MECHANICAL CHEMICAL AND OPTICAL CHARACTERSITICS OF ZIRCONIA CERAMICS FOR DENTAL RESTORATIONS

Natasha Stavreva
Faculty of Dentistry-Skopje, Department of Prosthodontics, University "St. Cyril and Methodius"- Skopje, natasha_stavreva@yahoo.com
Natasha Tosheska Spasova
Faculty of Dentistry-Skopje, Department of Orthodontics, University "St. Cyril and Methodius"- Skopje

Abstract: Zirconia, also known as "ceramic steel" has been used as a dental biomaterial for several decades. Its fracture toughness and bend strength are increased by the toughening transformation mechanism. The aesthetic is compromised by greyish-white appearance and poor translucency. Zirconia dental ceramics exhibit sufficient mechanical strength and toughness to allow their use in low-load areas of the mouth for longer restoration lifetimes. The purpose of this systematic review was to explain information for mechanical, chemical and optical requirements of monolithic dental restorations. Transformation-toughened zirconia offer the best mechanical properties and long-term stability, zirconia-toughened lithium silicate offers the best aesthetic outcomes and cubic stabilized zirconia offer a potential compromise. The properties of these materials can be changed to certain degree with appropriate application of intrinsic and extrinsic parameters.
Keywords: Zirconia, characteristics, dental restorations

1. INTRODUCTION

Dental restorations with the appearance of natural teeth require appropriate material selection, anatomical form, and surface texture as well as adequate translucence and color to create light reflection and absorption characteristics similar to those of natural teeth. [1]
Zirconia was introduced to prosthetic dentistry in 1986 with the InCeram Zirconia system (Vita Zanhfabrik, Germany), which was handmade. [2]
Pure zirconia at room temperature has a monoclinic crystal structure and transforms to the tetragonal phase above 1170 °C and a cubic phase above 2370 °C. [3] These phase transformations in pure zirconia are reversible but, in zirconia stabilized systems, they may be irreversible. The tetragonal-to-monoclinic phase transformation upon cooling is accompanied by an increase in volume (3-5%), which, for densified components, results in extensive microcracking and compromised mechanical properties. Doping zirconia with various oxides can stabilize the tetragonal and cubic phases to room temperature [3], thus avoiding this phase transformation and its detrimental effects on the mechanical properties.
Several polycrystalline zirconia materials have been developed for dental applications, including zirconia toughened alumina (ZTA), partially stabilized zirconia (PSZ), tetragonal zirconia polycrystal (TZP), and fully cubic stabilized zirconia (CSZ). CSZ is differentiated from the other 3 by its isotropic character, which can enhance light transmission. [4,5] Cations of valences lower than those of Zr^{4+} are used for stabilization to room temperature. [6]
Computer assisted design (CAD) and computer assisted manufacturing (CAM) have been utilized in dentistry to obtain infrastructural and prosthetic abutment with the tooth or implant. In these techniques, fully-sintered or partially sintered blocks of monolithic zirconia are machined to the required shape, dimensions, and tolerances. In the case of partially-sintered blocks, implants/restorations are machined up to 30% larger than the final size in order to compensate for shrinkage during sintering. [7]
Following preparation of a zirconia dental restoration using CAD/CAM and sintering, porcelain can be applied as a veneer and sintered onto the zirconia. Porcelain veneering of the zirconia requires cooling at a sufficiently slow rate so as to minimize thermal gradients and internal stresses which, ultimately, reduces the incidence of fracture, chipping etc. Of the veneered restoration. [8] However, there appear to be no long-term clinical studies to confirm the avoidance of fracture. The avoidance of cohesive failure of the veneering material arguably could be a reason to develop full-contour zirconia dental restorations. [3,9]. However, the use of full contour zirconia in dental applications has challenges, such as translucence when used in the aesthetic zone, long-term clinical stability, and tribological behavior. [3] Recent developments focus on improving the optical properties of full-contour zirconia restorations without veneering material. [10]

2. MECHANICAL CHEMICAL AND OPTICAL CHARACTERSITICS

Monolithic 3 mol% yttria-doped tetragonal zirconia polycrystal (3Y-TZP) is the most widely used zirconia material for dental applications. [11]

The color and appearance of monolithic zirconia dental restorations are affected by both intrinsic (materials) and extrinsic (features and surroundings) parameters. [12] Materials and processing issues relevant to the extrinsic characteristics, such as cement layer, thickness, and low-temperature degradation, can affect the optical properties. While desired esthetic characteristics of zirconia dental restorations can be controlled by these parameters, color matching must also be achieved by using consistent and appropriate light sources.

The light propagation through a material depends on 3 parameters: absorption coefficient (μ_a), scattering coefficient (μ_s), and scattering anisotropy factor (g). [13]

Lithium silicate glass-ceramics with additions of zirconia have been shown good optical and mechanical properties. [3]

Two types of glassy matrices, lithium metasilicate and lithium disilicate, have been used, with zirconia acting as a nucleating agent. [3] Different amounts of zirconia (up to 20 wt%) in lithium metasilicate have been shown to give good thermomechanical and optical properties. [14] Fine-grained lithium silicate glass-ceramics, with both 4 wt% and 10 wt% zirconia also have been used as dental restorative materials, [3,15] The Li_2O/SiO_2 with equal molar ratio of Li_2O to SiO_2 shows excellent mechanical and optical properties for dental applications. [16] Since zirconia has a higher molecular weight than stoichiometric lithium disilicate, the addition of zirconia increases the true density. As a result, the refractive index increases. [17] Lithium disilicate glass-ceramics, toughened with ZrO_2, also show decreases in the volumetric nucleation and crystal growth rates due to high critical cluster formation in the vicinity of glass transition temperature. [16]

Interpenetrating phase composite zirconia has been formed by liquid infiltration into a porous zirconia structure. The infiltrating liquid is either molten glass or a monomer that is subsequently polymerized to form a thermoset [3]. The use of zirconia was adopted from the earlier development of fully dense net-shape ceramics of alumina infiltrated with lanthanum-containing ceramics. [3]

The primary objective of the development of these interpenetrating phase composite materials is to facilitate clinical chairside CAD/CAM technology but the optical properties have not been reported and so require further examination. [4]

The recommended prepared thickness for the abutment tooth depends on the mechanical properties of the restoration material. A thin wall thickness helps to reduce the need for invasive preparation, with correspondingly lower risk of pulp damage, which is particularly important for younger patients. Thus, the favorable mechanical properties of monolithic zirconia make this ceramic ideal for fabrication of thin restorations. The fracture resistance of monolithic zirconia with a thickness of only 1.0 mm is adequate to survive in the oral environment. [10] However, appropriate tooth preparation and choice of cement for monolithic zirconia crowns are critical to ensure adequate mechanical performance.

Monolithic zirconia is used in dental restorations to replace enamel. Zirconia's lack of fluorescence diminishes its natural appearance, which is accentuated by its propensity to change from white to gray under low-light conditions. [18] In contrast, enamel remains essentially unchanged under these conditions. If the fluorescence of zirconia is increased by chemical or other means, the extent must be limited since dentin is 3 times more fluorescent than enamel owing to dentin's ultraviolet-photosensitive organic component. [19] Further, in common with dentin, zirconia backscatters incident light, also enhancing its similarity to dentin.

Features, such as interfaces between different phases (including pores), birefringence, pores and grains of diameters similar to those of the wavelengths of visible light, and rough surface finishes, can lower the translucency of zirconia. TZP is a highly dense, single-phase, fine-grained, polycrystalline material. Since the lattice parameters of tetragonal zirconia are nearly identical to those of the cubic form, [20] birefringence is minimal.

The main factors controlling the optical properties of nanocrystalline 8Y-CSZ (8 mol% Y_2O_3-doped cubic ZrO_2) also have been investigated. [21] The absorption coefficient decreased and light transmission increased after annealing in air at 750°C, even though the true porosity and grain size would not be expected to have changed at this low temperature.

The partial or full stabilization of zirconia and, hence, avoidance of the tetragonal-to-monoclinic phase transformation are achieved by the formation of substitutional solid solutions. [22] Since zirconium ions are tetravalent, if the stabilizing dopants are divalent or trivalent, they must be charge-compensated by the introduction of positively charged defects such as oxygen vacancies (ionic compensation) or holes (electronic compensation). [23] Thus, the valence, ionic radius, and concentration of the stabilizing dopant used as well as the processing temperature will influence the defect concentration [24] and therefore the optical properties.

3. CONCLUSION

Based on the findings of the present systematic review, the following conclusions were drawn:

1. The zirconia-based materials that have been considered for general dental applications are monolithic (ZTA, PSZ, TZP, CSZ), while there also are those specifically for esthetic (TZP, ZTLS, IPCZ) applications.
2. Zirconia offers mechanical advantages over other full ceramic dental restorations largely owing to the potential for transformation toughening.
3. Although CSZ does not exhibit transformation toughening, its translucency makes it a compromise material when esthetics are more important than mechanical properties, as in the case of low intensity stress conditions.
4. Although extrinsic parameters can be manipulated by the clinician in principle, the most effective approach to improve esthetic outcomes is through appropriate shade matching. In the clinical setting, this involves shade communication using a light emitting diode light of 5500 K (D50) illumination. In the dental laboratory, this involves the use of both high- and low-light intensities during fabrication.
5. While intrinsic parameters generally cannot be manipulated, it is possible to change the interaction of light with monolithic zirconia dental restorations through alteration of the oxygen vacancy concentration through annealing. It is possible to improve the light transmission of CSZ by annealing in air.

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