

Recent Advances in Zirconia Material

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Abstract

This article describes characteristics of zirconia materials and advancements in zirconia materials in relation to their application in dentistry. The usage of zirconia in dentistry is growing due to features such as high flexural strength, fracture toughness, biocompatibility, low plaque adherence, and low allergic response. The goal of this review paper is to highlight the most recent research that has facilitated the use of zirconia in all aspects of dentistry, including dental implants, fixed partial dentures (FPDs), and cast partial dentures. Zirconia is used in dentistry in a variety of applications such as dental posts, crown and bridge, implant abutment, and esthetic orthodontic brackets and to review methods of improving various shortcomings such as low thermal degradation, translucency, opposing enamel wear, aging, chipping of zirconia-based FPDs veneer, bone and implant interface (bone formation), and light transmission. Many of these flaws have been addressed, but there is still much study that needs to be done in the realm of surface treatments and the usage of nanotechnology.

Keywords: Aging, Chipping, Light transmission, Low thermal degradation, Translucency.

INTRODUCTION

Zircon has long been regarded as a valuable gemstone. The Persian terms “Zar” (gold) and “Gun” (gun) are the origin of the Arabic word “Zargun,” which is the origin of the word zirconium (Color). Due to a growing interest in esthetics and concerns about harmful and allergic reactions to particular metals, patients and dentists have been searching for metal-free tooth-colored restorations. The development of novel high-strength dental ceramics that appear to be less brittle, less constrained in their tensile strength, and less prone to time-dependent stress failure has therefore predominated in the later part of the twentieth century. These characteristics are especially appealing in prosthetic dentistry, where strength and appearance are important considerations.

Zirconium dioxide, generally known as zirconia, is frequently utilized in contemporary dentistry due to its superior mechanical properties, appealing appearance, and biocompatibility. It has been used as a principal ceramic dental material in dental implant abutments, complete dental implants, and indirect restorations. Tetragonal polycrystalline zirconia (3Y-TZP) is a biocompatible ceramic that is suitable for use in biomedical implants and dentistry due to its good mechanical properties and white translucent color. The strongest restorative ceramic is tetragonal zirconia polycrystal stabilized with yttria (Y-TZP). The usage of additives, dopants, sintering profiles, and heat treatments all affect the different shapes that Y-TZP can take.

Their exceptional mechanical properties, along with their biocompatibility and corrosion resistance, are the main draws. Using this cutting-edge method, dental implants' composition, surface energy, roughness, and topography can all be changed for better and possibly faster osseointegration. Biological processes at the bone-implant contact may also be impacted by nanotechnology implant surface modification.^[1-3]

DISCUSSION

One of zirconia's drawbacks was aging (low temperature deterioration). To stabilize the zirconia, the powder particle size was decreased to around 0.2–0.5 μ m, and more yttria was added. This increased cubic phase, which decreased the LTD and improved the zirconia's hydrothermal stability.^[4] Ce⁴⁺ enters the Zr tetragonal lattice as a random substitutional solution, but due to Ce⁴⁺ larger + size than Zr⁴⁺, it adopts a more symmetric 8-fold coordination, which reduces the tetragonality of the unit cell and stabilizes the tetragonal and cubic phases.^[4] When Ce is still in its initial oxidized form 4+, there are not any extrinsic vacancies, which could explain

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Received: Apr, 06, 2023; **Accepted:** Apr, 24, 2023; **Published:** Apr, 10, 2023

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How to cite this article: Gupta DK, Anant MK, Shukla S, Rakesh GK.
Recent Advances in Zirconia Material. J Res Adv Dent 2023;14(4):1-4.

Access this article online

Website:
www.jrad.co.in

DOI:
<https://doi.org/10.53064/jrad.2022.14.4.347>

Table 1: Shortcomings and recent advancements in zirconia

Shortcomings	Advancements
Ageing (low temperature degradation)	- The powder particle size decreased to approximately 0.2–0.5 μm, and increased yttria was added to stabilize zirconia, which increased cubic phase, resulting in decreased LTD and increased hydrothermal stability of the zirconia.^[2-4] - Zirconia toughened aluminas have achieved enhanced strengths and aging resistance.^[2-4] - LTD can be mitigated by maintaining a smaller grain size with homogeneous yttria distribution and by judicious incorporation of small amounts (<0.5 wt%) oxide sintering additives (e.g., Al_2O_3 and TiO_2) and colorants (e.g., Fe_2O_3 and Er_2O_3).^[4] - Ce⁴⁺ forms a random substitutional solution into the Zr tetragonal lattice but adopts a more symmetric 8-fold coordination due to the bigger size of Ce⁴⁺ with respect to Zr⁴⁺, resulting in decreased tetragonality of the unit cell, and the stabilization of the tetragonal and cubic phases.^[1] - The slower kinetics in Ce-TZP may be reasonably related to the lack of extrinsic vacancies when Ce is still in the initial oxidized state 4+. The first steps of degradation may thus be blocked, and this could explain why aging is strongly retarded.^[1,2] - Ce-TZP/A is the toughest dental ceramic material available, with a fracture toughness of 19 MPa m^{1/2}, and a flexural strength of 1400 MPa. Y-TZP suffers from LTAD caused by phase transformation, whereas Ce-TZP/A has complete resistance to LTAD.^[1] - It has been shown that hydrothermal degradation can be remarkably reduced by selecting specific pre-sintering temperatures and optimized solutions.^[1] - The standard 1450°C sintering temperature provides better overall properties.^[1] - More esthetic zirconia without compromising mechanical properties involves infiltrating the outer surface with a feldspathic glass, to produce a cross-section with a graded composition.^[4,5] - In an attempt to improve monolithic ceramics with acceptable translucency, processing of the next generation of 3Y-TZPs was refined largely by drastically reducing the concentration of alumina additive and eliminating - Porosity by sintering at a higher temperature. This led to modest improvement in translucency.^[4]
Less translucency	- Using a higher yttria content to produce partially stabilized zirconias, 4 mol% (4YPSZ) or 5 mol% (5Y-PSZ), with increased amounts of nonbirefringent c phase. This markedly improved translucency.^[4] - The wear rates of enamel were minimized when set against a highly polished zirconia surface. High surface polishes are a feature of all yttria zirconias because of their fine-grain sizes.^[6,14]
Wear of opposing enamel	- The conventional approach to overcoming aesthetic deficiencies has been to powder-fire porcelain onto a zirconia core but bilayer structures of this kind are vulnerable to chipping and delamination, exacerbated by thermally induced residual stresses. Attempts to minimize this vulnerability have been made by milling veneer and framework separately and then joining them with either resin-luting agents (Vita Rapid Layer technology) or fusion firing (Ivoclar IPS e.max CAD-on technology).^[4,5] - There were two alternatives proposed that might avoid chipping of veneering porcelains. One was hybrid-structured FDPs comprising CAD/ CAM-fabricated porcelain parts adhering to a CAD/CAM fabricated zirconia framework. Another option was full-contour zirconia FDPs using high translucent zirconia. Combined application of silica coating and/or silane coupler, and 10-methacryloyloxydecyl dihydrogen phosphate is currently one of the most reliable bonding systems for zirconia.^[6]
Chipping of zirconia based FDPs:	- Zirconia implants surface modification is done by subtractive methods using sand blasting, acid etching, laser etching or combination of acid etch and sand blasting.^[7] - Two trends in nanoscale modification of zirconia either by patterning the implant's surfaces or by applying novel ceramic coatings.^[7] - Zirconia surfaces with microgrooves of 30 μm (width) and 70 μm separation between grooves can enhance ALP and ALZ expression of human fetal osteoblasts.^[8] - Grit blasting and HF etching can improve the initial attachment of osteoblast-like cells: the response of MC3T3-E1 osteoblast cells to the rough glass-infiltrated zirconia created by HF etching treatment was enhanced.^[8]
Less bone implant interface	- Laser (light amplification by stimulated emission of radiation) irradiation has been also applied to increase the surface roughness and improve the bioactivity of zirconia. It was shown that cell proliferation, ALP activity, osteocalcin mRNA levels, and ALZ staining of MC3T3-E1 were all more effective on the rough surface created by irradiation with a fiber laser than on a polished smooth surface.^[8] - It was reported that zirconia surface with high SFE is favorable to the osteoblast bioactivity.^[8] - Calcium ions were incorporated (with calcium acetate) to zirconia by forming CaZrO_3, after firing the zirconia surface, which improved the SFE of zirconia and demonstrated good initial cell attachment, and what is important, without significantly affecting the flexural strength and hardness of zirconia.^[8] - The tribasic calcium phosphate-coating exhibited better mesenchymal stem cells adherence than the uncoated zirconia substrate.^[8]
Limited light transmission	- It was reported that the ALP activity and bone formation area of osteoblast cell on the HA films modified zirconia were increased.^[8,10] - Zirconia specimens coated with MSTF and nano-HA were reported to show a higher cell metabolic activity and proliferation after 7 days of culture when compared with uncoated zirconia.^[8] - For Y-TZP zirconia, the grains have irregular boundaries that limit light transmission (anisotropic), whereas cubic-containing zirconia is isotropic, which improves light transmission.^[6,11]
Problem with chemical bonding with resin to Y-TZP	- Improved light transmission occurs with smaller grains.^[11] - An alternative way to increase transmittance of Y-TZP is to reduce grain size well below the wavelength of visible light. Consideration of classical light scattering models indicates that a grain size <100 nm is necessary to produce acceptable transmittance in Y-TZP ceramics.^[4,10] - By the application of silicating/silanization, good bonding results have been reported, but this bond fails with increasing storage time due to hydrolysis. Other pre-treatment methods are plasma spray treatment, addition of low fusing porcelain layers, tribochemical silica coating, or the use of phosphate acid ester monomers.^[13,14] - Nevertheless, sufficient bonding after long-term storage was found only for cements that contain phosphate groups.^[14]

LTAD: Low-temperature aging degradation, ALP: Alkaline phosphatase, ALZ: Alizarin red

the slower kinetics in Ce-TZP. Aging may be significantly slowed as a result of the early mechanisms of degradation being blocked^[1-3] (Table 1).

LTD can be decreased by retaining smaller grains with uniform yttria distribution and utilizing very modest amounts (0.5 wt percent) of oxide sintering additives (such as Al₂O₃, TiO₂) and colorants (e.g., Fe₂O₃, Er₂O₃).^[4] Ce-TZP/A is the strongest dental ceramic material currently available, with a flexural strength of 1400 MPa and a fracture toughness of 19 MPa m^{1/2}. Phase change is the cause of the low-temperature aging degradation (LTAD) of Y-TZP, whereas Ce-TZP/A is totally immune to LTAD.^[4] By employing the proper pre-sintering temperatures and ideal solutions, hydrothermal degradation can be considerably reduced. The typical sintering temperature of 1450°C results in improved general properties^[4] (Table 1).

One of the most important esthetic factors is transparency. Zirconia can be made more esthetically beautiful without compromising its mechanical properties by embedding feldspathic glass into the outer surface, creating a cross-section with a graded composition.^[4,5] The processing of the subsequent generation of 3Y-TZPs was dramatically altered to produce monolithic ceramics with acceptable translucency. This was done by significantly reducing the concentration of the alumina addition and removing porosity by sintering at a higher temperature. Translucency was marginally improved as a result. Making partially stabilized zirconias with more nonbirefringent c-phase using a higher yttria content, such as 4 mol% (4YPSZ) or 5 mol% (5Y-PSZ). Translucency was substantially improved by this^[4] (Table 1).

Zirconia has the disadvantage of wearing away the opposing enamel. When enamel was pressed up against a highly polished zirconia surface, the rate of wear was lowered. Each and every yttria zirconia has a high surface polish because to its extremely small grain sizes.^[6]

Fixed partial dentures (FPDs) made of zirconia that chip raise serious concerns. Powder-firing porcelain onto a zirconia core has been the usual method for addressing esthetic issues; nevertheless, bilayer systems of this kind are vulnerable to chipping and delamination, which is exacerbated by thermally induced residual stresses. By cutting the veneer and framework separately and then joining them with either resin luting agents (Vita Rapid Layer technology) or fusion fire, attempts have been made to lessen this sensitivity (Ivoclar IPS e.max CAD-on technology).^[4,5] To prevent porcelain veneering from chipping, two solutions were offered. Hybrid-structured FDPs are one kind of FDP; they consist of porcelain pieces that were CAD/CAM fabricated and were fastened to a zirconia framework. Another option was full-contour zirconia FDPs manufactured of highly transparent zirconia. Combining silica coating and/or silane coupler with 10-methacryloyloxydecyl dihydrogen phosphate is one of the most reliable zirconia bonding solutions^[6] (Table 1).

It should be noted that zirconia material exhibits a lower bone implant interface. Sandblasting, acid etching, laser etching,

or a combination of both sandblasting and acid etching are subtractive techniques used to modify the surface of zirconia implants.^[7] Nanoscale zirconia modification has two trends: either designing the implant's surfaces or using cutting-edge ceramic coatings. Alkaline phosphatase (ALP) and alizarin red (ALZ) expression in human embryonic osteoblasts can be increased by zirconia surfaces with microgrooves of 30 m (width) and 70 m spacing between grooves. As demonstrated by the better responsiveness of MC3T3-E1 osteoblast cells to the rough glass-infiltrated zirconia produced by HF-etching treatment, grit blasting and HF etching have been proven to promote the initial adherence of osteoblast-like cells.^[8] Zirconia's surface roughness and bioactivity have both been improved by laser irradiation (light amplification by stimulated emission of radiation). On a surface created by fiber laser irradiation, cell proliferation, ALP activity, osteocalcin mRNA levels, and ALZ staining of MC3T3-E1 all performed better than on a polished, smooth surface. A zirconia surface with a high SFE has been discovered to encourage osteoblast bioactivity.^[8] CaZrO₃ was created when calcium ions were added to zirconia (through calcium acetate), increasing the material's SFE and showing strong initial cell attachment while having no effect on its flexural strength and hardness. In terms of mesenchymal stem cell adhesion, the tribasic calcium phosphate coating performed better than the untreated zirconia substrate. On the HA films modified zirconia, osteoblast cells were shown to have increased ALP activity and bone production area.^[8,9] Zirconia specimens coated with MSTF and nano-HA were discovered to exhibit more cell metabolic activity and proliferation than untreated zirconia after 7 days of culture^[8,10] (Table 1).

Zirconia's poor light transmission is one issue. When compared to cubic-containing zirconia, which is isotropic and encourages light transmission, Y-TZP zirconia grains' uneven boundaries impede light transmission (anisotropy). Smaller grains have better light transmission.^[6,11] Another way to boost Y-TZP transmittance is to reduce grain size much below the visible light spectrum. According to traditional light scattering models, Y-TZP ceramics must have grains smaller than 100 nm to produce acceptable transmittance^[3] (Table 1).

It has been noted that resin and Y-TZP do not chemically bind well. Silicating and salinization have been reported to produce strong bonds, although these bonds get weaker with longer periods of storage due to hydrolysis.^[12] Additional pre-treatment techniques include plasma spray treatment, the addition of low-fusing porcelain layers, tribochemical silica coating, and the use of phosphate acid ester monomers.^[13-15] Nevertheless, during long-term preservation, only cements containing phosphate groups demonstrated substantial bonding.

CONCLUSION

Excellent physical properties, white color, and superior biocompatibility and has made zirconia an esthetic alternative

to the metal and porcelain fused to metal crowns and bridges. However, there is still scope of research in the properties of zirconia-like translucency, wear of opposing enamel, aging, chipping of zirconia-based FPDs veneer, bone and implant interface (bone formation), and light transmission.

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