, ideal for micromechanical bonding.[1,51–53] This process is generated by the preferential chemical reaction between hydrofluoric acid and the silica phase of feldspathic ceramics ($6H_2F_2 + 6SiO_2 \rightarrow 2H_2SiF_6 + 4H_2O$),[54] thus forming a salt named hexafluorosilicate, which is removed by water spray.[23,52–56] According to Della Bona and colleagues, the bond strength of composite cements increases with increasing ceramic surface roughness caused by acid-etching.[22]

Ceramics reinforced with leucite,[3,12,18,19] lithium di-silicate,[1,3,20–23] alumina, and zirconium[3,12,14,15,24–26] have been largely used as restorative materials, and the surface treatment has been considered a factor directly related to the clinical success of those restorations.[1,3,12] Prior studies have demonstrated positive results for IPS Empress (Ivoclar-Vivadent, Schaan, Liechtenstein) and Cergogold (Degussa Dental/Dentsply, Hanau, Germany), which are examples of leucite-reinforced ceramics, using hydrofluoric acid for 60 seconds.[1,20,38,39,57,58] An illustrative clinical situation (Figures 1–6) depicts the substitution of unesthetic amalgam restorations with leucite-reinforced ceramic onlays (Cergogold) surface treated with hydrofluoric acid.

The same process occurs in ceramics reinforced with lithium di-silicate, such as the IPS Empress II system, which has a main crystalline phase constituted of long crystals embedded in a glassy matrix.[20,59] The use of this system is demonstrated in an illustrative clinical situation (Figures 7–10) of an anterior crown construction, surface-treated with hydrofluoric acid. According to Della Bona and colleagues, IPS Empress I and II ceramic surfaces have shown greater adhesion values when conditioned by 9.5% hydrofluoric acid compared with the value obtained with 4% acidulated phosphate fluoride.[38] Della Bona and colleagues have also demonstrated that microstructural differences between both systems have led to the achievement of higher adhesion and flexure resistance values for IPS Empress II. Borges and colleagues related that 9.5% hydrofluoric acid-etching for 20 seconds is enough to remove the second crystalline phase and the glassy matrix, thus creating an adhesion-favorable surface.[1] Airborne particle abrasion alone provides insufficient bond strengths.[60,61] Excessive airborne particle abrasion has induced chipping or a high loss of ceramic material and is therefore not recommended for cementing silica-based all-ceramic restorations.[12,61] Kato and colleagues compared airborne particle abrasion with different acid-etching agents and found that hydrofluoric acid and sulfuric acid–hydrofluoric acid provided the highest and most durable bond strengths.[53]

However, hydrofluoric acid surface treatment promotes shallow surface micromechanical retentions in aluminum oxide (Al_2O_3) or alumina-reinforced ceramic restorations due to its low silica content.[1,3,13,26] In-Ceram alumina system (Vita Zahnfabrik, Seefeld, Germany) has 82% alumina, whereas the In-Ceram zirconium system (Vita Zahnfabrik) is reinforced with 62% alumina, 20% zirconium oxide, and 12% lanthanum oxide.[1] According to Sen and colleagues, hydrofluoric acid chemical conditioning did not produce good results for those ceramics, and surface sandblasting can be considered a good alternative for creating a micromechanical adhesion-favorable surface.[40] This study also defined some important parameters to be followed to maximize the results of surface sand-

Figure 1. Clinical situation 1. Occlusal view of Class II mesio-occlusodistal amalgam restorations in the upper right second premolar and first molar.

Figure 2. Clinical situation 1.Occlusal view of onlay preparations with palatine cusp coverage.

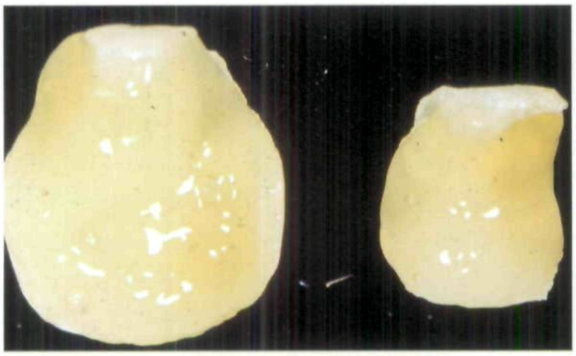

Figure 3. Clinical situation 1. Surface treatment with 9.5% hydrofluoric acid for 60 seconds.

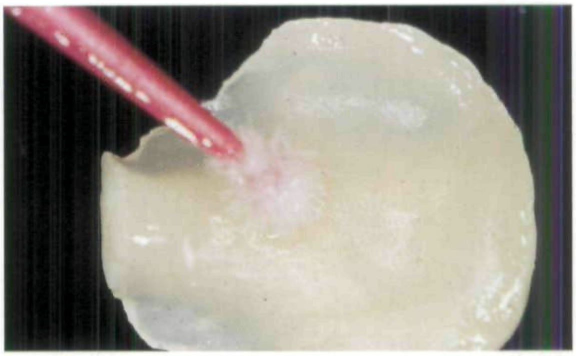

Figure 4. Clinical situation 1. Surface chemical treatment through the application of monocomponent silane bonding agent for 1 minute.

Figure 5. Clinical situation 1. Cementation of the restoration using a dual-composite cement.

Figure 6. Clinical situation 1. Final clinical aspect obtained with a ceramic restoration.

Figure 7. Clinical situation 2. Discoloration of the upper left central incisor, the initial clinical aspect.

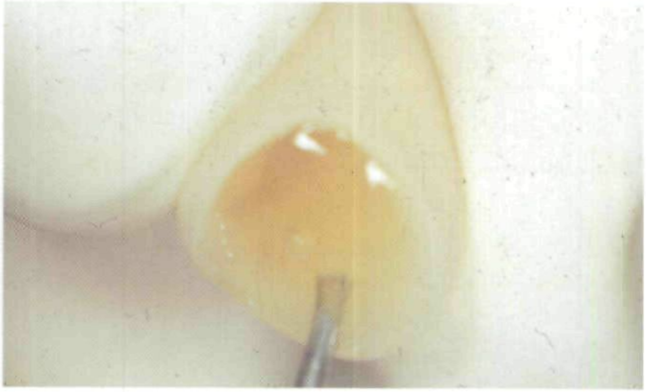

Figure 8. Clinical situation 2. Surface treatment of the crown with 9.5% hydrofluoric acid for 20 seconds.

blasting: pressure to be applied, particle size, particle shape, incidence angle of the particle, and wet versus dry particles. As an alternative treatment, silica coating and silane application with the Rocatec System (3M ESPE Dental Products, St. Paul, MN, USA) seems to provide a durable resin bond to glass-infiltrated aluminum oxide ceramic with bisphenol A glycidyl methacrylate (BIS-GMA) composite cements.[62–64] Awliya and colleagues and Kern and Thompson found significantly positive results with the adhesion of the composite cement when submitting In-Ceram alumina, In-Ceram zirconium, and Procera AllCeram (Nobel Biocare, Gothenburg, Sweden) ceramics to the shear test after sandblasting with 50 µm aluminum oxide particles compared with hydrofluoric acid chemical etching, diamond abrasion plus phosphoric acid, or control (no treatment).[3,12] In spite of this fact, Borges and colleagues showed that sandblasting with 50 µm Al_2O_3 particles was not effective in increasing irregularities on the surface of these ceramics, which could mean an unreliable surface treatment to improve adhesion.[1] Aluminum oxide particles and alumina have similar hardness, which tends to cause flattening of the alumina

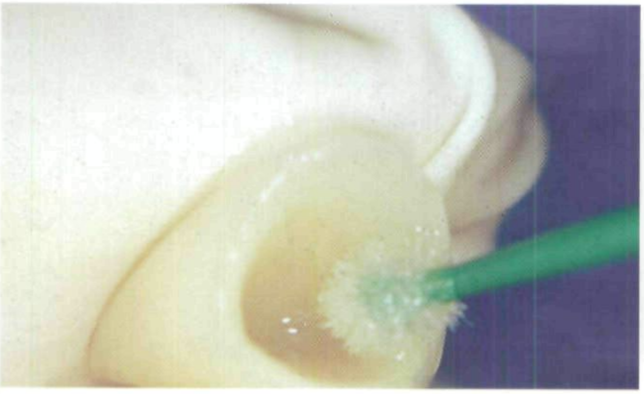

Figure 9. Clinical situation 2. Surface chemical treatment through the application of a monocomponent silane coupling agent for 1 minute.

Figure 10. Clinical situation 2. Final clinical aspect obtained with a ceramic restoration and diastemas closing with direct composite resin.

crystals.[1] Thus, an alternative, at least for glass-infiltrated aluminum oxide ceramics (In-Ceram alumina), is to use 1 to 3 µm diameter diamond particles, which show higher hardness rates than alumina particles found in the restoration.[40] Regarding densely sintered aluminum oxide ceramic (Procera AllCeram), Blatz and colleagues state that the small number of long-term in vitro studies on its bond strength does not allow for clinical recommendations.[65] According to Borges and colleagues, the retention should be reached with a retentive preparation design.[1] In this way, it seems that restorations manufactured with these materials can be cemented using glass ionomer cements or even zinc phosphate cements. To improve bond strength, chemical treatment can be used as an additional technique, as discussed below.

Chemical Treatment

Silane is a bifunctional molecule that acts as a bonding agent between the inorganic particles of ceramics and the adhesive composite resin matrix.[42,48,66,67] This bonding agent has a general chemical structure, R′—Si(OR)$_3$, where R′ is the organofunctional group, typically a methacrylate, that reacts to the adhesive system or the composite cement, creating a covalent bond after polymerization.[48,57] The alkyl group (R) is hydrolyzed to a silanol (SiOH), creating a covalent bond with the silicon inorganic particles (Si—O—Si), completing the bonding process.[48,57,68,69] According to Peumans and colleagues, silane has functional groups that promote chemical bonding with hydrolyzed silicon oxide from the ceramic surface, and with the methacrylate group from the adhesive system or the composite cement by copolymerization.[46] Monocomponent systems that contain alcohol or acetone-diluted silane require hydrofluoric acid treatment of the ceramic surface so that the surface becomes chemically active. The same process is necessary for double-component solutions, in which silane is diluted in an acid hydrous solution, hydrolyzing the coupling agent, which becomes able to react directly with the ceramic surface. If not used for the right length of time, polymerization over silane will form nonreactive polysiloxane bonding chains.[70]

The application of a silane coupling agent (see Figures 4 and 9) is important to the adhesion of ceramic restorations, which is responsible for the chemical union between the inorganic ceramic phase and the organic phase of the composite cement.[36,42,52,71–73] Della Bona and colleagues have demonstrated an increase in adhesive resistance when using silane with ceramics reinforced with feldspar, leucite, or lithium di-silicate, also concluding that only the application of silane over non-treated ceramics presents a low-resistant adhesive interface.[38]

Some studies have demonstrated significant results when associating silanization process with heat application, which helps to eliminate water, alcohol, and other solvents, and thus promotes the condensation reaction and the silica-silane covalent bonding.[74,75] Hooshmand and colleagues concluded that a 15-second washing using 80°C water prior to a 30-second drying using a 50°C air jet promotes a reduction of the number of adhesive flaws,[75] which has also been observed by Roulet and colleagues who used a 20°C temperature for 60 seconds and 100°C for another 60 seconds, obtaining a restoration adhesion twice as resistant compared with surface treatment without heat application.[74]

However, silane efficiency is compromised in ceramic systems highly reinforced with alumina because there is a reduced and unstable adhesion between silane and alumina.[3,40] In addition, the silane chemical bonding reaction depends on the presence of silica on the ceramic surface, which is not common in the composition of aluminum ceramics.[3,40] An alternative is to use phosphate-monomer-containing composite cements, which seem to provide strong and long-term durable resin bonds to air particle–abraded, glass-infiltrated aluminum oxide ceramics and to glass-infiltrated zirconium oxide ceramics.[62–65] The adhesive functional phosphate monomer 10-methacryloyloxydecyldihydrogen phosphate bonds chemically to metal oxides such as aluminum and zirconium oxides.[63] Some authors recommend the use of these cements without a silane or bonding agent,[62] whereas others suggest a silane coupling agent to increase wettability of the ceramic substrate.[16,64] The use of a retentive preparation design is indicated to obtain greater retention of alumina-reinforced ceramic systems, according to Borges and colleagues.[1]

TREATING INDIRECT COMPOSITE RESIN RESTORATIONS

All types of laboratory-processed composite restorations, surface treatments, and their corresponding compositions are summarized in Table 2.

The combination of polymerization processes based on high light intensity, temperature, pressure, vacuum, and nitrogen atmosphere have resulted in laboratory-processed composite resins reaching polymerization levels of up to 80%,[76] thus enhancing their mechanical properties and widening their indications.[77] Soares and colleagues, through a microtensile bond strength test, compared Targis and Solidex (Shofu Inc., Kyoto, Japan) indirect composite resins with Filtek Z250 universal composite resin (3M ESPE).[33] They used laboratory polymerization, hydrofluoric acid surface treatment, and aluminum oxide particle sandblasting, and concluded that no differences were observed between the laboratory-processed composite resin and the direct composite resin in bonding with the composite cement due to the similarity in their compositions.

Surface treatment of laboratory-processed composite resin restorations with hydrofluoric acid promotes a microstructural alteration of the composite because of the dissolution of the inorganic particles present in microhybrid composites.[78–81] However, surface mechanical treatment in laboratory-processed composites using sandblasting with aluminum oxide particles seems to be the best alternative to raise restoration surface energy because it promotes a nonselective degradation of the resin and results in a better adhesion to the composite cement.[33,36,56,79,82] An illustrative clinical situation (Figures 11–15) demonstrates the construction of a Targis/Vectris (Ivoclar-Vivadent) glass fiber–reinforced composite fixed partial denture; the composite resin of this system is classified as a second-generation resin with 67% inorganic particles (by weight) and 33% BIS-GMA, decane dimethacrylate, and urethane dimethacrylate organic matrix.[27] This case illustrates resin sand-

TABLE 2. LABORATORY-PROCESSED COMPOSITE COMPOSITION AND SURFACE TREATMENT PROTOCOLS.

Restorative Materials	Composition*	Surface Treatment Protocols
Solidex	61% UDMA and photostarters; 39% (vol) inorganic particles	Sandblasting with aluminum oxide for 10 s and silane application
Targis	33% BIS-GMA, DMA, and UDMA; 67% (vol) inorganic particles	Sandblasting with aluminum oxide for 10 s and silane application
Artglass	30% methacrylates; 70% inorganic particles	Sandblasting with aluminum oxide for 10 s and silane application
belleGlass	26% UDMA and DMA; 74% inorganic particles	Sandblasting with aluminum oxide for 10 s and silane application
Filtek Z250	40% UDMA, BIS-EMA, BIS-GMA; 60% inorganic particles	Sandblasting with aluminum oxide for 10 s and silane application

BIS-GMA = bisphenol A glycidyl methacrylate; BIS-EMA = bisphenol-A polyethylene glycol diether dimethacrylate; DDMA = decane dimethacrylate; UDMA = urethane dimethacrylate.

*According to manufacturers.

Figure 11. Clinical situation 3. Missing second right upper premolar.

Figure 12. Clinical situation 3. Surface sandblasting of a glass fiber–reinforced composite fixed partial denture with 50 μm Al_2O_3 for 10 seconds.

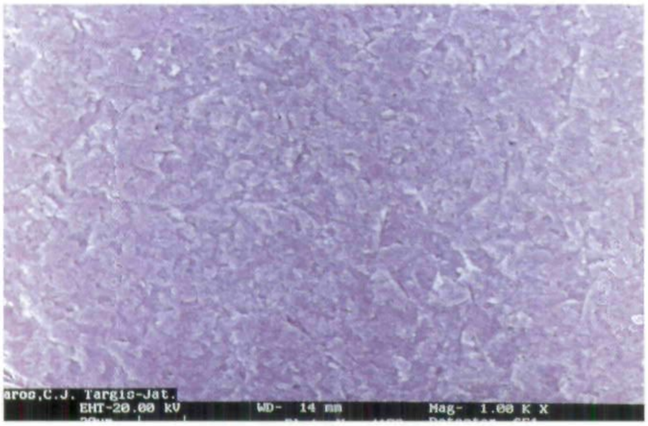

Figure 13. Clinical situation 3. Scanning electron microscopic image of the Targis surface treated with aluminum oxide sandblasting, showing angular and irregular surface fissures; the silane coupling agent and the adhesive system will penetrate these fissures (×1,000 original magnification).

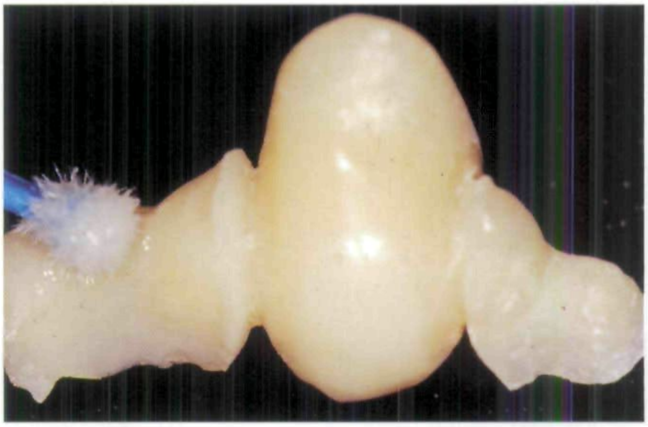

Figure 14. Clinical situation 3. Internal surface chemical treatment through application of a monocomponent silane coupling agent for 1 minute.

Figure 15. Clinical situation 3. Final aspect obtained with a glass fiber–reinforced composite fixed partial denture.

blasting with aluminum oxide particles, showing the microscopic characterization of the surface.

The presence of inorganic particles on the laboratory-processed composite resin surface makes it possible to develop better adhesion through the application of a silane coupling agent (see Figure 14). According to Soares and colleagues, aluminum oxide sandblasting did not produce a significant increase in adhesive resistance, but when it was associated with silane, higher bond strength values were obtained.[33] Furthermore, the complete dissolution of the inorganic particles promoted by hydrofluoric acid results in a surface characterized only by the presence of resin organic matrix,[1,52] which makes the restoration-to-cement adhesive interface less resistant.[33] Since all laboratory-processed composite resins present similar composition, their surface treatment tends to be the same.[33]

CONCLUSIONS

Based on this literature review, it is possible to conclude that the surface treatment of ceramics and indirect composite resins depends on the material composition, the use of abrading or etching techniques, and the employment of silanating agents. Therefore, it is up to the clinician to acquire a thorough knowledge of the restorative materials and follow their specific protocols to optimize the success of indirect restorative procedures.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are discussed in this article.

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