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REVIEW ARTICLE

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AN OVERVIEW OF ZIRCONIA AND ITS APPLICATION IN DENTISTRY

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ABSTRACT

To replace metallic dental prosthesis the structure of ceramics has been improved. Among in Ceramics Zirconia has come up in a big way because of its biological, mechanical and optical properties. It has adequate mechanical properties to be used in medical devices. With addition of yittrium trioxide properties of zirconia improved tremendously to be used in dentistry. This review article gives general properties as well as specific clinical guidelines for its use in dentistry.

Keywords: Zirconia, Biocompatibility, Fixed partial dentures, Implant abutment

INTRODUCTION

With the aim of replacing metallic dental prostheses, structural ceramics have been improved and have become increasingly more popular in dentistry. Among the dental ceramics, zirconia has emerged as a versatile and promising material because of its biological, mechanical and optical properties, which has certainly accelerated its routine use in CAD/CAM technology for different types of prosthetic treatment.[1]

The term zirconium refers to the metal, while zirconia refers to zirconia-dioxide (ZrO_2). The name “Zirconium” comes from Arabic word “Zargon” which means “golden in colour.” Zirconia was identified by the German chemist Martin Heinrich Klaproth in 1789 while he was working with certain procedures that involved the heating of some gems. In 1975, Garvie proposed a model to rationalize the good mechanical properties of zirconia, by virtue of which it has been called ceramic steel.[2]

Zirconium (Zr) is a metal with the atomic number 40. The material has a density of 6.49 g/cm³, a melting point of 1852ºC and a boiling point of 3580ºC. It has a hexagonal crystal structure and is grayish in color. Zr does not occur in nature in a pure state. It can be found in conjunction with silicate oxide with the mineral name Zircon ($ZrO_2 \times SiO_2$) or as a free oxide (ZrO_2) with the mineral name Baddeleyite.[3]

Although low-quality zirconia is used as an abrasive in huge quantities, tough, wear resistant, refractory zirconia ceramics are used to manufacture parts operating in aggressive environments valves and port liners for combustion engines, low corrosion, thermal shock resistant refractory liners or valve parts in foundries. Zirconia blades are used to cut Kevlar, magnetic tapes. High temperature ionic conductivity makes zirconia ceramics suitable as solid electrolytes in fuel cells and in oxygen sensors. The good results obtained from orthopedic procedures brought significant confidence to dentistry for the utilization of zirconia as a support material (supposedly as a substitute for alloys) for esthetic restorations as well as for oral implants.[4]

Phases of zirconia (monoclinic, tetragonal and cubic)

The spatial arrangement of the atoms in zirconia is characterized by distinct crystallographic structures, characterizing a property known as polymorphism. Its three phases, or crystal structures, are characterized by specific geometry and dimensional parameters: **monoclinic, tetragonal and cubic.**

Zirconium oxide crystals are arranged in crystalline cells (mesh) which can be categorized in three crystallographic phases: *1)* the cubic (C) in the form of a straight prism with square sides *2)* the tetragonal (T) in the form of a straight prism with rectangular sides and *3)* the monoclinic (M) in the form of a deformed prism with parallel sides. The cubic phase is stable above 2,370°C and has moderate mechanical properties, the tetragonal phase is stable between 1,170°C and 2,370°C and allows a ceramic with improved mechanical properties to be obtained, while the monoclinic phase, which is stable at room temperatures up to 1,170°C, presents reduced mechanical performance and may contribute to a reduction in the cohesion of the ceramic particles and thus of the density. The tetragonal to monoclinic phase transition results in a 3% to 5% volume increase which produces crack in bulk zirconia and reduction in strength and toughness. Under this condition pure zirconia would be useless for dental application.[5]

Biocompatibility

Biocompatibility problems which occurred in the 1990s due to impurities of radioactive Uranium and Thorium are not an issue today. It has been reported that zirconia is not cytotoxic and shows no mutagenicity. Dust from milling zirconia, in contrast to that of asbestos, may not cause medical problems. In vitro and in vivo studies have confirmed a high biocompatibility of zirconia, especially when it is completely purified of its radioactive contents.[6]

Toughening mechanism

In the presence of a small amount of stabilizing oxides, and at room temperature, it is possible to obtain partially stabilized zirconia ceramics in the tetragonal phase only, known as Tetragonal Zirconia Polycrystals (TZP). The finely dispersed tetragonal ZrO_2 grains within the cubic matrix, provided that they are small enough, can be maintained in a metastable state that is able to transform into the monoclinic phase. Tetragonal-to-monoclinic phase transformation in zirconia can be induced by stress, temperature and surface treatments.

After the ageing of yttrium-stabilized zirconium dioxide in body fluid or water, some tetragonal-to monoclinic phase transformation on the surface of zirconium dioxide has also been reported. Even though some phase transition does occur, reports indicate that the effect on the material's mechanical properties is negligible.[3]

Furthermore, transformation toughening is not the only mechanism acting in zirconia-based ceramics. Microcrack toughening, contact shielding and crack deflection can also contribute, to a different degree, to the toughening of the ceramic. (Figure 1)

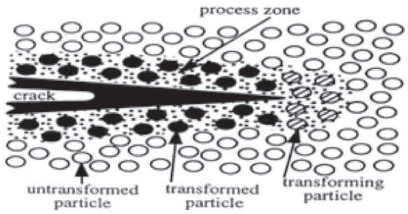

Figure 1: Transformation toughening

Types of zirconia used in dentistry

a. Zirconia toughned alumina (ZTA)

Ceramics based on zirconia are combined with a matrix of alumina (Al_2O_3), forming a structure known as ZTA (alumina reinforced with zirconia grains). The stability of the tetragonal phase at room temperature did not initially involve the use of doping, but instead is controlled by the size, morphology and particle localization (intra-or intergranular). In ZTA, particles above a critical size will attain monoclinic symmetry after cooling. Among the dental ceramics, the only commercial example of a toughened ceramic through dispersion is the In-Ceram Zirconia which is an inter penetrating composite which was developed with this philosophy, with the addition of 33mol% zirconia stabilized with 12mol% ceria to the precursor InCeram Alumina (70 to 80% aluminum oxide) to be used initially by the craft technique of infiltration slip casting (slipcasting). This technique has a small contraction with sintering; however, the amount of porosities incorporated during the handmade infrastructure has reduced the resistance of prosthetics made with this material. On the other hand, the industrial processing of pre-sintered blocks of the same material results in parts with higher mechanical properties, creating tougher prostheses, but with contractions around 25%.[1]

b. Mg-PSZ (magnesia partially stabilized zirconia)

The micro structure of Mg-PSZ consists of an array of cubic zirconia partially stabilized by 8 to 10 mol% of magnesium oxide. Due to difficulty in obtaining free silica Mg-PSZ precursors (SiO_2), magnesium silicates can form a low content of magnesia, favoring the transformation from tetragonal to monoclinic (tetragonal to monoclinic) and resulting in lower mechanical properties and stability of the material. Fully sintered blocks have been manufactured with this material, and require rigid and strong machining systems.[1]

c. Yttria full stabilized tetragonal zirconia polycrystal (3Y-TZP)

The 3Y-TZP consists of an array of partially stabilized zirconia with a 2% mol yttria oxide. In 1977, it was reported that ZrO_2 fine grain (usually <0.5 mm) with small concentrations of Y_2O_3 stabilizers could contain up to 98% of the metastable tetragonal phase after sintering.

The main feature of this microstructure is to be formed by tetragonal grains of uniform diameter in the order of nanometers, sometimes combined with a small fraction of the cubic phase. Due to the inherent opacity of zirconia, the abutment should be adequately prepared to allow enough space for both the substructure and the veneering material.[1] (Figure 2)

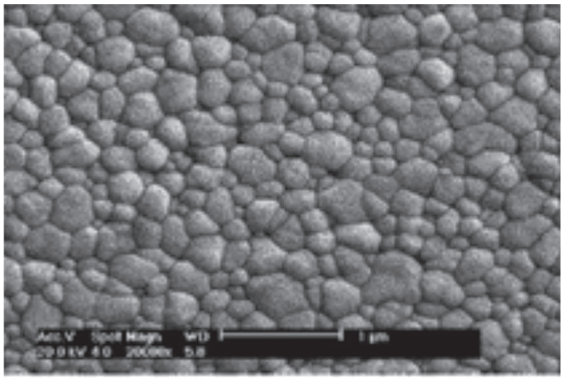

Figure 2: Scanning electron micrograph of 3Y-TZP for dental applications sintered according to manufacturer's recommendations

Uses of zirconia in dentistry[7]

1. Single tooth restoration
2. Fixed dental prosthesis
3. Posts
4. Implants
5. Implant abutments

Case selection criteria for zirconia crown restorations (i.e limited interocclusal space, para-functional habits, malocclusion, short clinical crowns, tooth mobility, tooth inclination) and basic clinical sequence do not differ from other all-ceramic crowns.

After milling a 0.5 mm-thick uniform zirconia core should be fabricated for single posterior crowns. Particularly in anterior region, strength and esthetic requirement may allow the fabrication of 0.3mm thick copings; however reduction of the coping thickness from 0.5mm to 0.3mm can negatively influence the fracture loading capacity of zirconia single crowns.

Zirconia posts were first introduced by Meyenberg *et al.* reported that the flexural strengths (900-1200 MPa) of these posts were comparable to cast gold or titanium, and that it is possible to have the same post dimensions as high gold alloys or titanium. Currently in prosthodontics, zirconia is a widely used material because of its good chemical stability, high mechanical strength, high toughness, and a Young's Modulus similar to that of stainless steel alloy.

However, zirconia posts (Figure 3) fall short of the requirement that an ideal post should be easily removed when retreatment is needed, because it is nearly impossible to remove zirconia posts from the root canal when a failure occurs. It is impossible to grind away a zirconia post, but removal of a fractured zirconia post by ultrasonic vibration has been found to cause temperature rise of the post and on the root surface. Another disadvantage stems from the rigidity of zirconia posts. It is noteworthy that wear, loss of retention, and fracture of posts under intraoral forces are more desirable than tooth fractures.[8]

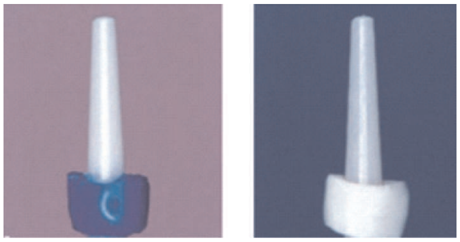

Figure 3: Zirconia post

The first study of implants (Figure 4) on zirconia was recorded in 1993, when a group of researchers inserted experimental Y-TPZ implants in the mandible of dogs. With fluorochrome markers, the authors reported the direct apposition of new bone formation to implants after 120 days from the intervention. Confirming the early findings, several studies have shown that there were no adverse reactions, mutagenic or genetic effects on bone formation, pathologic or peri-implant soft tissue inflammatory states, or the mobility of the implant after installation of the prosthesis. A high proliferation of osteoblasts was also observed, presenting an excellent tissue response and good density of cortical bone newly formed around 97.5% of the implants after the period of osseointegration. However, despite the initial encouraging results when compared with longitudinal and multicenter studies made with titanium implants, the clinical and laboratory data are scarce for a wide and safe clinical application.[1]

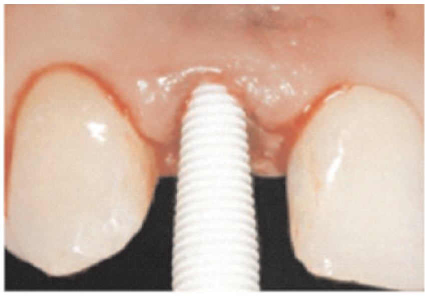

Figure 4: Zirconia implant

The use of zirconia frameworks in implant prostheses enables the achievement of good esthetic results, using simplified and conventional ceramic techniques. The need to mask the dark oxide color of cast alloys or milled titanium is eliminated. Creating more esthetic and translucent reconstructions, especially in the light shade ranges, is more easy and predictable.[9]

Another important parameter to be considered in the selection of an implant material is its affinity towards bacteria/plaque. Lesser plaque accumulation has been reported with zirconia implants. Bacteria such as S sanguis, Porphyromonas gingivalis, short rods, and cocci have shown lesser adherence to zirconia than to titanium surface. The adhesion of Streptococcus to zirconia has also been shown to similar to that to glass ceramics. There seems to be no difference between polished and glazed zirconia as far as adherence of bacteria is concerned.[10]

The use of zirconia in dental implant abutment has been introduced because of its high fracture resistance compared to alumina and other dental ceramics. Zirconia has high affinity for bone tissue, and bone/implant interface is similar to that seen around titanium dental implants. Zirconia abutments provide new opportunities for implant restorations and offer sufficient stability to support implant retained reconstructions especially in incisors and premolar locations. Zirconia abutments are indicated in areas with extremely limited gingival tissue height. Zirconia also minimizes the grey color transmitted through the peri-implant tissues associated with metal components.[11]

The adaptation of most zirconia-based restorations fabricated with CAD/CAM technology is within the acceptable range for meeting clinical requirements. Some basic *in vitro* studies have evaluated the adaptation of single crown restorations in terms of clinical parameters for tooth preparation. Komine et al.[12] concluded that rounded shoulder or chamfer preparations were recommended for the finish line design of zirconia-based restorations.

The 90-degree shoulder preparation, which has a sharp axiogingival internal line angle, had a negative influence, since a scanning laser appeared not to completely irradiate the area of the axiogingival internal line angle. Increasing the convergence angles of the tooth abutments reportedly improved the internal and marginal adaptation of zirconia-based crowns.

FPDs fabricated with the CAD/CAM system exhibit smaller marginal discrepancy values than those fabricated with the CAM-only system. Beuer et al.[13] reported the complex fabrication process and variability of manual procedures for the CAM-only system, such as definitive die preparation with a spacer, and stated that waxing and wax pattern removal from the die might cause differences in adaptation. In terms of the state of zirconia at milling, four-unit FPDs made from fully sintered zirconia have been reported to show significantly better marginal adaptation than FPDs made from pre-sintered zirconia. Some studies have evaluated the influence of porcelain firing cycles on the distortion of zirconia-based FPDs. Some studies reported that porcelain firing and glaze cycles did not affect the marginal adaptation of zirconia-based four-unit FPDs. In contrast, other studies have demonstrated that veneering procedures may have a significant influence on the marginal adaptation of zirconia-based restorations. The thermal incompatibility between framework material and veneering porcelain can be one of the reasons for distortion resulting from veneering porcelain firings.[12]

Zirconia has the potential to allow for the use of reliable, multiunit all-ceramic restorations for high-stress areas, such as the posterior region of the mouth. The mechanical properties of zirconia are highest ever reported for any dental ceramic. These capabilities are highly attractive in prosthetic dentistry, where strength and esthetics are paramount.[14]

Bonding and cementation

Conventional methods applied to the bonding to silica based ceramics (i.e. acid etching and silane application) are not successful for bonding to high-strength ceramics. Therefore, numerous *in vitro* studies have investigated the bonding ability of adhesive systems to zirconia framework material. Initial suggestions for achieving superior bonding to a zirconia framework would be a combination of airborne particle abrasion and resin composites containing 10 methacryloyloxydecyl dihydrogen phosphate (MDP) monomer. In 1998, Kern et al. achieved a durable bond to airborne particle-abraded (110 µm Al_2O_3 at 0.25 MPa) zirconia ceramics after 150 days of water storage with thermocycling using resin composites with a special adhesive monomer.[12]

Airborne particle abrasion, silane application, and use of a Bis-GMA resin cement resulted in an initial bond that failed spontaneously after simulated aging. These findings were verified by a long-term study in which specimens were subjected to two years of water storage and repeated thermocycling. The authors demonstrated that application of an MDP containing bonding/silane coupling agent to a zirconia surface abraded with Al_2O_3 particles afforded strong and durable bonding. To date, combined surface treatment with airborne particle abrasion and a specific adhesive monomer with a hydrophobic phosphate monomer have proved reliable for bonding to zirconia ceramics.[12]

Monolithic Zirconia Crowns

Monolithic zirconia posterior crowns (no layering porcelain) have the potential to outlast other layered restorations, such as porcelain-fused-to-metal (PFM), because there is no porcelain to delaminate, chip, or fracture. Layering porcelain can be added to a zirconium coping to heighten esthetics, but the weak adherence of the stacked or pressed layer has been a common area of clinical failure when the layering material is in function (just as it has with the traditional PFM crown).

Advances in zirconia have made it less opaque and more esthetically appealing than in previous years. This material may not be as esthetic as a high-quality porcelain-fused-to-metal from a skilled ceramist, but improvements in zirconia esthetics (i.e., opacity, hue) have allowed all-zirconia restorations to become a clinically acceptable choice in all but the most esthetically demanding situations. For patients who have parafunctional habits, for whom a questionable occlusal scheme exists, or who display signs of heavy occlusal loading, full-contour zirconia crowns may be indicated, particularly when moderate esthetics is acceptable.[15]

The use of liner materials can provide a tooth color shade to the zirconia framework. The application of liner material simultaneously with veneering is recommended for some veneering ceramics as it improves the core/veneering bonding strength and thus reduces the interfacial failure rates. Liners enhance the core-veneer bond and reduce interfacial failure of pressable veneering materials as well.[16]

SUMMARY

The technological evolution of dental ceramics has been remarkable over the past four decades. From feldspathic porcelains to zirconia-based all-ceramics, tremendous progress has been made in terms of mechanical performance, with a ten-fold increase in flexural strength and fracture toughness. Common important characteristics of all-ceramic systems, such as the proportion of glassy phase and amount of porosity, both influence optical and mechanical properties. Residual stress states between crystalline phases and glassy matrix, as well as microcracking also play a key role in the development high strength ceramics.

The advent of zirconia ceramics in conjunction with computer technology has led both dental science and industry to experience their own dream. The interpretation of this zirconia dream could be defined as the general clinical application of a highly biocompatible zirconia ceramic material that is resistant on a long term basis to all thermal, chemical and mechanical impacts of the oral environment in a wide range of dental restorations.

Although clinical long-term evaluations are a critical requirement to conclude that zirconia has good reliability for dental use, biological, mechanical, and clinical studies published to date seem to indicate that ZrO_2 restorations are both well tolerated and sufficiently resistant.

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