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ROLE OF ZIRCONIA IN PROSTHODONTICS: OVERVIEW

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Abstract:

In light of minimally invasive dentistry, the advent of a new generation of particle-filled and high strength ceramics, hybrid composites, and techno-polymers in the recent decade has provided an extended palette of dental materials, broadening the clinical indications in fixed prosthodontics. In the last two decades, there is an increase in the demand for non-metallic restorations. Zirconia is one of the recent advances in dental materials that comes under the ceramic oxide group. This article gives an overview of zirconia in the field of prosthodontics and crown & bridge.

Key words: zirconia, ceramics, advances in dentistry

Introduction

Advancements in technology leave their footprint in the progress of the dental and medical fields for Achieving supreme precision, better esthetics to mimic, and ally with the biological tissues. Structural ceramics have been improved and have become increasingly popular in dentistry, intending to replace the infrastructure of metallic dental prostheses. Because of its physical, mechanical, and optical qualities, zirconia has become a versatile and promising material, expediting its CAD/CAM technology used for various prosthetic treatments.

History

The metal zirconium (Zr) has an atomic number of 40. Martin Heinrich Klaproth, a chemist, was the first to discover it in 1789. It was first used as a biomaterial in the 1970s. Though its usage was reported in the late '90s, its usage as a hip replacement material and fixed prosthodontics were since 2004.[1]

Sources:

Zr does not exist in its purest form in nature. It can be found as a free oxide (Zirconia, $ZrO2$) with the mineral name Baddeleyite or in combination with silicate oxide with the mineral name Zirconate ($ZrO2x\ SiO2$). After the purification process, the material produced can be used as a biomaterial ceramic.

Biocompatibility of zirconia

Zirconia's biocompatibility has been thoroughly investigated. There were no reports of local (cellular) or systemic adverse responses to this material. Collagen fiber orientation and bone levels in implants around zirconia and titanium implant necks were identical. The fibers in both materials run parallel-oblique and parallel to the implant surface; plaque accumulation was identical at zirconia and titanium abutments.[2]

Forms of zirconia:

There are 3 phases :[3]

The 3 phases are

Monoclinic: below 1170°C (low temperature)

Tetragonal: 1170°C - 2370°C (Intermediate temperature)

Cubic: above 2370°C (very high temperature)

ZrO2 is a polymorphic substance used in three different shapes: monoclinic, tetragonal, or cubic. The monoclinic phase is stable at room temperatures up to 1170°C(1167), the tetragonal phase at temperatures between 1170 and 2370°C, and the cubic phase at temperatures above 2370°C (2367).(Figure:1) However, these alterations are linked with considerable volume changes: When zirconium oxide is heated during the monoclinic to tetragonal transformation, it loses 5% of its volume; yet, when it is cooled, it gains 3% to 4% of its volume.

The tetragonal to monoclinic phase transition produces cracks in bulk zirconia samples and reduces strength and toughness. The high-temperature tetragonal phase can be stabilized at room temperature by changing the composition using Mg, Ca, Sc, Y, or Nd doping. Single-phase tetragonal zirconia stability is enhanced by highly soluble trivalent stabilizers such as yttria, which induce vacancies, or tetravalent stabilizers such as ceria, oversized or undersized concerning zirconium. The most common stabilizer for dental applications is yttria (Y2O3). The addition of 3 to 5 mol% of Y2O3 results in a stabilized core ceramic referred to as yttria-stabilized zirconia or yttria-stabilized tetragonal zirconia polycrystals (Y-TZP). Mg-PSZ core ceramics have also been made from magnesia (MgO). Ceria (Ce2O3) is used as a stabilizer in a Ce-TZP/Al2O3 core ceramic. Another possibility for stabilizing the tetragonal phase at room temperature is to reduce the crystal size to less than 10nm.

Transformation toughening:[3]

The structural stabilization of zirconia by yttria results in a significant proportion of metastable tetragonal phase. This metastable tetragonal phase strengthens and toughens the structure by a localized transformation to the monoclinic phase when tensile stresses develop at crack tips (Figure:2). The resulting volume expansion adjacent to the crack tips produces a high local

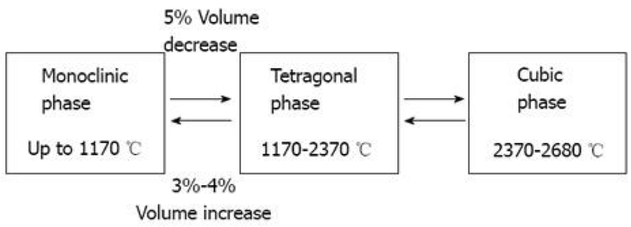


Figure:1 (courtesy: Craig's: Restorative Dental Materials,12th edition)

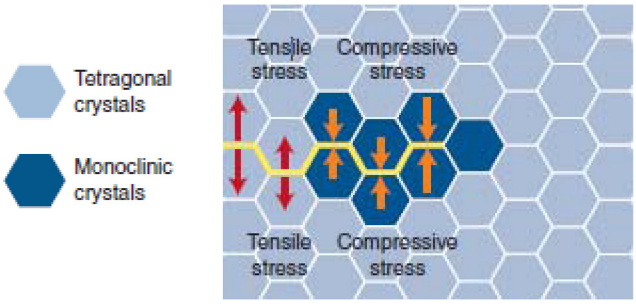


Figure: 2 (courtesy: Craig's :Restorative Dental Materials,12th edition) compressive stress around the crack tips, which increases the localized fracture toughness and inhibits the potential for crack propagation. Many types of crack shielding processes are possible, including micro cracking, ductile zone formation, and transformation zone formation. Because of this strengthening and toughening mechanism, the yttria-stabilized zirconia ceramic is sometimes referred to as "ceramic steel."

Low-temperature degradation (LTD) or aging

One property of zirconium oxide that has not been well studied is the phenomenon of low-temperature degradation or "aging." Water and non-aqueous solvents are involved in the formation of zirconia hydroxides along a crack. This process accelerates the expansion of the fracture and can result in reduced strength, toughness, and density, leading to failure of the restoration.

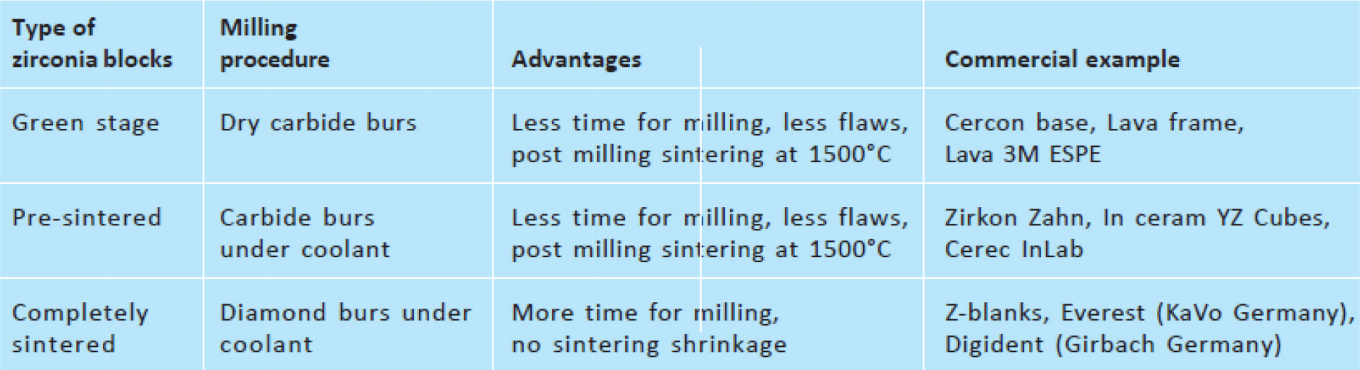
Esthetic properties and light transmission of zirconia[2,3]

Metal-ceramic restorations with opaque cores do not meet the need for aesthetic restorations and other ceramic materials. The translucency of the most robust zirconia-based ceramic crowns, on the other hand, is said to be less than that of lithium disilicate glass ceramics, which have been shown to have excellent aesthetic performance. Among non-zirconia core materials, an optimal esthetic result has been reported with Procera AllCeram, a 99.9% aluminum oxide densely sintered ceramic, and IPS Empress lithium disilicate glass-ceramic. In 2005, it was renamed IPS e.max Press (Ivoclar Vivadent AG), which had better translucency and mechanical properties.

Alumina and glass-ceramic have, respectively, fair to high relative translucency; nevertheless, their mechanical properties are lower than ZrO2 ceramics. The structure and thickness of the zirconia matrix and the physical characteristics and degree of glazing of the veneering porcelain affect light transmission through Y-TZP. Cekic-Nagas I et al. 2012 concluded that measuring the degree of conversion of different resin luting agents beneath zirconia ceramic materials may produce better clinical outcomes—the greater thickness of zirconia results in lower light transmittance.[4]

Fabrication methods and sintering[5] (Figure:3)

Zirconia ceramics are commonly used in dentistry as framework materials and are usually milled from a zirconia block using a CAD/CAM machine device. Blocks can be milled at three different stages: orange, pre-sintered, and fully sintered. Frameworks made from green and pre-sintered



Type of zirconia blocks	Milling procedure	Advantages	Commercial example
Green stage	Dry carbide burs	Less time for milling, less flaws, post milling sintering at 1500°C	Cercon base, Lava frame, Lava 3M ESPE
Pre-sintered	Carbide burs under coolant	Less time for milling, less flaws, post milling sintering at 1500°C	Zirkon Zahn, In ceram YZ Cubes, Cerec InLab
Completely sintered	Diamond burs under coolant	More time for milling, no sintering shrinkage	Z-blanks, Everest (KaVo Germany), Digident (Girbach Germany)

Figure: 3 (courtesy: Craig's: Restorative Dental Materials,12th edition) zirconia are milled in an enlarged form to compensate for the shrinkage during sintering, usually 20%-25% for a partially-sintered framework. The color of the zirconia can be individualized with the addition of oxides to the green-stage framework. Milling completely sintered zirconia blocks is a time-consuming operation that wears the diamond burs out faster and costs more.

Bonding to zirconia[5]

The longevity of an indirect restoration is closely related to the integrity of the cement at the margin. One technique commonly used to condition the ceramic surface is that of air abrasion. Air abrasion with aluminum oxide particles is often used to eliminate pollutants and improve micromechanical retention between the resin cement and the restoration; these particles may be silica-coated or not. With zirconia ceramics, hydrofluoric acid etching and common silane agents are ineffective. Several coating agents were used in other experiments to improve the formation of chemical bonding with zirconia. However, only those containing a phosphate monomer agent effectively formed a stable bond with zirconia materials.

Removable prosthesis:[6]

Zirconia in its different nanoforms like nanotubes, nanofibers, powder, whiskers can be used to reinforce the complete denture prosthesis. Nishiyama H et al., with their study, concluded that complete maxillary dentures with nano-zirconia frameworks might be an alternative prosthetic treatment option. And zirconia can be used to fabricate frameworks as an alternative to metal frameworks. But it has the disadvantages of brittleness when fabricated in thin sections as a clasp.

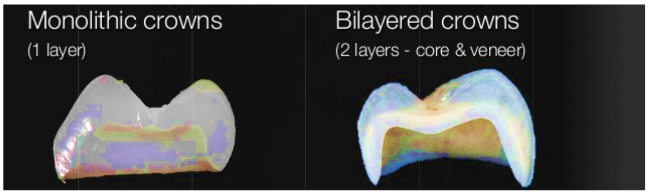


Figure:4 Monolithic crown and layered zirconia crown

Zirconia dowels

Kakehashi et al. experimented with zirconia ceramic post clinically and reported that the zirconia post showed a high success rate. In another study, 79 zirconia dowels with direct resin core building were retrospectively evaluated. All dowels were cemented adhesively, and no failures were observed.[7]

Zirconia in fixed partial dentures:

There are two types of zirconia

Two types include: (Figure:4)

Monolithic zirconia: These are pure zirconia crowns made of a single block of zirconia, making it more durable without any fear of cracks or chipping off but less esthetic when compared to layered zirconia. It is indicated in posterior crowns and bridges.

Layered zirconia:

These are not pure zirconia, as it comes with a zirconia core layered with ceramic on the top,

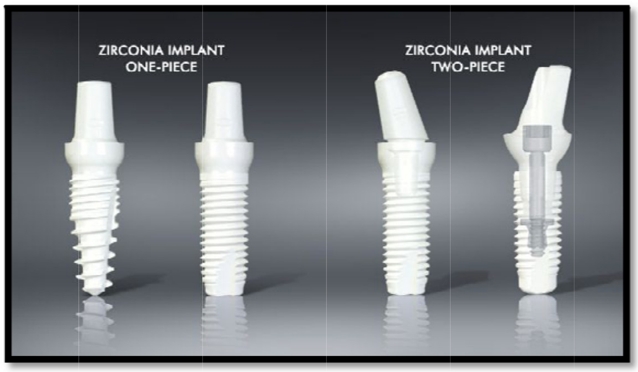


Figure: 5 zirconia dental implants

improving the esthetics. It has chances of a ceramic chip off, so indicated in anterior crowns and bridges.

Indications/advantages:

1. Anterior crowns for better esthetics prevent gingival discoloration, which is common in metal-ceramic restorations
2. Bruxism cases where the ceramic chip off is frequent, monolithic zirconia can be used
3. Indicated in Patients who were allergic to metals in metal ceramics as this is biocompatible.
4. Fluorosis /discolored teeth conditions where ceramics tend to show underlying discoloration can be prevented by the opacity of zirconia.

Contraindication/disadvantages[5]

1. A very short clinical crown that does not permit the adequate height of connector (occlusal-gingival and mesiodistal)
2. In Class II Division II malocclusion patients, due to deep bite.
3. Bruxism
4. Participation in extreme sports
5. Clinical situation wherein biomechanics is compromised.
6. Expensive
7. Wear the opposing natural teeth
8. Cantilever pontic
9. When the abutment is mobile

Tooth preparation:[5]

The tooth preparation needed to accommodate a zirconia restoration is essentially a porcelain-fused to- metal crown with a few modifications. The 3M ESPE recommendations for its Lava zirconia 1.5 to 2.0 mm of incisal/occlusal reduction 1.5 to 2.0 mm of axial reduction. The range of reduction is related to aesthetic needs. More the tooth reduction, more space is available for the lab technician to appropriately layer various porcelains to achieve better aesthetics. The axial taper should be greater than or equal to 4 degrees. The horizontal angle of the margin should be greater than or equal to 5 degrees. Due to the limitations of the die-scanning process and the subsequent machine milling, sharp angles in the preparation must be avoided.

A circumferential deep chamfer or rounded shoulder at the gingival margin is recommended. Ninety-degree shoulders, troughs at the margins, feather-edge margins, undercuts, or sharp line angles are unacceptable. Furthermore, the technician needs to consider the final shade and select an appropriately colored zirconia that allows layering of various translucencies of porcelain to develop a restoration that demonstrates "color from within."

Cementation techniques:[5]

Placement of zirconia restorations can be via standard cementation or by bonding.

Due to zirconia's inherent strength, conventional cement-like zinc phosphate or polycarboxylate can be used; however, these types of cement may not be the first choice due to their physical properties as well as their opaque nature. Opaque cement may show through the zirconia and affect the final appearance of the restoration. Glass ionomer, resin-modified glass ionomer, and self-etching resin types of cement have all been used with success. These have the potential to enhance aesthetics. In the case of short or extremely tapered preparations, a bonded resin cement may be best. Zirconia does not etch with hydrofluoric acid due to the lack of a glass matrix, nor does it contain silica to allow silane coupling to occur.

Zirconia in implant dentistry:[5] (Figure:5)

Ceramics from aluminum, titanium, and zirconium oxides have been used for root form, endosteal plate-form, and pin-type dental implants. Kohal and Klaus presented 8the first clinical report of zirconia dental implants in the literature. The compressive, tensile, and bending strengths exceed the strength of compact bone by 3 to 5 times. The aluminum, titanium, and zirconium oxide ceramics have a clear, white, cream, or light grey color, which is beneficial for applications such as anterior root form devices. When compared to other types of synthetic biomaterials, minimal thermal and electrical conductivity, minimal biodegradation, and minimal reactions with bone, soft tissue, and the oral environment are also recognised as advantages. Although initial testing revealed that these polycrystalline alumina materials had adequate mechanical strengths, long-term clinical results revealed a functional design and material limitation. The established chemical biocompatibilities, improved strength and roughness capabilities of sapphire and zirconia, and the basic property characteristics of high ceramics continue to make them excellent candidates for dental implants. Monolithic zirconia offers enhanced mechanical properties for implant restorations, but development is needed to optimize esthetics. L.D. Friedlander conducted a retrospective study that suggests that ZrO endosseous implants can achieve a survival rate similar to titanium implants with healthy and stable soft and hard tissues. Levartovsky et al. in 2019 in their clinical research, conclude that the survival and success rate of monolithic zirconia restorations installed in patients with bruxism was excellent.[9]

Conclusion:

The use of zirconia-based fixed dental prostheses was gaining importance from the last two decades. There are some disadvantages like opacity, wearing opposite natural tooth, decreased strength in thinner sections on par with the advantages. To date, the research results are promising. However, significantly more clinical research is needed regarding this concept. Overall, the potential for zirconia-based all-ceramic restorations appears to be very good.

References:

1. Saridag S, Tak O, AlniacikG.Basic properties and types of zirconia: an overview. World J Stomatol2013;2(3):40-47.
2. Anusavice KJ. Phillips Science of Dental Materials,12th edition, Elsevier publisher,New Delhi; 2012.
3. Sakaguchi RL, Powers JM. Craig's :Restorative Dental Materials,12th edition, Elsevier publisher, New Delhi; 2012.
4. Cekic-Nagas I, Egilmez F, Ergun G, Kaya BM. Light transmittance of zirconia as a function of thickness and microhardness of resin cements under different thicknesses of zirconia. Medicina oral, patologia oral y cirugia bucal. 2013 Mar;18(2):e212.
5. Malya , Sajjan S, Rao B, Rama Raju AV, Satyanarayana raju M.An overview on zirconia. TPDI 2015; 6(2) 32-9.
6. Nishiyama H, Tanaka S, Nemoto R, Miura H, Baba K, Nishiyama H, Tanaka S, Nemoto R, Miura H, Baba K. Zirconia-Reinforced Framework for Maxillary Complete Dentures. International Journal of Prosthodontics. 2018 Mar 1;31(2).
7. Kakehashi Y, Lüthy H, Naef R, Wohlwend A, Schärer P. A new all-ceramic post and core system: clinical, technical, and in vitro results. International Journal of Periodontics & Restorative Dentistry. 1998 Dec 1;18(6).
8. Kohal RJ, Klaus G. A zirconia implant-crown system: a case report. International Journal of Periodontics & Restorative Dentistry. 2004 Apr 1;24(2).
9. Friedlander L.D., Munoz C.A., Goodacre C.J., Doyle M.G., Moore B.K. The effect of tooth preparation design on the breaking strength of dicor crowns: Part 1. Int. J. Prosthodont. 1990;3:159–168.