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Promoting porcelain–zirconia bonding using different atmospheric pressure gas plasmas

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ABSTRACT

Objectives. To evaluate the effects of different atmospheric-pressure plasma (APP) on the physicochemical properties of yttria-stabilized zirconia, and promoting the adhesion of veneering porcelain.

Methods. Cercon base zirconia disks were prepared to receive different treatments: as-polished, three APPs (oxygen, OP; argon, AP; and CF_4, CP), and grit-blasted (GB). Their surface roughness and hydrophilicity were measured, and surface morphology was examined either after treatments, after simulated porcelain firing, or additional thermal etching. X-ray photoelectron spectroscopy (XPS) analysis characterized the surface chemical compositions. Shear bond strength (SBS) tests examined the adhesion between veneering porcelain and zirconia either before or after thermocycling. The layered ceramic disks were also sectioned to inspect the porcelain–zirconia interfaces. Statistical analysis was performed with one-way ANOVA and *post hoc* Duncan's test.

Results. Grit-blasting caused surface damage and increased roughness. All APP-treated disks exhibited deeper grain boundaries and enlarged grain sizes after thermal etching, while CP disks revealed additional particle dispersions. Three APPs rendered the zirconia surface superhydrophilic. XPS spectra of three APP groups revealed increased hydroxyl groups and reduced C–C contents, and CP group especially showed the existence of Z–F bonds. CP exhibited the highest SBS both before and after thermocycling, while AP and GB also showed improved SBSs compared to the as-polished. OP presented reduced SBS, and its cross-sections showed increased microporosities in the veneering porcelain.

Significance. APP did not change surface morphology but enhanced wettability. CP and AP improved porcelain–zirconia SBSs, primarily through surface hydroxylation. OP induced the microporosities in porcelain and adversely affected the adhesion.

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1. Introduction

With its renowned strength and stability, yttria-stabilized tetragonal zirconia (YTZ) has been recognized as a suitable material to fabricate anterior and posterior dental prostheses. The evolution of CAD–CAM technologies has overcome the design and manufacturing limits of YTZ and expanded its applications [1]. Contemporary all-ceramic prostheses are composed of zirconia copings and various veneering porcelain to support the chewing functions and esthetic appearance. Although the bilayer YTZ restorations have achieved acceptable clinical outcomes, they revealed higher failure rates compared to metal-ceramic counterparts [2,3]. Chipping and delamination of veneering porcelain were the frequent causes of failures due to low veneer/core interfacial fracture resistance [4]. Compared to traditional alloy prosthetic materials, YTZ presents inferior chemical bonding and mechanical interlocking [5,6], as well as mismatched coefficients of thermal expansion to the silica-base glass ceramics [7–9]. Additionally, microporosities and flaws in both ceramics accelerate the disconnections at the interfaces [10]. Although high-translucency zirconia has been introduced to fabricate monolithic restorations, porcelain veneering is still required for the anterior restorations due to its versatility and natural appearance [11].

Several surface treatments have been developed aimed at improving the zirconia–porcelain bonding, such as aluminum oxide particle grit-blasting, liner application, hot etching, glass coating, silica deposition, and laser ablation [6,12,13]. For the mechanical methods, grinding and grit blasting are commonly used due to their low cost and effectiveness in increasing surface roughness and wettability. However, controversial results have been reported for using grit-blasting to enhance the adhesion of porcelain [14,15]. Grit-blasting induces the tetragonal (t) to monoclinic (m) phase transformations [16,17]. The produced monoclinic zirconia exhibits a lower coefficient of thermal expansion compared to that seen with veneering porcelain, which may also increase the tensile stress of veneering ceramic and the risk of fractures [18,19]. Although refiring or heat treatment could reverse the phase transformation [20,21], surface flaws caused by grit blasting are detrimental to the clinical survival of zirconia-based restorations [21,22]. The hot etching, selective infiltration etching, and laser ablation treatments have been advocated as alternative mechanical approaches. However, these require expensive equipment or complicated operations, which are not practical in common dental laboratories.

Plasma treatment is an economic technique for the surface modification of metals, polymers, and biomaterials in many industries, and has been used for several decades. The gas plasma is activated by high electrical energy, which causes a series of collisions between electrons and gas molecules and eventually disassociates the gas molecules to be ionized. These ions and activated plasma species are energetic to modify or induce various chemical and/or physical reactions on the surfaces, without excessively altering the bulk properties of the substrate. The gas plasma can also be generated at low pressure, or at atmospheric pressure by applying a sufficiently electromagnetic field over the gas. Although low pressure plasma efficiently generates a high concentration of reactive species, it requires expensive vacuum systems and maintenance. Furthermore, it is not feasible to treat a complex geometry without using adjunctive equipment.

Atmospheric-pressure plasma (APP) has been developed with the aid of rapidly emerging plasma technology to overcome the limits of vacuum operation. APP jets are generally small devices owing to the use of pointed electrodes in corona discharges [23] and insulating inserts in dielectric barrier discharges [24]. An APP jet operates by sinusoidal excitation voltages with pulse widths in the nanosecond-to-microsecond to effectively couple energy to the electron population and result in better electron energy distribution function. By changing the gas or plasma parameters, APPs generate different reactive species that can induce surface modifications, including cleaning, etching, and chemically selective surface functionalization. It is also suitable for a variety of biomedical applications of sterilization, acceleration of tissue repair, and cancer therapy. In the last decade, several studies have applied low pressure and APPs to chemically modify dental zirconia and facilitate the adhesion of resin and porcelain. Non-thermal or low temperature plasmas generated by oxygen, argon, or their mixture at different proportions have been shown to effectively enhance the hydrophilicity and surface energy of Y-TZP substrates [25,26]. SF_6 as a gas source of fluorination plasmas has also shown promising results in generating zirconium fluoride and increasing surface hydrophilicity [27]. With these findings, plasma treatments could be potential approaches to modifying YTZ and enhancing its surface reactivity. However, there is no agreement on the appropriate gas plasma with regard to treating zirconia to promote the bonding of veneering porcelain. Therefore, the aims of this study were to examine the effects of plasma treatments on changing the physical and chemical properties of dental zirconia, and improving adhesion between veneering porcelain and zirconia. The null hypotheses of this study was that none of APP treatments changed the properties of zirconia and the porcelain–zirconia bonding.

2. Materials and methods

2.1. *Preparation of the specimens*

YTZ specimens were prepared by cutting the partially sintered cylinder blanks (Cercon base, DeguDent, Hanau, Germany) into disks (Ø 19.5 × 2.0 mm) using a low speed saw, and then sintering these in the Cercon heat furnace (DeguDent) according to the manufacturer's instructions. A total of 150 full density disks were generated and embedded in a fast-cure acrylic resin (SamplKwick, Buehler, Lake Bluff, USA) with the test surfaces exposed. These disks were then polished consecutively with 180-, 320, 400-, 600- grit sandpapers under water cooling to obtain standardized surface roughness. The specimens were cleaned ultrasonically in distilled water and ethanol, and randomly distributed into five groups to receive different surface treatments: as polished, grit-blasted (GB), oxygen plasma (OP), argon plasma (AP), and CF_4 plasma (CP).

In the GB group, disks were grit-blasted utilizing 105 μm aluminum oxide particles at a distance of 10 mm under 3.5-bar pressure for 20 s. Subsequently, the specimens were ultrason-