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Review Article

ZIRCONIA: A MATERIAL SCIENCE MARVEL WITH VARIED DENTAL APPLICATIONS

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ABSTRACT
Zirconia (Zirconium oxide) is a biocompatible material with_mechanical properties similar to those of metals. Due to its high wear resistance, Zirconia finds numerous applications in day to day life, for example in blades are commonly used to cut Kevlar, magnetic tapes, cigarette filters etc. Similarly, high temperature ionic conductivity makes Zirconia ceramics suitable as solid electrolytes in fuel cells and in oxygen sensors. Due to its favourable mechanical properties, it has found varied applications in dental treatments, (unlike other glass ceramics) and gives better aesthetic results than conventional dental restorations which have a layer of metal, veneered with dental ceramics. This paper details the chemistry, properties and applications of this material for dental purposes.

Key Words: *Zirconia, All-Ceramic Restorations*

INTRODUCTION
The success of a dental restoration depends on the mechanical properties, the chosen material, anatomical form, surface texture, translucency and color. The most common materials used for crown and bridge work is porcelain fused to a metal framework used because of its excellent mechanical properties (Connor, 1996).
However, the major drawbacks of this material are its aesthetics and its biocompatibility. The search for a material with similar mechanical properties, biocompatibility and at the same time aesthetics has led to the evolution of Dental Zirconia.
The 1st solution to the aesthetic problems due to the use of metal in PFM restorations had led to the development of ceramic cores/substructures which are subsequently veneered with layering ceramic providing relatively superior aesthetics. The refractive index of yttrium stabilized zirconia is 2.2 in comparison to 1.5 of glass.

MATERIALS AND METHODS
Chemistry of Dental Zirconia

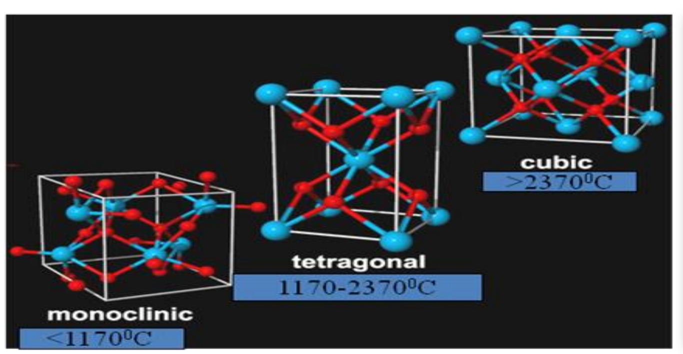

Figure 1: Phases of Zirconia

Partially Stabilized Zirconia, (PSZ) has more favourable mechanical properties than the Fully Stabilized Zirconia due to the addition of Yttria (Brodbelt, 1980). Pure zirconia in equilibrium state exists in three

polymorphic forms: monoclinic- below ~1170ºC, tetragonal in the temperature range ~1170-2370ºC and cubic above ~2370ºC. Zirconia is doped with oxides of calcium, magnesium, cerium, Yttrium (3-8%) as when used singly, it lacks phase stability. Yttrium stabilized Tetragonal Zirconia Polycrystals (Y-TZP) are most stable. Its high fracture resistance is attributed to its energy-absorption property during martensitic transformation of tetragonal to monoclinic crystals (Piconi, 1999). Lack of phase stability leads to phase transformation even when subjected to minor stresses which in turn leads to a 4% expansion of the crystals developing internal stresses and ultimately failure of the restoration. Increased stability is seen in the tetragonal phase than in the cubic phase. This is because of tight adherence of the yttrium to the cubic crystals (Denry, 2007), thus leaving the tetragonal crystals devoid of yttrium. This eventually leads to martensitic transformation of the tetragonal crystals and thereby it's eventualities.
Some mechanical properties of dental relevance of Zirconia are summarised below (Tsukuma, 2008). Zirconia based dental ceramics have superior mechanical properties to conventional glass ceramics and are therefore able to easily withstand high occlusal forces during function (Heffernan,2002).

Table 1: A Comparison of mechanical properties of various core materials

	3-Y TZP	Cobalt chromium alloy	Lithium di silicate
Tensile Strength	900-1200MPa	960MPa	330 MPa
Compressive strength	2000MPa	183GPa	400 MPa
Porosity	<0.01%		1%
Density	>6 gm cm^3	8.90 g cm^3	
Youngs modulus	210 GPa	220GPa	95 GPa
Fracture toughness	7-10 MPa	1300 MPa	2.75 MPa
Thermal conductivity	1.8-2.2 W/m.k	13 W/mºC	
Hardness	10-11 Gpa	40-45 HRC	5800MPa

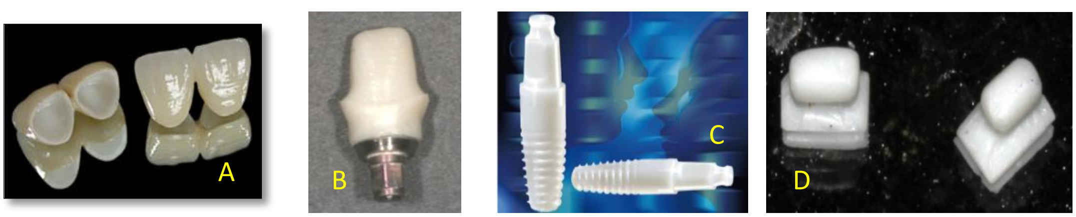

Figure 2: A- crowns and bridges, **B-** Implant abutments, **C-** Implants, **D-** Intramucosal inserts

Zirconia has a variety of clinical applications because of its biocompatibility, aesthetic, and mechanical properties. Zirconia is now used for a variety of reasons such as crowns, bridges, implant abutments, intramucosal inserts, and implants owing to its high resistance to degradation its chemical stability

CURRENT LIMITATIONS IN USE OF ZIRCONIA:

Translucency of Zirconia

Conventionally used dental zirconia is opaque (refractive index-2.65). As compared to glass ceramics, which have inferior mechanical properties, Zirconia is not able to match the light transmitting properties of natural teeth, especially when used in situations on the front teeth where esthetic requirements may be high. Therefore, an exciting aspect of Zirconia is the development of translucent variants.
Tsukuma *et al.*, (2008) fabricated highly transparent titanium dioxide doped 8% Y-TZP by pre-sintering the zirconia at 1400 degrees followed by sintering with a hot isostatic press at 1650 degrees under 150Mpa and observed that the transmittance is very sensitive to pore size and frequency. Dias et al, (2008) compared the transmittance and irradiance of Empress, Empress Esthetic and Empress 2. Higher values of irradiance were measured using the QTH (Quartz Tungsten Halogen) than while using the blue LED (Light Emitting Diode). Another factor that interferes with light transmission is the difference in the

refractive index between the crystals and the glassy matrix. A maximum scattering effect is expected when there is a large mismatch between the index of the particles and the glassy matrix itself. Leucite [1.51] and lithium di silicate [1.55] have similar indices to the glassy matrix [1.50] (Heffernan, 2002).

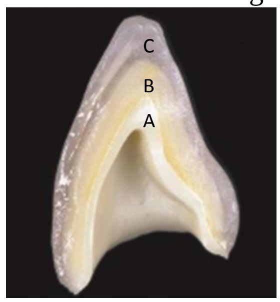

Figure 3: Cross Section Of A Crown, A- Zirconia Core, **B-** Body Porcelain, **C-** Enamel Porcelain.

However, the presence of porosity in these glass ceramics might have a higher influence on the light transmission than the particles themselves. The mismatch between the refractive index of the pore [1.00] and of the glassy matrix may lead to a significant light scattering effect (Heffernan, 2002) (Zhang, 2004). The transmittance was significantly influenced by the type of ceramic and its thickness. Opalescence is an optical property, where there is a scattering of shorter wavelengths of the visible light, giving an object a bluish appearance in the reflected color and an orange/brown appearance in the transmitted color (McLaren, 1997). Cho *et al.,* (2008) stated that all ceramic materials being made must simulate opalescence of natural teeth. He tested the opalescence of all-ceramic core, veneer and layered specimens of shades A2 and A3 of clinically relevant thickness with a color measuring spectrophotometer. He concluded in his study that the opalescence varied with different materials and shades.

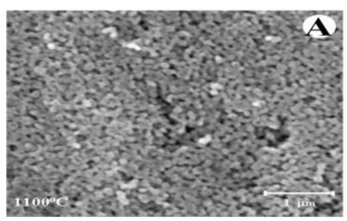

Figure 4-Scanning Electron microscopy-porosity within the zirconia grains.

Alaniz *et al.*, (2009) observed the optical properties of transparent nanocrystalline yttria stabilized zirconia (size~50 nm) using a current activated method. All the samples produced were transparent not translucent. Only porosity above a size of (~50nm) caused significant scattering of light and thus reduction of transmission. The opacity of Zirconia has been attributed to the presence of porosity. Yang et al, (2009) proposed that making nano-sized Al_2O_3-BN coating 3Y-TZP ceramic composites for CAD/CAM–produced all-ceramic dental restorations. He concluded that when 3% alumina was used the phase stability was at its maximum. Oilo *et al.,* (2008) observed that the veneering process which involves firing of the veneering porcelain at high temperatures one to five times leads to a decrease in the flexural strength by 20% and microhardness by 9%.

No significant differences were found in the surface roughness (porosity) fracture patterns or dimensions. It can be concluded that the translucency of Zirconia depends upon factors such as the size and frequency of the porosity, thickness of the porcelain and the wavelength of the incident light. Various attempts of developing translucent zirconia materials have been reported in literature. Some of these are infusion of different glasses[alumina (Sato, 1984), silica, lithium di-silicate, leucite] into the presintered zirconia material, alteration in the pattern of sintering (Tsukuma, 2008), preparation of nanocrystalline powders to get a dense zirconia mass. Efforts are being made to make zirconia as translucent as other glass ceramics like lithium di silicate as this would avoid the necessity of a coping and help conserve more tooth structure. Opalescence varies by the kind of ceramics. The opalesence values of ceramics are lower than those of tooth enamel. All-ceramic materials that can simulate the opalescence of natural teeth should be developed.

As there is a difference in the refractive indices of the porosity and Yttrium stabilized tetragonal Zirconia crystals (3Y-TZP), incident light in the range of visible spectrum (400nm-700nm) does not transmit through the mass, and thereby makes Zirconia.

Delamination of Ceramics from the Zirconia Surface

Conventionally Zirconia is used as a substructure and a glass ceramic is veneered onto it.

The factors affecting delamination of the veneering ceramic from a zirconia surface are:

a. Chipping of veneering ceramics occurs because of improper support by the framework, overloading and fatigue, surface defects, mismatch of higher thermal expansion coefficient of porcelains bonded to Zirconia, low thermal Conductivity of Zirconia.

b. Delamination occurs because of poor core veneer ceramic bond strength, improper surface finish of framework, flexion of the framework, phase transformation at the interface, improperly applied and sintered liner material.

c. Fracture of The Core/Framework Fracture occurs because of improper designing of the framework, improper occlusion, surface damages and structural defects.

d. Misfit of the core / framework

Accurate impression and master die preparation must be performed to prevent mismatch between framework and abutments. Optimal sintering temperature and time to control shrinkage amount of the core/framework.

Various studies have been performed for surface treatment of the Zirconia core. The commonly evaluated techniques include grinding, airborne-particle abrasion, application of a liner material supplied by the veneer manufacturers, LASER induced roughening and heat treatments. Their results have been documented (Aboushelib, 2008), (Guazzato, 2005), (Sundh, 2005), (Kosmac, 1999), (Spohr, 2008) but they do not clearly demonstrate the superiority of one technique over another. The most recent of such techniques is Selective Infiltration Etching.

A lot of current research in this area of dental materials science is devoted to modifying the Zirconia surface in order to prevent delamination.

The development of translucent Zirconia as described previously will allow the use of monolithic restorations thereby making crowns aesthetic and at the same time avoid delamination of the veneering ceramics.

CONCLUSION

Thus it may be realised that Zirconia a material that has taken dentistry by storm has some favourable properties while at the same time a lot of research is required to optimise its Trans and bond strength. With current trends of patients preferring dental materials going into their mouth with minimal or no metal, the development of this material is indeed very exciting.

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